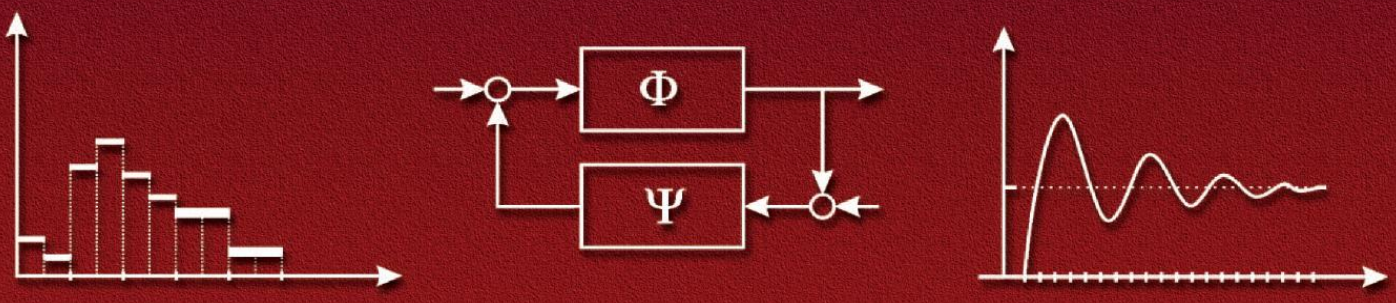
Institute of Automatic Control

FACULTY OF AUTOMATIC CONTROL, ELECTRONICS AND COMPUTER SCIENCE

ACTIVITY REPORT 2007 2009



SILESIAN UNIVERSITY OF TECHNOLOGY

GLIWICE 2010

SILESIAN UNIVERSITY OF TECHNOLOGY

**FACULTY OF AUTOMATIC CONTROL,
ELECTRONICS AND COMPUTER SCIENCE**

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Activity Report
2007-2009

Gliwice, July 2010

Edited by: Mieczysław Metzger

Cover design: Anna Szadkowska

Printing and binding:
Wydawnictwo Politechniki Śląskiej, Gliwice, ul Akademicka 5.

ISBN 978-83-931511-0-3

Contents

GENERAL INFORMATION

The Institute of Automatic Control was founded on October 1, 1977, as a result of fusion of several groups at the Faculty of Automatic Control at the Silesian University of Technology. Currently the Institute of Automatic Control is one of the three institutes constituting the Faculty of Automatic Control, Electronics and Computer Science. The Institute members are involved in teaching of more than 1000 students from several study specialisations. General research directions of the Institute involve automatic control and robotics, modelling and analysis of systems and signals as well as biotechnology and biocybernetics.

According to the evaluation by the **State Accreditation Committee**, the level of study conducted in the direction of **Automatic Control and Robotics** at the Faculty of Automatic Control, Electronics and Informatics, fully complies with the accepted quality standards. **Moreover the Board of the State Accreditation Committee has evaluated this level as excellent**.

From the time the uniform ranking of research units was introduced, the Institute of Automatic Control has been ranked in the **highest category of research quality**.

The Institute of Automatic Control is sufficiently well equipped for research and teaching in the fields of automation, control, biotechnology and robotics. There are also several modern, automation oriented and professionally equipped research/laboratory stations.

Research and teaching activities of the Institute are headed and coordinated by the Board of Directors including the following members:

Professor Andrzej Świerniak	- Director, Head of the Institute,
Professor Mieczysław Metzger	- Vice-director for Research.
Professor Marek Pawełczyk	- Vice-director for Teaching,

The following professors are members of the Institute of Automatic Control:

(For E-mail adresses see biographical sketches)

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Adam Czornik	- professor,
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New educational enterprises

Based on the two decades of research effort in biotechnology (in the bioinformatics lead by professor Andrzej Świerniak as well as in industrial biotechnology lead by professor Mieczysław Metzger) two important educational enterprises have been undertaken. The first one involves new courses in Information Processing and Control in Biotechnology for students in Automatic Control and Robotics. The second one is interdepartmental study in Biotechnology initiated by three Faculties: The Faculty of Automatic Control, Electronics and Computer Science, The Faculty of Chemistry and The Faculty of Environmental and Energy Engineering. Our Faculty is responsible for specialization Bioinformatics.

Professor Pawełczyk coordinates two large projects sponsored by the European Union under the European Social Fund, and the Human Capital Operational Programme in particular. One of the project, performed in 2009-2012, concerns working out the curriculum, recruiting students each year and running a new speciality, which is information technologies in automatic control and robotics. Within this project the students are offered a close contact with industry. They have a chance to meet its representatives, visit the enterpises, and get acquaint with modern technology. The curriculum directly responds to demands of enterprises operating in the knowledge-based fields. The academic staff is also being accordingly prepared. The aim of another project, performed in 2010-2015, is to enlarge number of well-qualified, ready to undertake sophisticated industrial projects, graduates in automatic control and robotics. To recruit very good students and increase their motivatin during study, about 40% of them are offered very attractive scholarships. All the students are also encouraged to participate in a number of group or individual projects, certified courses in the field, scientific conferences, tours to enterprises and seminars with employees, and industrial internship.

CONTROL AND ROBOTICS GROUP

INFORMATION ABOUT RESEARCH ACTIVITIES

Research activities of the Control and Robotics Group include a wide variety of research projects of both theoretical and applied character. Topics of research are concentrated in two main directions:

- control and optimization,
- robot control systems.

CONTROL AND OPTIMIZATION THEORY

Control Systems Benchmarking and Assesment

M. Błachuta, G. Bialic

Complex systems are comprised of numerous loops which are controlled by local SISO controllers. The decision to retune or replace any of these controllers should be preceded by an investigation whether and to what extent this would improve performance. Such procedure is referred to as benchmarking or control performance assessment. Most related pieces of research done so far assume MV control as the performance lower bound.

The main point stressed in the literature is that the system delay d is known to the process engineer which seems to be too optimistic.

Another disadvantage of MV based benchmark is that it does not take the control effort into account see fig.1–2. In order to remove this drawback a modified MV strategy is considered in this paper resulting in the LQG problem.

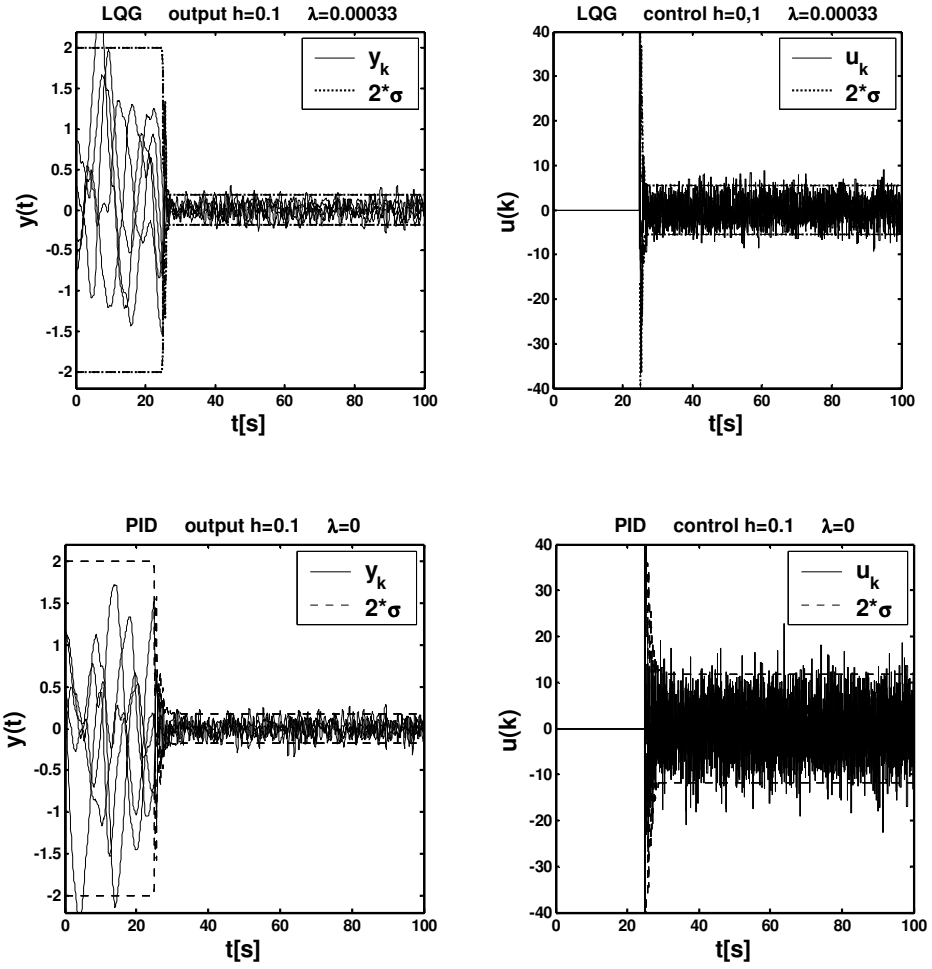


Fig. 1. Realizations of y(t) and u(t) for LQG and PID controllers with the same control quality (a → a').

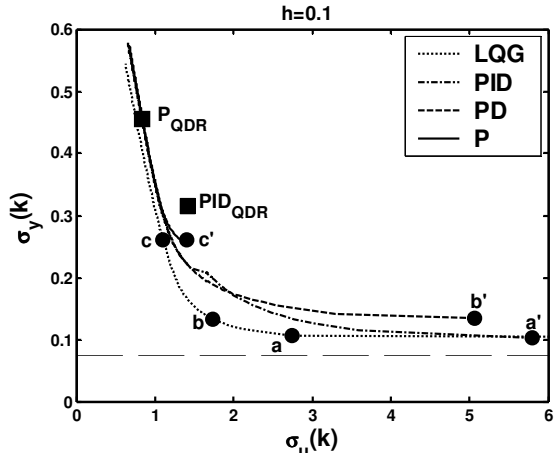


Fig. 2. Standard deviation of output vs control.

Since most of control loops in industry are equipped with PID type controllers, it is interesting to know the distance of their control performance from the best achievable one. Furthermore, it is interesting to know how the controller settings determined on the basis of the disturbance characteristics would improve the performance.

The research in this area is directed on development of performance assesment methods alternative to MV benchmark, and on optimal re-tuning of industrial controllers, accounting for disturbance characteristics.

Design and development of light electric race vehicle

M. Błachuta, R. Czyba, K. Kowalski, K. Slósarczyk

This work is subjected to the design and development of a light EV for participation in an 'energy efficient' endurance race, namely the Greenpower Corporate Challenge. The limited electric energy contained in four 12V automotive batteries is required to be converted into mechanical thrust energy in an optimal manner in order to maximise the vehicle range and challenge the race objective. The latter is improved by reduction of air drag, unnecessary weight, rolling resistance and increase in powertrain efficiency. To optimise this attributes a basic vehicle dynamics model has been developed. It enabled simulation of vehicle dynamic behaviour on the track as well as aided the design of the powertrain control strategy. The shape of bodywork has been iteratively improved through an extensive use of computational fluid dynamics (CFD) analysis using Fluent software. CFD indicated any air vortex or air stagnation fields in the vehicle body structure, which causes power loss due to the air drag. A design of lightweight alloy chassis has been aided through the finite stress element analysis. For weight and complexity save a one-wheel-drive powertrain solution was chosen, with the motive power being transferred using a fixed ratio spur polyamide gear solution exhibiting high efficiency of 98%. Vehicle steering design acknowledged Ackerman's wheel geometry law and provided an adequate force feedback to the driver for steering accuracy. For efficient use of electric energy a suitable powertrain control strategy has been developed. This is realised by two PI controllers: i) constant motor current, ii) constant motor voltage; and the smart switching between them enabling features such as: turbo, freewheel and regenerative braking. In order to monitor the vehicle performance during the race a suitably tailored telemetric system has been developed. Vehicle data were transmitted to the stationary laptop using GSM network with an in-

house developed LabView application for data demonstration. During race the vehicle exhibited satisfactory performance resulting in a 6th position out of 34 teams and was awarded with IMechI "Best Engineered Car" award. The above work was realised by final year students from different faculties within a framework of joined MSc project. The EV has been prototyped in the Laboratory of Embedded Systems and the work of students K. Kowalski and K. Slósarczyk was supervised by M. Blachuta and R. Czyba, respectively. More information about this project can be found at: www.silesiangreenpower.polsl.pl.

Investigation of Properties of LQG and Predictive Controllers

M. Błachuta, R. Grygiel

The theory of predictive control is widely recognized as a design tool for modern control algorithms. Although the state-space design of predictive control has quite a large literature, there have been still some weak points, particularly when a stochastic disturbance is present in the system. In the ongoing project, these points have been clarified to a great extent. New state-space predictive control laws have been derived that are computationally more efficient and provide better quality than the classical ones.

Realistic stationary noise models have been incorporated into the design of predictive controllers within a unified framework basing on receding-horizon LQG instead of the hitherto used nonstationary models. Set-point following has been reformulated as a reference model tracing. An alternative approach to digital control of continuous-time system is being developed that bases on both the continuous-time model of the system to be controlled and a continuous-time reference model of the sampled-data system. The proposed method does not exhibit the disadvantages of prevailing purely discrete-time approach.

Appropriate reference models and their influence on control signal are chosen as the main design tools, and the results of model-system mismatch are studied extensively for both delayed and delay free systems.

Anti-aliasing vs. spectral filters

Marian Błachuta, Rafał Grygiel

In the control literature strong belief is expressed that additional analog elements are necessary prior to sampling to guarantee correct digital signal processing and control. This belief is usually supported by heuristic speculations based on Shannon-Kotelnikov Reconstruction Theorem, which states that in order to reconstruct the signal $s(t)$ from its samples $s(ih), -\infty < i < \infty$, the sampling should be twice the highest frequency component in the signal. Since the spectra of physical signals often stretch on infinite frequency range, this gives rise to the idea of filters that cut off the portion of frequency spectrum lying outside the region determined by that theorem.

Anti-aliasing filters usually take the form of Butterworth filters whose cutoff frequency equals to the so called Nyquist frequency $\omega_N = \pi/h$ depending solely on sampling period h. As an alternative, so called integrating or averaging samplers are considered in the literature. We studied the impact of antialiasing filters for pure signal processing

and in the discrete-time LQG control context, and we have found that there is no reason for using them in the noiseless case, and practically no use in the case of noisy measurements. Certain improvement can be gained in terms of both output signal and control signal variance in the case of large level of noise. The best results in the latter case are obtained when the continuous-time output is passed through a continuous-time Kalman filter before being sampled.
The same findings are true also for discrete-time PID control, when the parameters are tuned based on both practical tuning rules like QDR or Ziegler-Nichols and when they are chosen optimally so as to minimize the output variance.
Optimal tuning of PID controllers that takes the disturbance and noise parameters into account leads to the results comparable with those of LQG controllers without any analog filter.

Design and Analysis of 2DOF Systems with Fast Control Loops

M. Błachuta

Control systems usualy have two different tasks: reference tracking and disturbance attenuation. In standard 1DOF control systems the controller is responsible for both of them, and very often neither of them is maintained properly. Typically, controller settings are chosen so as to arrive at accectable transients after step-wise change of the set-point value, and disturbance characteristics are usually completely ignored. On the other hand, the controller settings can bo chosen to minimize the variance of the output signal but then the transients caused by set-point change can be completely unsatisfactory. The cure is a 2DOF feedback & feed-forward system where feed-forward is responsible for reference tracking, while feedback is aimed at attenuation of disturbances and minimalization of the effects of model-system mismatch. The control loop can then be designed in accordance to its own task leading to improved performance of the entire control system. Although such structure results both from our approach to LQG systems, and from Dynamic Contraction Method, the research based on higher order controllers designed in accordance with plant dynamics is rather heuristic.

Linear – quadratic regulator with output feedback and nonzero external excitations

R. Gessing

Augmented and minimal realization state space models are proposed for direct implementation of the discrete-time linear-quadratic regulator (DLQR) with measured not all the state variables but only the output of the plant. Both the models are related by means of original transformation with a rectangular matrix. Using this transformation it is shown that the resulting closed-loop (CL) system with dynamic output feedback regulator (DOFR) has the same stable roots of its characteristic equation as the CL system with state feedback and DLQR; the additional zero roots of the first CL system generated by DOFR do not change its properties, essentially. It is also shown that the CL system with DOFR realizes the optimal control with feedback from an augmented state, resulting from solving an appropriate DLQR problem. By appropriate choice of

the state weighting matrix in the performance index, it is possible to obtain a partial pole placement of the CL system. The internal model of disturbances included to the augmented plant improves the quality of control. The researches concern also the continuous-time as well as multivariable systems.

The properties of the observer based LQ regulator are also researched. It is shown that this regulator is optimal for adequate initial condition of the observer. The latter statement concerns both continuous-time and discrete-time systems. The case of nonadequate initial conditions is also researched.

The properties of the classical LQ regulator applied in the system with nonzero external excitations are also analysed. It is shown that LQ observer based regulator with sufficiently fast observer modes gives transients which are almost optimal.

Description, Analysis and Design of Discrete-Time Systems Using Continuous-Time Methods

R. Gessing, M. Błachuta

At present most of the controllers are realized using microprocessors working mostly at high sampling frequencies. Application of the Z-transform approach to the synthesis with such controllers is connected with some difficulties. Therefore, the researches concern the application of the continuous-time methods for their description and design. One variable, as well as multivariable systems can be treated in this manner. Especially in the multivariable systems with controllers having different sampling periods the proposed method is useful since in that case there are difficulties in designing.

Modified Feedback Structure with Higher Order Derivatives in Regulator

R. Gessing

The idea of the researches is based on several facts. First, if the rational transfer function (TF) of open loop system has appropriately suited polynomial (*n-1)*-th order in numerator to the polynomial of *n*-th order in denominator then the closed loop system may be stable for very high gain. Second, this kind of open loop TF may be achieved by appropriate choice of the "dynamics" *Q(s)* of regulator, in which the described approximations of the first and if needed - higher order derivative are used. The performed simulations show that these approximations are implementable. Third, we propose the structure of feedback loop with the block diagram in which the high gain *k* and "dynamics" *Q(s)* of regulator are separated: *k* appears after the summing junction with set point *w* and *Q(s)* before it. Owing to this the proposed feedback structure implements model reference control with the reference model *1/Q(s).* The proposed structure is *usually* insensitive to relatively large plant parameter changes. It works well with linear and nonlinear plants. The structure applied to nonlinear plant gives the linearized approximate model described by *1/Q(s)*. Therefore it may be used for linearization. Since the structure is very robust it becomes that it may be also used to non stationary linear and nonlinear plants. Taking into account the large possible plant parameter changes, it is shown that the structure may replace some adaptive control

systems. In implementations all the calculations related with approximation of the regulator "dynamics" *Q(s)* may be performed using appropriate microprocessor. Therefore the regulators implemented in appropriate microprocessors have created possibility of utilization of the proposed approach. Approximations of higher order derivatives in *Q(s)* gain noises and cause rapid and nervous change of control *u*. Therefore the proposed solution may be applied to actuators which accept these changes. Further researches concern multivariable systems.

Parallel Compensator and Its Application to Nonminimum Phase and Other Difficult Plants

R. Gessing

Design of regulators assuring appropriate accuracy for nonminimum phase plants meets great difficulties. This is caused by the fact that usually insignificant increase of the proportional regulator gain causes instability and small gain causes law accuracy even in a constant steady state. If the integral part is introduced in regulator, to reduce the steady state error, then its gain is also very limited giving very slow transients. In the researches, following the Smith compensator we propose for nonminimum phase plants the compensator which connected in parallel to the plant changes its model which becomes minimum phase. For the changed replacement plant model it is easy to design regulator with high gain which assures appropriate accuracy. The kind of the changed model depends upon our choice and the goal of the control. If the main goal of the control is the accuracy of stabilization under stepwise excitations then the changed model may take the form of a first order lag with the gain equal to that of the plant. The time constant of this model has also a limited influence on under- and over-shot of the step response. If the main goal of the control is tracking or disturbance rejection of signals with frequencies belonging to some working frequency band then the changed model, in the form of rational transfer function with relative order equal to one, should be chosen in this manner that it is minimum phase and in the working frequency band its frequency response is approximately the same as that of the plant. Especially in the case of stabilization the proposed system structure is very robust since the frequency response of the replacement plant model lies in the first negative quadrant of the Nyquist plain (first order lag). In the case of tracking or disturbance rejection the demand of closing the frequency response of the replacement plant to that of the plant causes some decrease of robustness, since the frequency response of the replacement plant may lay now in the first and second negative quadrants of Nyquist plain (closer to the critical point *(-1,j0)*. To the replacement plant the relay implementation of the control may be applied; it has similar properties as a continuous-time one, which results from performed simulations. It is shown that the described idea of parallel compensator may be also used for other difficult plants to improve the transients.

It is shown that the continuous and relay systems with parallel compensator are equivalent from the point of view of the output signal, if the hysteresis of the relay tends to zero and the saturations of the control in continuous system are equal to the switched amplitudes of the relay.

Two-Level Control of Large-Scale Systems with Incomplete Information

R. Gessing, Z. Duda

Control tasks in large scale systems composed of distributed subsystems are usually solved in a two-level or multi-level hierarchical structure. Very important issues in control of such systems are information and computation. Especially complicated are control problems with decentralized incomplete measurement information available for particular decision- makers. The problems related to limited resources allocation are formulated and solved. It is assumed that local controllers have detailed information essential for particular subsystems, which is aggregated and transmitted to a coordinator. Then, the amount of information transmitted to and processed by the coordinator can be significantly decreased. For coordination an elastic constraint is proposed. It leaves some freedom in taking decision by local controllers, which receiving only some directions from the coordinator can use its own information better. Owing to the elastic constraint and assumed information structure it is possible to partially decompose the calculation and to realize the decentralized control.

Another approach (without the elastic constraint) is used for a system composed of interconnected linear static subsystems. It is shown that control strategies using the elastic constraint are suboptimal. Optimal strategies are found and compared with suboptimal ones.

Whether the Opinion About Superiority of Fuzzy Controllers is Justified

R. Gessing

In the project, using some MATLAB fuzzy logic toolbox Demos, in which the fuzzy controllers are compared with the classical PID ones, it is shown that the well tuned classical PID are significantly better than those fuzzy presented in the Demos. It is shown, that using fuzzy approach, it is very difficult to shape the input-output nonlinearity, describing the so called fuzzy block of the fuzzy controller. There arises the question whether this observation concerns also other systems with fuzzy controllers and therefore whether it has some more general character. One may suppose that yes and this view is supported by the following consideration.

The fuzzy block or nonlinear static element described by the function $u=f(e,de)$, theoretically gives some limited possibility of improving controller. However first, the same possibility gives the nonlinear element described by the function $u=f(e,de)$, which may be easier implemented using other methods e.g. lookup tables or polynomial approximation; the latter methods gives the possibility of local shaping of the nonlinearity. Second, the local shaping of a demanded nonlinearity by means of the fuzzy approach is a very difficult if at all implementable way. Third, the problem of demanded, static nonlinearity with two or more inputs and one output which improves controller is weakly recognized in nonlinear control theory Fourth, the essential disadvantage is non analytical description of the nonlinearity $u=f(e,de)$ using fuzzy approach, which creates additional difficulties in analyzing the stability and operation of the system; only methods based on simulations are available.

The considerations of the project do not support the idea of fuzzy controllers.

The Continuous System Equivalent to the System with Sliding Mode Control

R. Gessing

It is shown how to create the continuous system equivalent to the system with sliding mode control. The equivalence means that under the same excitations of both the systems the outputs in both the systems are the same. In the case of minimum phase plants, the equivalent continuous system arises from the system with sliding mode control, by the replacement of the relay with some appropriate saturation-type nonlinearity. The latter nonlinearity may be implemented using the amplifier with high gain and saturation with constraints of the control determined by the switched magnitudes of the relay. In the case of non-minimum phase plants it is noted that similar equivalence exists for the continuous and relay system with parallel compensator. The latter system may be treated as the system with modified sliding mode control. In the equivalent continuous system the chattering effect, related with sliding mode control doesn't exist. It is noted that both the systems are designed with accounting the Criterion RD1 (the relative order of the open loop system is equal to one). It is also noted that both the systems, under small measurement noises, are very robust with respect to large and fast change of the plant parameters. The appearance of some exact measurement noises may cause some problems.

The Controllers of the Boost DC-DC Converter Accounting Its Minimum- and Non-minimum-Phase Nature

R. Gessing

Switched power DC-DC converters are commonly used in different applications, e.g. for generation a set of DC higher level voltages from one DC power supply. To keep the constant output voltage independently upon varying conditions (change of load, input voltage, etc.) different kind of controllers are applied. Some other situation is when there is a need of adjustable, or programmable output voltage which then should track the demanded reference voltage. Due to nonlinearity of the converter, which additionally is non-minimum phase, some appropriate solutions are needed.

In the project it is shown that the model of the boost DC-DC converter is minimum phase for operation on the left-hand side of the extremum of the steady state characteristic and non-minimum phase -- on the right-hand side. For operation on the left-hand side a simple proportional controller is proposed which gives significantly better quality of control than many other controllers appearing in literature. However, it is noted that efficiency of the converter during operation on the left-hand side is smaller, therefore another original proposal of the controller based on nonlinear transformation and state feedback, designed for operation on the right-hand side, is proposed.

Researches on autonomous robot

A. Babiarz, K. Jaskot

The biped robots were one of the major task in robotics research. Hence, many kinds of robots have been built to replace humans working in different environments. Among

them biped robots still receive less attention, but there is some interest in this field of robots since they offer better adaptability and ability to address complex jobs.
The main topic is designing a robot which can replace human and it has construction based on human kinematics. The legged robots have from 2 to 15 degrees of freedom. Every joint has from 1 to 3 degrees of freedom. We can distinguish the following joint in human kinematics:

- Ball-and-Socket: The ball-shaped end of one bone fits into a cup shaped socket on the other bone allowing the widest range of motion including rotation. Examples include the shoulder and hip.
- Hinge: A convex projection on one bone fits into a concave depression in another permitting only flexion and extension as in the elbow and knee joints.
- Gliding: Flat or slightly flat surfaces move against each other allowing sliding or twisting without any circular movement. This happens in the carpals in the wrist and the tarsals in the ankle.

The basic design concept and specification for the biped robot is listed as follows:

- developing a biped robot with lower body,
- compacting in size and light in weight.

Thus, the final concept design has the following features:

- total of 7 degrees of freedom per one leg:
  - 3 DOF on the hip,
  - 1 DOF on the knee,
  - 3 DOF on the foot,
- controller: it is based on Atmega8,
- servo: Hitec HS-325HB, HS-645MG, HS-815BB,
- materials: aluminum and plastic,
- several force sensors distributed on the foot surface.

The whole biped robot is presented on figure 1.

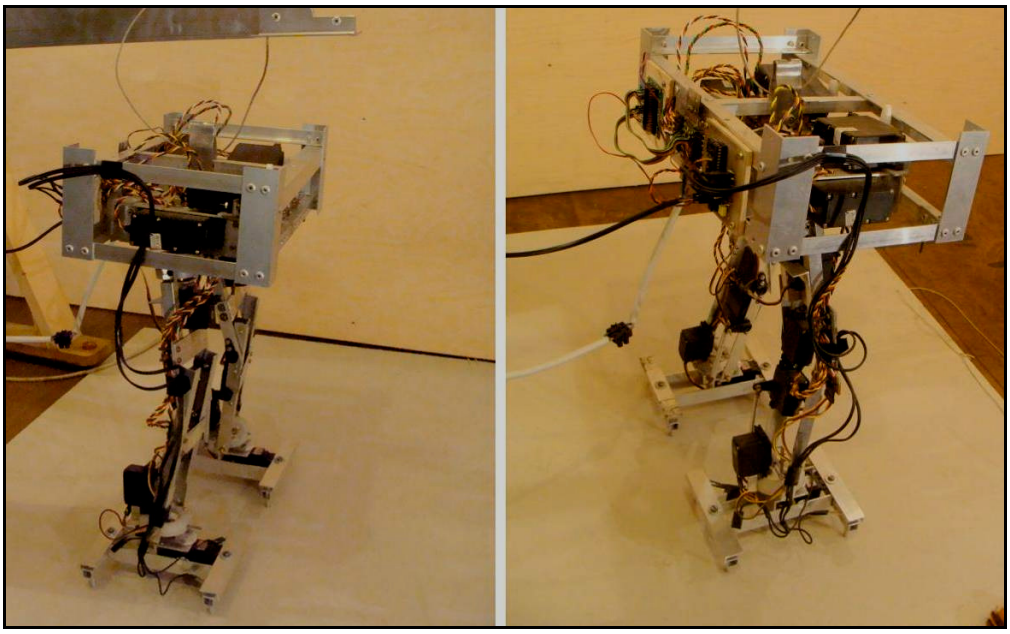


Fig.1. Biped robot.

The most important task is to build sensor system. The sensor system allows recognize surrounding environment and detects probably collisions during movement.
We use force sensors (figure 2) to recognize contact moment with base.

Fig. 2 Force sensor CZN-CP1

The another project based on Robonova KIT. We designed our sensor and control system. The robot is shown on figure 3.

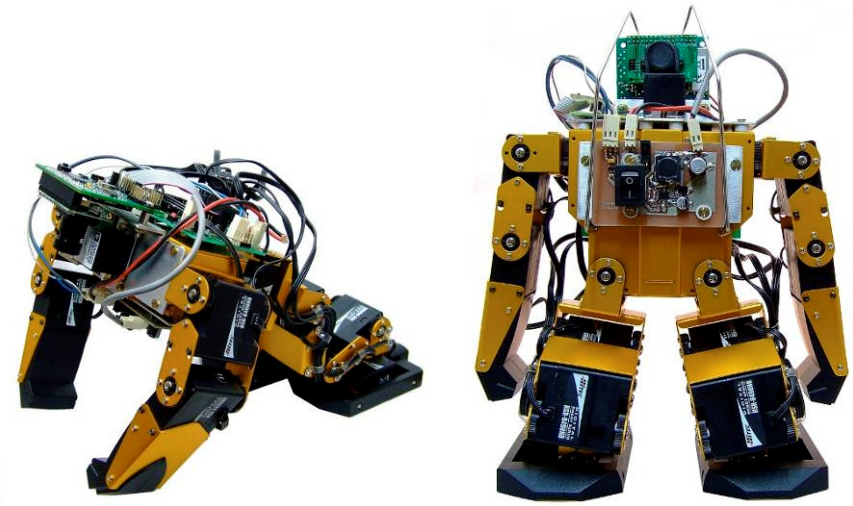


Fig.3. The robot.

The sensor system consist of force sensor, camera CCD and IMU (Inertial Measurement Unit) ADIS 16360. The exemplary measurements are shown in fig. 4a and fig. 4b.

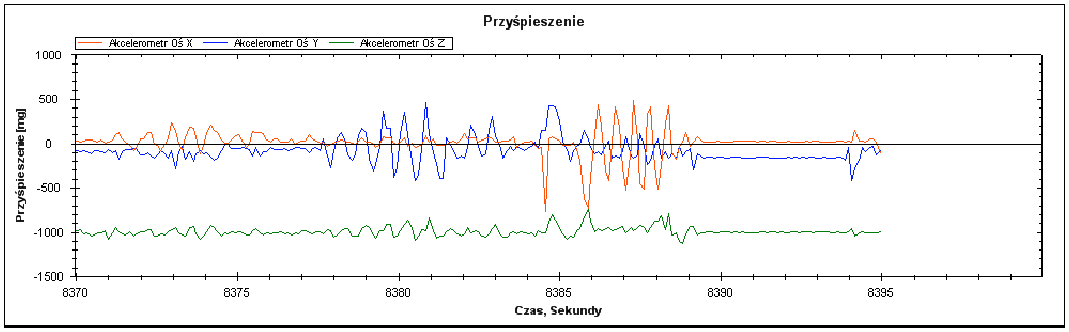


Fig.4a. Example of measured time responses.

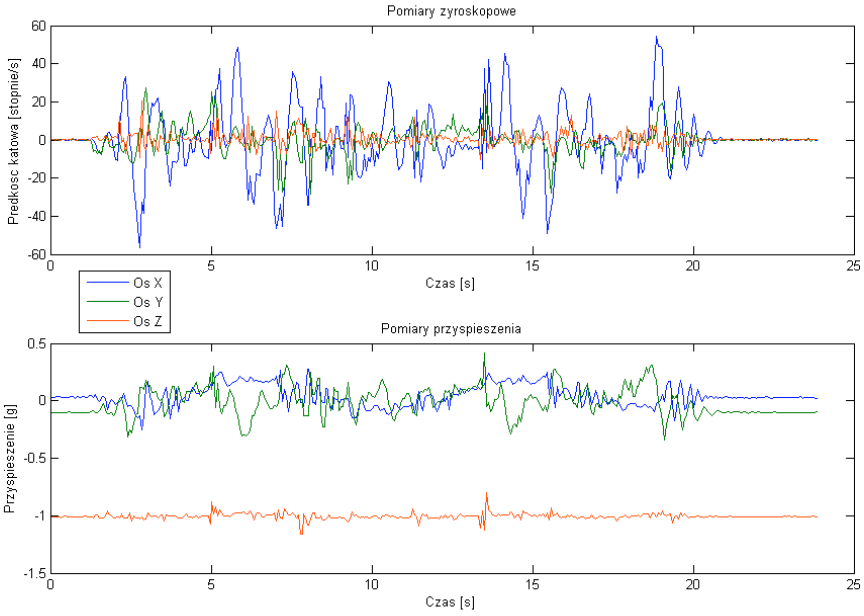


Fig. 4b. Example of mesured time responses.

Autonomous mobile platform.

Mobile platform has been built using a remote-controlled car on a scale 1/8th (length 55cm, width 43cm) and it was delivered by the HPI Racing. We add our control system. To build a control system for mobile platform we uses microcontroller ARM7TDMI-S, GPS, encoders, IMU (Inertial Measurement Unit) and radio modules Xbee 2.4GHz (Figure 5). The appearance of mobile platform with installed controller and the GPS system is shown in figure 5.

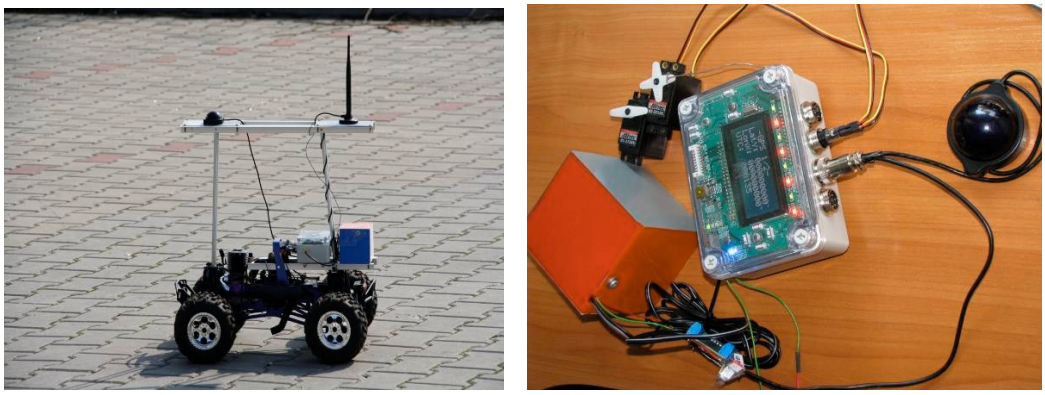


Fig. 5 Control system – main controller, GPS, IMU, servos and mobile platform

Example trajectory (Fig. 6) shows positions and orientation taken from GPS and electronic compass.

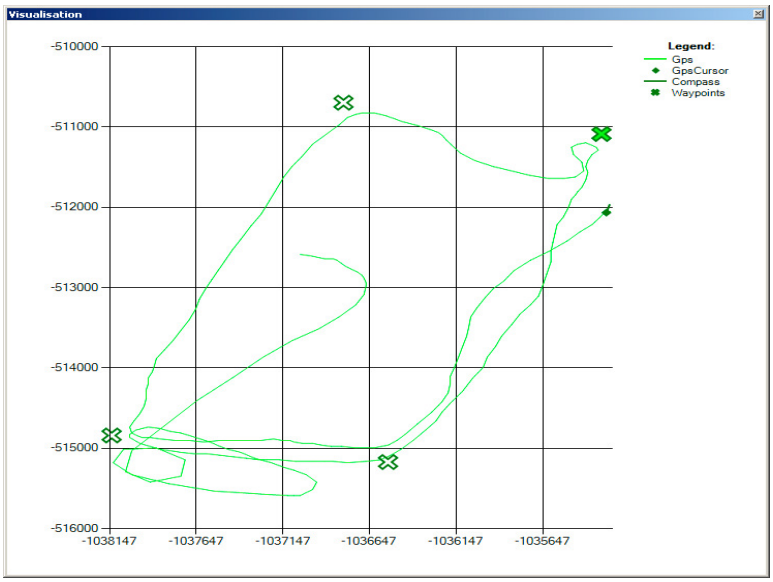


Fig. 6 Example of trajectory

During drive we also recorded measurements such as velocity (GPS, encoder), azimuth (GPS, electronic compass), servos.

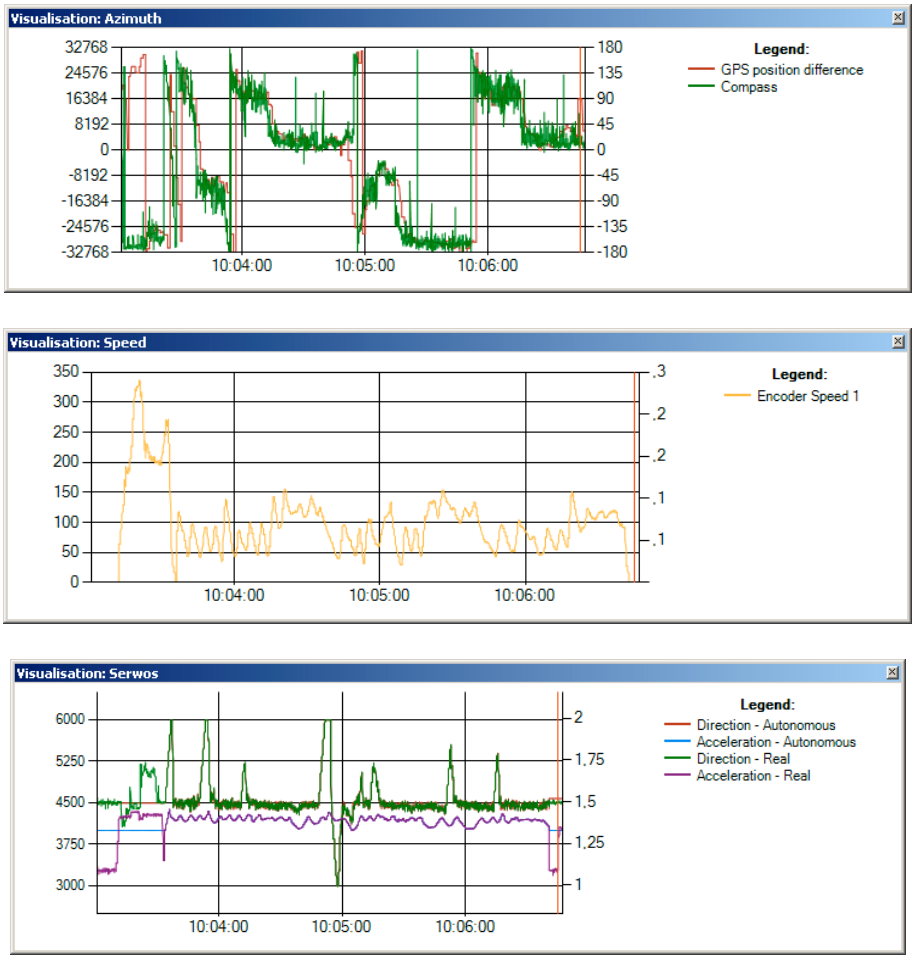


Fig. 7 Exemplary measurements recorded during autonomous drive

Application of Dynamic Contraction Method in nonlinear system control

R. Czyba, M. Błachuta

The specific interest is application of the Dynamic Contraction Method (DCM) to the synthesis of a control system for a non-linear object. It is applied to a realistic non-linear aircraft model F-16. Dynamic properties of an aircraft depend on both its structure and aerodynamic qualities as well as on the control law applied. Classical control methods assume that the object dynamics are linear and stationary around equilibrium. Unfortunately, due to high non-linearities that occur in plant dynamics such control systems do not function correctly in extreme conditions. Therefore control of complex objects under changeable conditions needs a special approach to the subject. A way of the algorithmic solution of this problem is the application of the Localization Method (LM). The peculiarity of the LM method is the application of the higher order derivatives jointly with high gain in the control law. The generalization and development of LM is the Dynamic Contraction Method (DCM) which allows to create the desired output dynamics for non-linear and non-stationary objects assuming that information about the system parameters and the external disturbances is incomplete. In general, the goal of the design of an aircraft control system is to provide decoupling, i.e. each output should be independently controlled by a single input, and to provide desired output transients under assumption of incomplete information about varying parameters of the aircraft model and unknown external disturbances.

Although the Dynamic Contraction Method has been applied to an aircraft model, an industrial robot, an AC induction motor drive, and can be successfully applied in other objects, e.g. in automobile industry to design ABS system.

Multivariable control of an Unmanned Aerial Vehicle type quadrotor

R.Czyba, G. Szafrański

Unmanned vehicles are very important when it comes to operation in a hazardous areas or/and inaccessible environment. The prime examples are the aerial robots for boarders surveillance, forest fires monitoring, management of a large infrastructures and power grids inspections.

A quadrotor one of the unmanned aerial vehicle (UAV) with four fixed pitch rotors is a highly maneuverable vehicle. It has a potential to hover and to take off , fly, and land in very small areas. However, a quadrotor is a complex unstable dynamically system and difficult to fly without modern embedded control systems. The attitude control system is an important feature since it permits the robot to maintain in a desired orientation. Hence, it prevents quadrotor from crashing during the particularly maneuvers taken.

All the operations related to control algorithms are implemented on the

Freescale MPC555 microcontrollers. The Embedded Target for Freescale MPC5xx from Mathworks allows to deploy code generated from Real-Time Workshop Embedded Coder directly onto the MPC5xx family processors for real-time execution. Using Simulink user can manage the peripherals of the microcontroller and implement various of control algorithm via block diagrams.

The flying platform is highly nonlinear and dynamically unstable system and thus very hard to control. The fast prototyping method together with Matlab/Simulink software and rapid development kit based on PowerPC microprocessor has been used as a control algorithm development platform. To ensure the attitude stabilization the wide variety of control algorithms can be implemented and tested. The PID controller and the Dynamic Contraction Method have been applied and practically verified for the previously formulated control task. The peculiarity of the DCM method is the insensitivity to plant parameters changes and external disturbances, and works well for non-linear and non-stationary objects.

The flying platform is currently under development process that should lead to obtain more advanced capabilities of the autonomous flying vehicles.

Jump linear systems

A. Czornik, A. Świerniak

Modern control systems must meet performance requirements and maintain acceptable behaviour even in the presence of abrupt changes in their dynamics due, for example, to random abrupt environmental disturbances, changes in subsystems interconnections, random failures, abrupt changes in the operating point of a non-linear plant etc. This can be found, for instance, in control of solar thermal receivers, robotic manipulator systems, aircraft control systems, large flexible structures for space stations (such as antenna, solar arrays), etc. In some cases the relevant stochastic model may consist of a set of linear systems with modal transition given by a Markov process. Such systems are called in the literature jump linear systems. For such systems problems of stability, stabilizability, controllability, detectability and observability are being considered for both continuous and discrete time cases. Different concepts of controllabilty have been already introduced but sometimes they are not suitable to practical applications. Therefore new concepts of controllability which seem to be more appropriate for applications are introduced. For these definition of controllability necessary and sufficient conditions are being found and relationships with other types of controllability are under consideration. Also connections between controllability and stabilizability is investigated. Moreover appropriate LQ and LQG problems and their adaptive versions are being considered. The applications of jump linear systems to robust and fault tolerant control is also discussed.

Characteristic exponents of linear discrete time-varying systems

A. Czornik, A. Bal, P. Mokry, A. Nawrat,

The study of characteristic exponents of linear discrete time-varying systems gives rise to a number of interesting and challenging mathematical problems. In our research we are concentrated on the investigation of the influence of small perturbation of the coefficients on the Lyapunov, Bohl and Perron exponents. In that purpose we introduce concepts of additional numbers such as central exponent, sigma exponent and exponential exponent and we try to describe the possible changes in the characteristic exponents under small perturbation in terms of these numbers. The determination of the movability boundary of the exponents under various perturbations is one of important problems of the modern theory of characteristic exponents. This problem has been solved for continuous-time systems for many cases. Similar problems for discrete-time systems have not yet been investigated. We also investigate the concept of joint spectral radius and generalized spectral radius of a family of matrices. It turns out that the asymptotic behavior of all the possible products of the matrices of the family (as the number of factors goes to infinity) is determined by the value of them. The concepts of generalized spectral radiuses has been also successfully applied in wavelet theory, nonhomogeneous Markov processes, probabilistic automata, iterated function systems, hysteresis nonlinearities.

Hierarchical stochastic control and nonconventional filtration in large scale systems.

Z. Duda

Control tasks and state estimation in large scale systems composed of distributed subsystems are usually formulated in a two-level (multi-level) structure with a coordinator on the upper level and local controllers on the lower level. In such problems very important issues are available information and computation. Especially complicated are mentioned problems with decentralized incomplete measurement information available for particular decision makers. It is assumed that the considered system is described by a linear output equation and a linear state equation with control being a random variable for the coordinator generated by decision rules of the local controllers. The stochastic control problem with a quadratic cost for the large scale system was formulated and solved in previous works with R. Gessing. This problem can be related to limited resource allocation in which local controllers have detailed information essential for particular subsystems, which is aggregated and transmitted to the coordinator. Then, the amount of information transmitted to and processed by the coordinator can be significantly decreased. Control rules are linear functions of state estimates performed by the coordinator and local controllers. The approach to state filtration is based on modified innovations and orthogonality principle and leads to decentralized filters for the local controllers and augmented optimal filter for the coordinator.

Translation of Block World Planning in the Presence of Uncertainty to Linear Programming

A. Gałuszka

STRIPS language is a convenient representation for artificial intelligence planning problems. There are many different algorithms of state space searching which use STRIPS representation for planning. Some of them search for a solution through a space of world-states. Because of a size of this state space it is difficult to generate an optimal plan for planning instances. Moreover in real world applications knowledge about environment is incomplete, uncertain and approximate. That is why planning in the presence of uncertainty is more complex than classical planning. To increase computational efficiency of planning with uncertainty a transformation to Linear Programming problem is proposed. Translation to Linear Programming allows reducing computational complexity of searching for the solution. That is because planning in the presence of incompleteness is usual at least NP-complete problem, Linear Programming is polynomial-time complete problem and translation from STRIPS to Linear Programming is also polynomial. The cost of this approach is that algorithm can results in non-interpretable solutions for some initial states (what is followed by assumption $N \neq NP$). Simulations that illustrate the reduced problem are implemented in MATLAB.
Keywords: planning with uncertainty, STRIPS language, linear programming, computational compexity.

Non-cooperative Game Approach to Multi-Robot Planning

A. Gałuszka, A. Świerniak, K. Skrzypczyk

In the research multi-robot environment with STRIPS representation is considered. Under some assumptions such problems can be modelled as a STRIPS language (for instance Block World environment) with one initial state and disjunction of goal states. If STRIPS planning problem is invertible then it is possible to apply machinery for planning in the presence of incomplete information to solve the inverted problem and then to find a solution for the original problem. In the research the planning algorithm that solves problem described above is proposed and its computational complexity is analyzed. To make the plan precise non-cooperative strategies are used.

In this research we propose a methodology that solves the problem of plan generation for robots being in conflict. This methodology joins STRIPS language and game theory: is based on block world environment, invertability of STRIPS planning problems, conformant planning and non-cooperative game. The STRIPS domain is modified according to classical one in such a way that generating conformant plan is easy meaning a computational complexity. The modification guarantee also that the plan exists but causes that it is not precise. To precise the plan uses the Nash equilibrium is proposed.

Graph Representation Of Psychosocial Factors In Chronic Somatic Diseases

A. Gałuszka

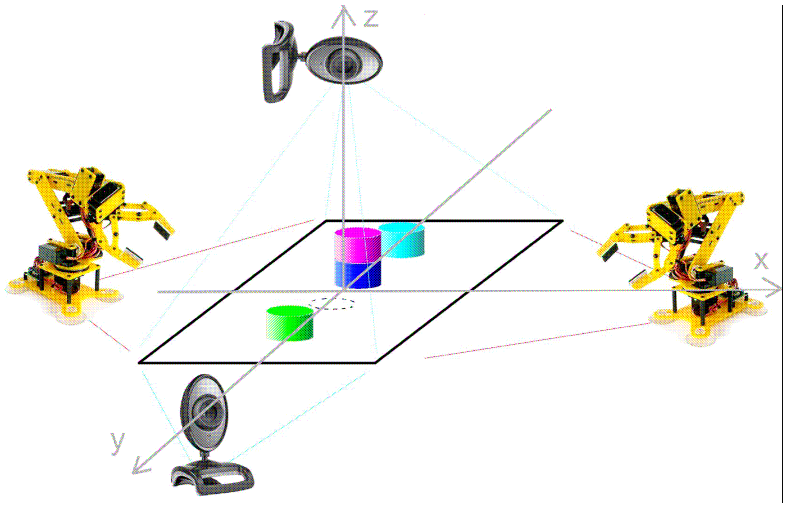
Two so-called diseases of civilization were taken into account in this research: arterial hypertension and neoplasm with bad prognosis. These diseases were explored under 'psychological' point of view, i.e. such psychological properties like: hope, anxiety, meaning of life, coping with stress, different tests of self-esteem and other health cognitive-emotional processes were explored. Most of these factors describe emotional sphere of human life. Such kind of data are usually analyzed using different statistical tests that verify assumed hypothesis. In the case explored in this research data are special since they are unique in country-scale: over 70 psychosocial factors were determined for almost 200 patients suffering for serious diseases. Moreover the dynamic of these disease were taken into account: the data collection has been divided into 3 stages.

A motivation for this research is to consider all of these unique data. Contribution of this research is a proposition of graph representation for correlation exploration between all available data. As it is shown such model can describe differences and similarities of cognitive-affective processes between diseases.

Semantic representation of simple Block World environment in application to ARM1 robot arm control

A. Galuszka

The aim of this project is to build the working laboratory stand by applying a vision system. Laboratory stand contains of a scene with up to 10 colour cylinder blocks and an ARM1 manipulator which is moving the blocks with application of elementary block world algorithms. The aim of this expansion is to add two web cameras from top and from side that would recognize the scene by calculating position of all blocks with means of semantic reasoning. To do so appropriate vision system program needs to be created in order to analyse the frames from the cameras and infer the actual state of the scene.



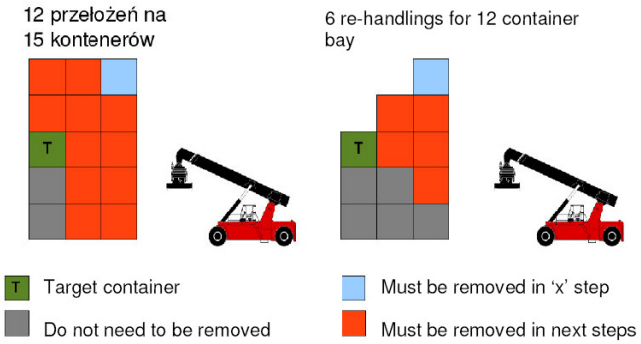
The program should work in the background, waiting for the signal to start recognition, create and send the output data as soon as possible and turn back to idle state, again waiting for another start signal. This would help the operation and simplify

the usage of control programs of manipulator. The implementation solves problems of representing uncertain and incomplete information.

Re-handling Operations in Small Container Terminal Operated by Reachstackers

A. Galuszka, K. Skrzypczyk, D. Bereska and M. Pacholczyk

In this project an average number of re-handlings analysis is proposed to solve the problem of finding bays configuration in small container terminal in Gliwice, Poland. Rehandlings in this terminal can be performed only by reachstackers. The goal of the heuristic is to plan the reachstacter moves in the terminal, assuming that the target containers are reached and the number of re-handings is minimized. The real situation requires also to take into account the model of the problem environment uncertainty caused by the fact that many containers are not delivered to the terminal on time, or can not be sent on scheduled time. To enable this, the heuristic uses some assumptions to simplify problem analysis. Our intention is to propose efficient in time method for support decision-making processes in small container terminal in Gliwice, Poland (www.ptkholding.pl/index).



FPGA devices in image recognition

Aleksander Nawrat, Krzysztof Daniec

In Department of Automatic Control and Robotics there are researches on hardware implementation of digital signal processing algorithms in FPGA. FPGA device is "processor" with no hardware structure. Designer using hardware decryption languages like VHDL is building hardware using base elements like latches and gates. Using advanced software designer is able to create SoC (System on Chip) which is complete embedded system on one device with processor, buses and communication controller. Using those techniques it is possible to perform hardware implementation of specific algorithm. Using FPGA's engineer can create hardware implementation of specific algorithm. This implementation can mach more faster than soft implementation using for example PC. Sample evaluation board is shown in figure 1 and working algorithm on figure 2.

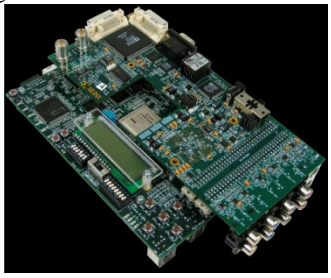


Fig. 1. FPGA evaluation board

Fig. 2. Sample object detection

In Department of Automatic Control and Robotics there are researches on hardware implementation of image processing algorithms. Video stream is captured from high definition cameras and its processed by system implemented on FPGA. Those researches are necessary for such tasks like object detection on UAV's where weight of the electronics is very important factor.

Project and demonstrator of the technology of the system supporting operational-procedural activities for defense and safety of the state

Stanisław Kozielski, Adam Czornik, Aleksander Nawrat, Krzysztof Simek, Damian Bereska, Adam Gałuszka, Krzysztof Skrzypczyk, Dariusz Mrozek, Bożena Małysiak-Mrozek, Paweł Kasprowski, Michał Kozielski, Katarzyna Harężlak, Adam Duszeńko, Krzysztof Daniec, Kamil Kozak, Roman Koteras

The purpose of the project is to prepare the scientifically-technical case study for the system supporting activities of the state in scope of its defense. Defense is a very important part of the internal and external national politics. Operational activities efficiency requires usage of advanced computer systems supporting officers of various services in their duties.

On the market, there are systems supporting basic actions of such services, but there are no tools providing sophisticated functions concerning criminal data processing. Construction of a such system is a complicated task. Sample structure is shown on figure 1. It requires preparing an appropriate environment for building and exploiting this system and taking into consideration many formal, legal and technological functionalities. They concern registration, processing and accessing of data, reporting user operation performed with criminal data. Because of that fact, tasks included in the project comprise:

- Collection of various documents required for project and implementation of the system
- Analysis of process realized by this kind of systems
- Designing database and system architecture
- Implementing the prototype of the system
- Preparing documentation used for latter certification

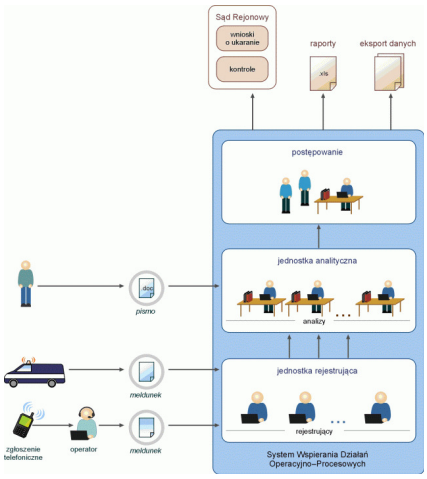


Fig. 1. Sample schema of operational-procedural activities

In Department of Automatic Control and Robotics was performed researches on analysis of criminal data gathered in the system. Those algorithms are based on graphs and can perform automatic search is large amount of data to find connections between elements which can be very helpful in criminal analysis.

Wireless broadband communication using WIMAX standard

Aleksander Nawrat, Adam Czornik, Adam Gałuszka, Krzysztof Skrzypczyk, Damian Bereska, Krzysztof Simek, Piotr Jurgaś, Marcin Pacholczyk, Krzysztof Daniec, Kamil Kozak, Roman Koteras

In Department of Automatic Control and Robotics are researched broadband wireless communication based on IEEE 802.16d standard. Main goals of this research project was to create concept, design and implement prototype which gives secure broadband wireless communication on Wimax standard. Main parts of those project was:

- Design and creation of electronic devices
- Design and implementation of monitoring and control software for electronic devices

During the project there was designed electronic devices, software, casings for BTS (Base Transceiver Station) and for CPE Customer Premises Equipment. On figures 1 and 2 are casings of client devices with PCB.

Fig. 1. Casing for CPE

Fig. 2. Casing for CPE with PCB

Using designed devices was developed test installation and tests of the system was performed.

Client and base station can be used for building network infrastructure in all terrain. Sample infrastructure is on figure 3.

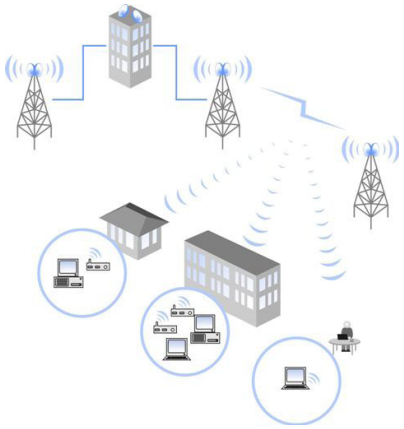


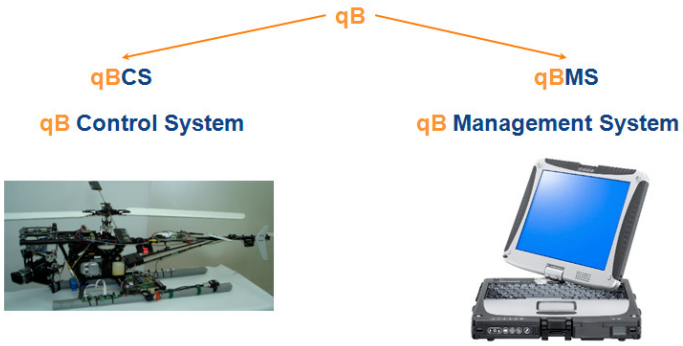
Fig. 3. Sample infrastructure.

As a result of Wimax project was created prototypes of devices which can be used for building secure broadband wireless infrastructure.

qB - Distributed, real time UAV control system

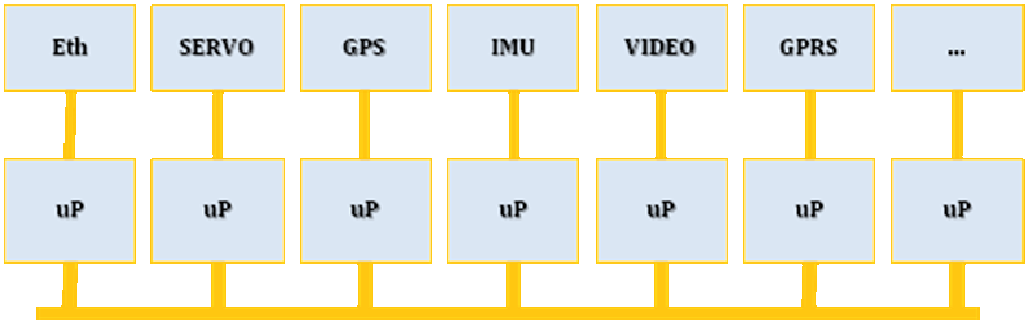
Aleksander Nawrat, Kamil Kozak, Roman Koteras, Krzysztof Daniec

Autonomous flying objects can be used in wide range of civil or military applications starting from monitoring purposes like monitoring of high voltage line with infra red video camera and image processing algorithms, or recognition mission after natural cataclysms like avalanche or flood, up to military combat missions of any type. It can be concluded that properly designed and programmed autonomous vehicles will be able to perform sophisticated and dangerous for human being missions in the future. They can be used in places where living organisms will have no chances to survive. Additionally, if any accident will happen that is not a big lose comparing to death of a human being. However, autonomous operation of a vehicle is a very complicated problem. It involves tightly coupled operation of many sensors, actuators and controllers, joined together by software that operates in real time mode.



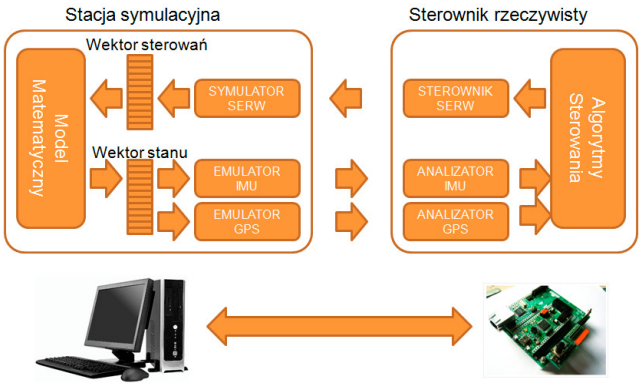
Designed software called qB is a flexible platform for both controlling and monitoring purposes of autonomous objects. It consists of two separate and independent parts: qBCS (qB Control System) distributed, embedded, real time system designed in ANSII C language responsible for autonomous flight of the physical model and qBMS (qB Management System) designed in C# for remote monitoring and controlling purposes.

qB - Control System integrated data from different data sources as sensors, filter them and prepare in form of state vector for control algorithms. In order to maximize portability and scalability of the system it was designed as distributed platform on top of CAN network with use of CANopen protocol.

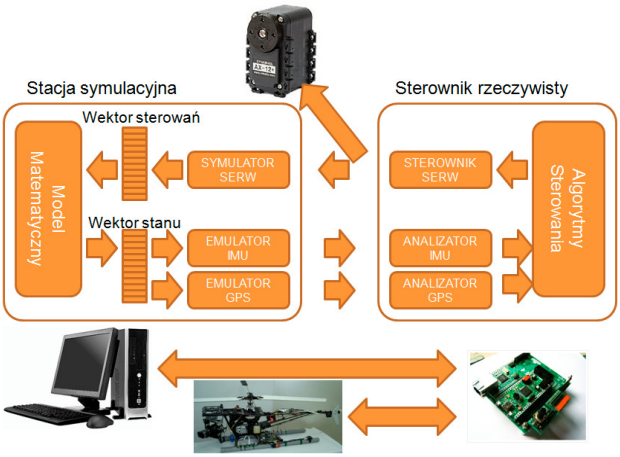


It must be mentioned that the crucial part of control system is its stability of long time operation and deterministic time of task context switching realized by underlying operating system. This will allow to clearly define sampling rates of all sensors and periods between control algorithms iterations. To fulfill such assumptions it is necessary to use real time operating system.

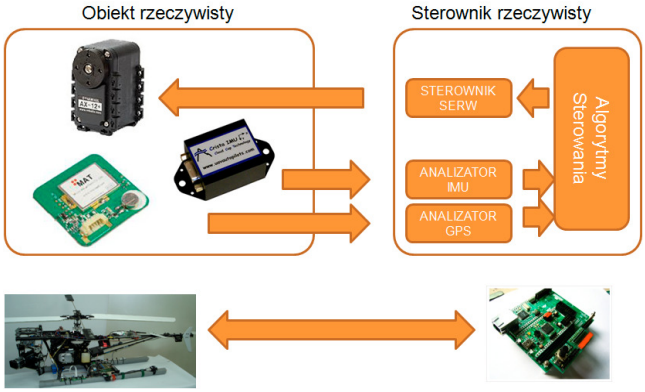
Developed platform should operate in three different modes - SIL, MIX, HIL.



SIL (Software In The Loop) mode does not involve any hardware. All physical operations of the model are simulated. The state of controlled object is calculated due to its implemented mathematical model. It is a full simulation mode, utilized to test algorithms in safe laboratory conditions, without a possibility of crushing for the vehicle's physical model.



MIX mode enables testing hardware modules together with running algorithms of mathematical model. It is a transition mode between SIL and HIL modes. It enables making tests whether hardware modules are working correctly or not.



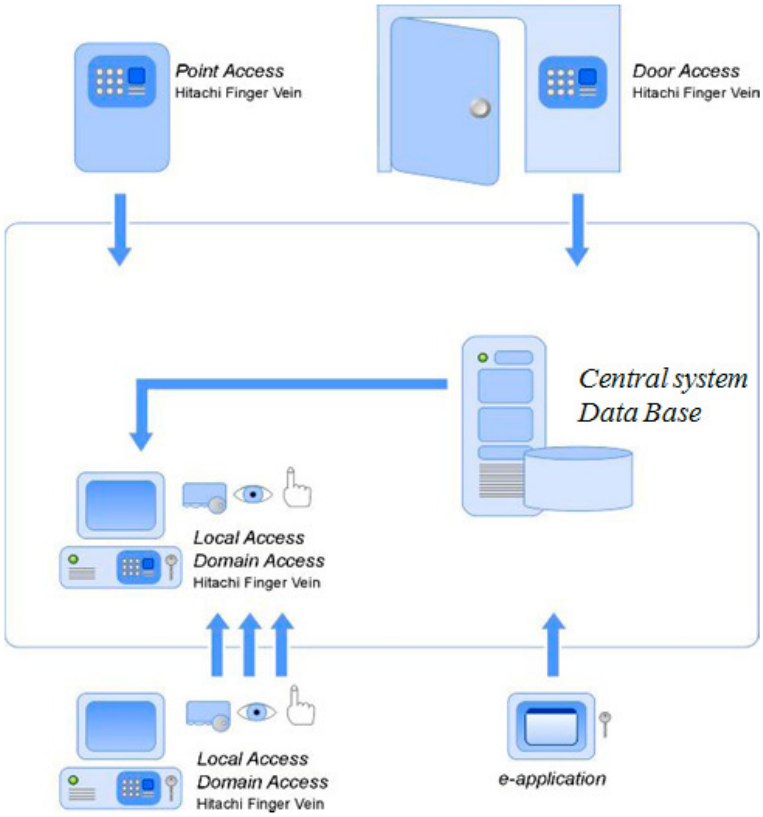
The last mode there is a HIL (Hardware In the Loop) mode. There are processed the readings from physical sensors only. It is a normal operation mode of on autonomous vehicle.

qBMS is a software platform designed for standard PC computers working under Microsoft Windows operating system. It consists of graphical interface that allow to visualize the state variables of controlled physical model with running qB Control System and underlying business logic responsible for data gathering and processing. Base station is working in two different modes so called "online" mode and "analytical" mode. "Online" mode is used to visualize the data in real time, it means while normal operation of controlled physical model. In "analytical mode" researchers are able to analyze data stored while "online" mode. qBMS is designed as plug-in system with use of the newest software development patterns, what guarantees extendibility of the project.

Biometric systems

A. Czornik, A. Świerniak, A. Nawrat, A. Gałuszka, K. Skrzypczyk, K. Simek, R.Koteras, K. Daniec, K. Kozak

Biometric systems are a quite new brand of science and nowadays are more often used to grant secure access to buildings, private areas or workstations for example. In a modern, actually used, security systems access is granted mainly based on known user password or public key infrastructure. However enhancements to existing security systems based on biometric analysis can highly improve its security and efficiency. Currently, technology of secured microprocessor pass card with biometric data was not developed. Biometric and PKI are two different ways of security systems evolution, successful merge of enumerated technologies will increase overall security and determine new evolution path.



Fast evolution of technology especially internet gives enormous abilities in a field of data access what leads to the serious security problems such as phishing, spoofing, pharming. Connected with this fact evolution of security systems is a must. Day by day those systems become more sophisticated. Simple password and username is not enough, nowadays users can often met with tokens, single use passwords, certificates. Main goal of all those techniques is to enhance security of data they are protecting. However, all

security systems consist of two simple authorization arguments: something you know (username, password), something you have (token, certificate, microprocessor card) . This are arguments that can be easily stolen. That is why biometric systems are crucial part of security systems development, they give possibility to introduce third authorization argument to the designed system - something about you - unique physique feature so called biometric feature.

Inertial Measurement Unit

Aleksander Nawrat, Kamil Kozak, Roman Koteras, Krzysztof Daniec

Object orientation measurement is one of the most crucial aspects of sensor system designed for any flying object. Without precise knowledge about object orientation it is impossible to correctly control the vehicle. Object orientation can be defined as relative position of coordinate system connected with the object versus reference system. Reference systems are already defined and two of them are commonly used. First one is ECEF - *Earth Centered Earth Fixed* and NEV - *North East Vertical*. In order to determine object orientation the center of object coordinate system is localized in object center of gravity. Exemplary orientation of coordinate system axis is shown on
Fig. 1

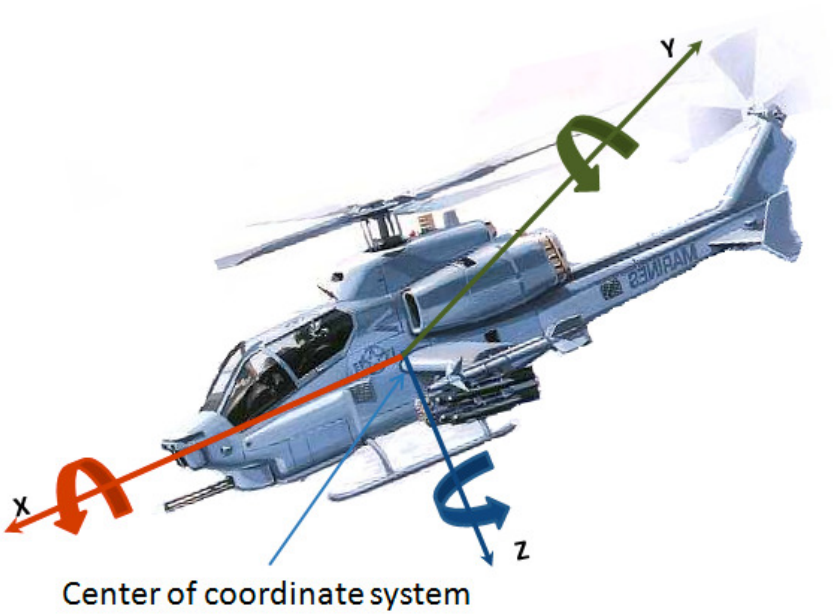


Fig. 1 Object coordinate system

Inertial Measurement Unit it is a precise electronic device with implemented sophisticated mathematical algorithms that allow to translate analog sensor inputs into digital representation of object orientation. It is used as one of a main sensors on board of autonomous vehicles and robots
Fig. 2. IMU is usually mounted on the bottom side of an object away from the center of gravity.

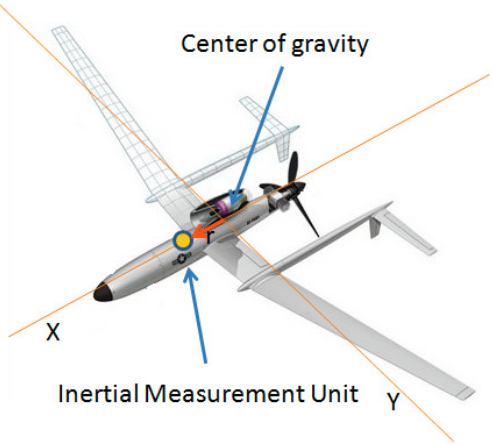


Fig. 2 IMU localization.

A study of robotic vision methods applied to the molecular docking problem

M. Pacholczyk, D. Bereska

The technique called molecular docking can be regarded as a potential method for computer aided drug design and optimization. The problem of molecular docking is usually referred to as a process of finding a proper ligand (in our case a drug molecule) that fits (geometrically and energetically) a specific region of protein designated as protein binding site. Such matching should cause particular biochemical response i.e. viral protein function inhibition.

The problem can be solved using either geometric or energetic approach. In current paper we consider geometric aspect of molecular docking using methods derived from the domain of robotic vision.

In order to account for interactions between a protein and a ligand we use interaction surfaces introduced by H.-J. Bohm. The interaction surfaces represent a number of biochemical rules governing fundamental types of possible molecular interactions (i.e. hydrogen bonds or hydrophobic interactions) stored in the form of easy to use set of geometric constraints. In our approach we assume ligand is a small molecule without internal degrees of freedom and protein is a rigid immobilized body. The 3D structure (cartesian coordinates of atoms) of both the ligand and the protein is considered known and taken form public database of protein structures The ProteinDataBank (PDB). The location of protein binding site and types of protein-ligand interactions, used as reference, are obtained thanks to the LIGPLOT software.

As a solution to the problem of finding a correct pose of the ligand in the binding site we study a robotic vision method called geometric hashing introduced in. Geometric hashing was previously used in molecular docking domain, however without using any biochemical model of protein-ligand interaction. The protein and the ligand were simply considered as arbitrary rigid bodies. Basically the idea of geometric hashing is to find an object in scene using a database of models of objects. In our case the scene is understood as protein binding site and the object as a ligand, both represented as discrete sets of points in 3D space. The geometric hashing algorithm consists of consecutive preprocessing and recognition phases. During the preprocessing phase ligand geometric features of interest are stored in an array called hash-table, while

during the recognition phase the binding site features are matched with the ligand features in a voting process.

We tested our method trying to reconstruct native binding pose of the SO4 ligand in 5TIM complex of trypanosomal triosephosphate isomerase structure downloaded form PDB database. As a measure of binding affinity we use RMS deviation from the reference pose.

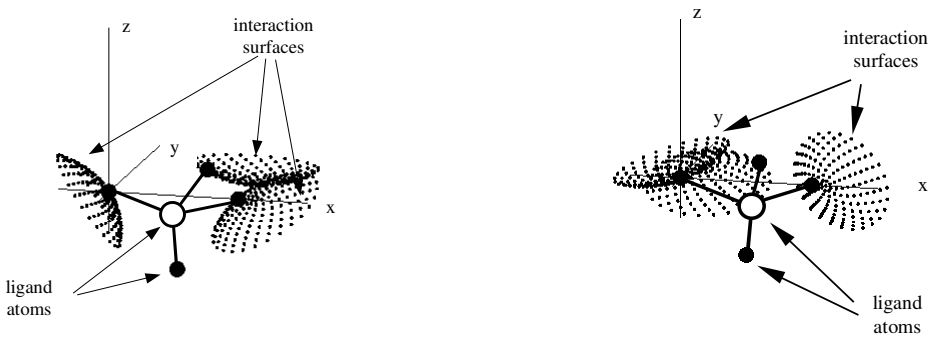


Fig. 1. The reconstructed pose of SO4 ligand – results obtained with geometric hashing technique

Computational methods for docking ligands to protein active sites

A. Polański, Z. Starosolski, M. Pacholczyk, A. Owczarek, P. Wolanczyk, M. Kimmel

The aim of this study is identification of parameters of models for computing interaction binding affinities (energies) between certain chemical molecules. The work plan has the following elements: (1) Overview the static models for computing energies of ligand-ligand and protein-ligand interactions. (2) Download, from available databases, data describing relative positions and conformations of ligands and proteins. (3) Estimate parameters of models using suitable optimization methods and hypotheses.

One of the models with which we already have experience is SCORE 1

$$\Delta G_{binding} = \Delta G_0 + \Delta G_{hb} \sum_{h-bonds} f(\Delta R, \Delta\alpha) + \Delta G_{ionic} \sum_{ionic} f(\Delta R, \Delta\alpha) + \Delta G_{lipo} \left| A_{lipo} \right| + \Delta G_{rot} NROT$$

In the above $\Delta G_{binding}$ – free energy of the binding, ΔG_0 – constant binding energy connected with loss of rotational and translational entropy of the ligand, ΔG_{hb}, ΔG_{ionic} contributions from the ideal hydrogen bond and the ideal ionic bond, ΔG_{lipo}-contribution from lipophilic interaction, $|A_{lipo}|$- lipophilic contact surface, ΔG_{rot} – reduction of binding energy connected with loss of degree of freedom in the ligand, *NROT* – the number of acyclic rotatable bonds in ligand, $f(\Delta R, \Delta\alpha)$ – penalty function, accounting for deviations ΔR from the ideal length and the ideal angle $\Delta\alpha$ of a hydrogen bond.

Protein databanks include already around 30,000 protein structures, many of them complexed with ligands. In our study, we will use a carefully defined subset of these

structures to estimate constants present in energy function such as the one presented above. The idea is to find constants, which result in docking solutions as close as possible to those listed in the databanks.

We will collaborate with chemists from the Silesian University.

Exploring the landscape of protein-ligand interaction energy using probabilistic approach

M. Pacholczyk, M. Kimmel

Analysis of protein - small molecule interactions is crucial in the discovery of new drug candidates and lead structure optimization. Small biomolecules (ligands) are highly flexible and may adopt numerous conformations upon binding to the protein. Using computer simulations instead of sophisticated laboratory procedures may significantly reduce cost of some stages of drug development. Inspired by probabilistic path planning in robotics, stochastic roadmap methodology can be regarded as a very interesting approach to effective sampling of ligand conformational space around a protein molecule. Protein - ligand interactions are divided into two parts electrostatics, modeled by the Poisson-Boltzmann equation, and van der Waals interactions represented by the Lennard-Jones potential. The results are promising since it can be shown that locations of binding sites predicted by the simulation are in agreement with those revealed by experimental x-ray crystallography of protein-ligand complexes. We would like to extend our knowledge beyond scope available to most of the current molecular modeling tools toward better understanding of the ligand binding process. We try to accomplish this goal using two-level model of protein-ligand interaction and sampling of ligand conformational space covering the entire surface of protein target.

SVD as a tool for pattern discovery in gene expression data

K. Simek

Singular Value Decomposition (SVD) is a matrix factorization known from linear vector algebra, which reveals many important properties of a matrix. It is a standard tool in many areas of physical sciences, and many algorithms in matrix algebra make use of SVD. Recently, gene expression data have been analyzed using SVD. In gene expression analysis the principal aim of application of SVD is to detect and extract internal structure existing in the data and corresponding to important relationships between expression of different genes. The most important feature of SVD which predisposes it to be used to the analysis of microarray data is, in many cases, existance of meaningful biological interpretation of the characteristic modes obtained from decomposition of gene expression matrix.

In the clustering literature, SVD is sometimes applied to reduce dimensionality of the data set prior to clustering.. Since characteristic modes are uncorrelated and ordered, the first few that are the most significant and reflecting most of data variation are usually used in cluster analysis. The proposed approach differs from that known from the literature, where characteristic mode coefficients (gene coefficient vectors), are used for clustering instead of original variables. Here SVD is applied in order to select a set

of original genes and then use them for samples clustering by one of standard algorithms.

The proposed gene selection algorithm inspects gene coefficient vectors corresponding to the set of the most significant characteristic modes. Each coefficient is compared to the threshold value, the meaning of which is similar to a 3σ statistical significance cutoff. If the magnitude of the element is greater than the threshold, the corresponding gene is selected to the clustering set. Variation of the threshold value gives possibility of changing a number of selected genes. In the result we obtain a set of genes having patterns 'similar' to the dominant modes.

The method was succesfully applied to the analysis of several different sets of biological gene expression data aquired in the Comprehensive Cancer Centre Maria Skłodowska-Curie Memorial Institute Branch Gliwice, Poland, using Affymetrix Human Genome U133A arrays.

Predictive approach to the control of mobile vehicle in dynamic environment

Krzysztof Skrzypczyk

Operation of the mobile vehicle inside of the dynamically changing environment implies many complex problems that must be solved by the control system. Inaccuracy and uncertainty of the sensory system of the mobile vehicle is one of the most problematic issues that the system must cope with. Even when the vehicle operates in static static workspace the aforementioned issues may lead to the collision. The problem is going more and more intense when the workspace is dynamic - the vehicle must interact with moving objects. One of the possible ways of handling this problem is using predictive approach to the control. It is intuitive fact that the knowledge of the trajectory of moving object can improve the motion planning process of the mobile vehicle. Therefore a lot of attention has been paid to this topic in literature. Unfortunately the prediction is only an estimation of the state of the process in the future. Data provided by prediction schema are very often uncertain. Therefore a technique of dealing with uncertainty of the prediction should be provided. In our approach we propose to apply game theoretical schema in order to reduce results of uncertainty and its influence on the process of control of the robot.

ROBOT CONTROL SYSTEMS

Researches on robot motion and path planning

A. Babiarz

Robot path planning is one of the most difficult task that scientists want to solve. The path may be modeling with straight line or piecewise polynomials of various order. The most popular task is to find collision-free path. The higher robot's degree of freedom is the more difficult task will be. The solution it can be find using probabilistic method. The first of them is Probabilistic Roadmap (PRM), the second is Rapidly-exploring random trees (RRT). The method can be use to find solution of manipulator robot and biped robot.

For example the biped robot has 17 degrees of freedom (kinematics bases on human kinematics). The solution of inverse kinematics is impossible to compute. Then the solution may be computed using probabilistic methods and sensor system which detects collision in workspace. The another task is stabilization of gait and description of walk's pattern. The sensor system should recognize sort of ground. This information allows to path planning in different surrounding environment.

Research on colour image processing

D. Bereska, H. Palus

Colour image processing has a history going back over 30 years but such systems have been undeveloped in the past. Research in this field required high performance computers, colour cameras, special framegrabbers and colour monitors. Binary and grey-level image processing were therefore much easy. Nowadays, the role of colour in image processing cannot be understated. The situation in many subtopics of image processing has changed: colour images are commonplace and monochromatic images are rather exceptional.

Our research concentrates on the following low-level colour image processing problems: acquisition of high-quality colour images, representations of colour images in different colour spaces, pre-processing methods (edge preserving filters, colour quantization etc.), colour image segmentation techniques and evaluation of segmentation results. In practise there does not exist an ideal colour space for all stages of image processing process. The decision on which colour space to use depends on given task.

We investigated the properties of HSI perceptual colour space. The HSI colour solid was visualised and the number of colour points in horizontal sections through this solid was calculated. The knowledge about a structure of colour space can be helpful for improvement of procedures in low-level stage of colour image processing and recognition e.g. colour image segmentation. We reviewed also different standard RGB

colour spaces on the background of device-dependent RGB colour space and observed some limitations of standards. Experiments with images of Gretag Macbeth ColorChecker Chart (Fig.1) acquired by the digital still camera were conducted. The knowledge of colour gamut of digital camera was very important for determining the colour transformation from RGB to CIELAB. In experiments the reference data for colours was the CIELAB components measured by spectrophotometer.

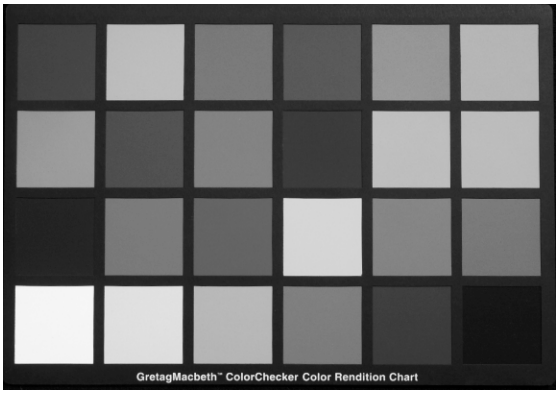


Fig. 1. ColorChecker Chart from Gretag Macbeth.

Higher colour reproduction accuracy in case of using the sRGB colour space was shown. New colour-difference formulae CIE94 and CIEDE2000 have been proved successful in evaluating colour reproduction accuracy.

Colour image segmentation plays an important role in many applications e.g. object recognition, image compression, content based image retrieval etc. An error in this process will be propagated further. The goal of colour image segmentation is to identify homogeneous regions in colour image that represent objects or meaningful parts of objects present in a scene. One of simplest methods of colour image segmentation is thresholding of image. The thresholds are defined as results of analysis of histograms of colour components. In the case of using HSI colour space a hue histogram plays the special role. Sometimes the hue histogram shows colours that do not appear in the image and it is not fit for analysis of histogram for the purpose of location of thresholds. This histogram needs any correction based on the expansion of the idea of achromatic pixels in quasi-achromatic pixels direction. We have proposed a set of additional IF-THEN rules, which link intensity and saturation together for quasi-achromatic pixels and generate corrected hue histogram.

We developed also new algorithms from two main classes of segmentation techniques: pixel-based techniques and region-based techniques. Clustering in image processing is the grouping together of pixels from an image, depending the calculated similarity between them. Clustering can be often defined as an unsupervised classification of pixels. The image data is clustered in three-dimensional colour space (usually RGB). Many colour clustering techniques have been proposed in the past. We shortly describe here three classical and two less popular clustering techniques suitable for segmenting of colour images. All these techniques are iterative. We asserted that evaluation functions *VM* and *Q* could be very helpful in search of best segmentation results during clustering process. Additional criterion for the choice of clustering technique can be the time of computing: from fast k-means to slow cluster merging

technique. We observed that the postprocessing stage is very important for the segmentation results.

During last years we are developing an original region-based segmentation technique for colour images. This technique is based on the concept of region growing without seeds and, in postprocessing process, on a small regions removal by region merging. Experimental results of proposed segmentation technique are good. We tested our technique working in different colour spaces (RGB, CIELAB and HSI). An additional region merging procedure removes oversegmentation results and small highlights. Majority of colour segmentation techniques uses several control parameters, e.g. a number of clusters in clustering techniques or some values of thresholds in region-based segmentation. These parameters should be adjusted to obtain optimal image segmentation. The choice of values of parameters is non-trivial task. This segmentation technique was also used in process of grey-scale segmentation of the comet assay images. The comet tail and head were successfully extracted.

The segmentation results are strongly determined by a control parameters: threshold ***d***, which limits the value of homogeneity criterion and threshold ***A,*** which defines an area of small region used in postprocessing (Fig.2). During this merging process each region with a number of pixels below ***A*** is merged into a region with a larger area if the homogeneity criterion is fulfilled. After the merging, a new mean colour of region is calculated and the labels of pixels belonging to a region are modified. Experimental investigations of presented segmentation technique were performed using F and Q evaluation functions. The idea of using this kind of functions can be formulate as: the lower is the value of F or Q, the better is the segmentation result. If quantitative evaluation function of segmentation results is applied then a choice of values of parameters is simpler. The segmented images can be further postprocessed e.g. by removing small regions that are usually not significant in further stages of image processing.

Fig. 2. Example of segmentation results in RGB colour space for image Peppers: original image (left), parameter value: **d**=30 (middle), parameter values: **d**=60, **A**=500 (right).

In the case of noisy images, we propose the different filters that can be applied as pre-processing stage for colour image segmentation. Next we address the problem of performance of preprocessing before colour image segmentation. Our interests are limited to nonlinear colour filters working in the spatial domain. Most often comparing such filters is based on calculation of different quality factors (e.g. PSNR, NCD etc.). Our main idea here is to use an evaluation function, coming from research on segmentation, to evaluate the performance of preprocessing. The experiments were

realized using both original and noisy images corrupted by Gaussian and impulsive noise.

Last topic of our research in the field of colour image processing is based on the concept of colourfulness. Colourfulness of the image is main attribute for image quality assessment. We have shown different methods of defining and computing of colorfulness of the image. All experiments have been carried out on the set of natural color images with different perceptual colorfulness. We have tested the images using simple colorfulness estimate based on statistical parameters of the pixel cloud along red-green and yellow-blue axes. During image processing the colorfulness of the image can be changed: by increasing after color enhancement or by decreasing after image compression. Sometimes the colorfulness of the image should be invariant. We have presented it on examples, which show that the colorfulness can be useful for evaluating the color quantization algorithms beside such traditional performance functions as RMSE and ΔE. Based on these experiments, we can formulate more general conclusion: concepts coming from colour science can effectively applied in colour image processing.

Colour and hyperspectral images contour detection

R. Bieda

Edge detection is a very important process in vision systems to use for image understanding and scene analysis by either computer-based systems or men. Determination of object boundaries is important in many areas such as medical imaging (X-ray image analysis, computer tomography, mammography), dactyloscopy, quality control, photogrammetry (analysis of satellite and aerial pictures) and intelligent robotic systems (visual systems for object recognition and classification).

Edges in grey-level images can by thought of as pixel locations of abrupt grey-level change. A change in the image function can be described by a gradient that point in the direction of the largest growth of the image function.

The research concentrates on the following low-level *m*-channels image processing problems based on edge and contour objects detection.

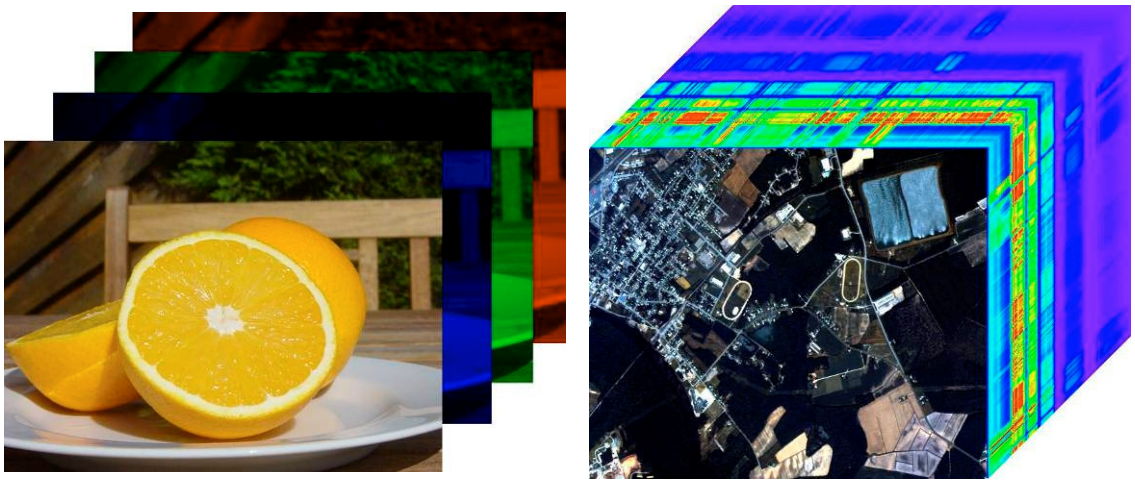


Fig. 1. Example of colour images witch three channels and hyperspectral cube image with 224 –channels.

While edge detection in grey-level images is a well-established area, edge detection in colour (e.g. in RGB space m=3) and hyperspectral (e.g. in AVIRIS data m=224) images has not received the same attention. The fundamental difference between colour/hyperspectral images and grey-level images is that, in a colour/hyperspectral image, a m-components vector is assigned to a pixel, while a scalar grey-level is assigned is a pixel of a grey level image.

The aim of the methods of image contour detection is the information which will be used in segmentation process or object recognition. Current research is focused on tested method based on kernel end spectral-pattern edge detection.

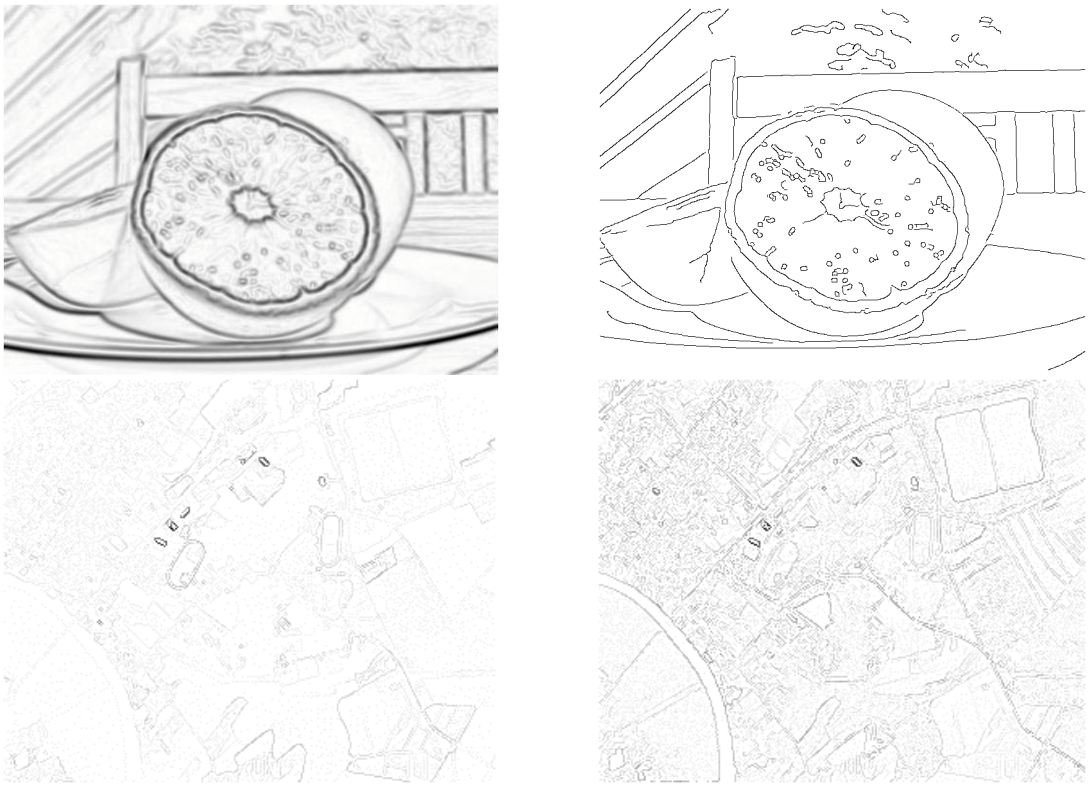


Fig. 2. Example of gradient map and contour of colour image (top row), and gradient map of hyperspectral images for 190-channel with Triangular kernel and 55-channel for Gaussian kernel (bottom row).

Research on modeling, planning and simulation of robot manipulator movement

T. Szkodny

The fundamental problems of robotics are concentrating in following topics:

1. Mathematical modeling of kinematics and dynamics of stationary and wheel mobile robots (with using Matlab/Simulink and Real Time Workshop programming environment).
2. Planning of stationary and wheel mobile robots movement with taking into consideration the kinematics, dynamics of robots and drive characteristics of actuators.
3. Choice of the settings of controllers for stationary and wheel mobile robots.
4. Simulation of the movement and control of the stationary and wheel mobile robots, with using Matlab/Simulink and Real Time Workshop programming environment. (for following robots: AS, L-1, IRb-6,experimental).
5. Computing algorithms of position coordinates of chosen points and manipulation object in relation to the cameras frame (camera NI-1742).
6. Designing of the interfaces connecting cameras with robots controllers (camera Ni-1742 with KUKA KRC3 robot controller).
7. Calibration algorithms of camera in relation to robot base frame (camera Ni-1742 in relation to base frame of KUKA KRC3 robot).
8. Solution algorithms of the inverse kinematics problem of stationary and wheel mobile robots and its implementation to the robot controller (for following robots: experimental, Robix with Manipulator OOO1÷OOO4, KUKA KRC3).
9. Designing of the interfaces connecting cameras with implemented solution algorithm of the inverse kinematics of problem of robot (camera Ni-1742 with implemented solution algorithm of the inverse kinematics of problem of KUKA KRC3 robot).
10. Planning algorithms of movement robot with using the vision information of camera (for the KUKA KRC3 robot with vision information of the camera Ni-1742).
11. Modeling of kinematics of wheel mobile military manipulator.

In late three years (2007-2010) the Foundation Robotics Laboratory was equipped to:

1. KUKA KRC-3 Robot with six degree of freedom,
2. Adept Six-300 Robot with six degree of freedom,
3. 2 Inteligent Cameras Ni-1742.

It allowed to worked following new didactic laboratory exercises:

1. Programming of KUKA KRC-3 Robot,
2. Application of Vision Information to Programming of KUKA KR3 Robot,
3. Programming of Adept Six-300 Robot.

In the Fig.1 is illustrated the KUKA KRC-3 laboratory station. The Fig.2 shows the Adept Six-300 laboratory station.

Fig.1. The KUKA KRC-3 laboratory station

Fig.2. The KUKA KRC-3 laboratory station

Microcomputer system for preventive maintenance of industrial ventilators

A. Staszulonek

There are hundreds of thousands industrial ventilators working globally in a continuous mode. They are frequently used in the processes where undisrupted air or other gases transportation is critical for plant or process functioning. Almost always these ventilators work completely unsupervised or at best are periodically checked with the professional, portable equipment. This happens usually when noticeable malfunctioning occurs. Frequency of this checkup is thus very seldom and usually too late to prevent significant damage of the equipment. Test and measurement equipment used for this checkup is highly expensive and requires qualified personnel to install, carry diagnostic tests and interpret the test results. All this results in high repair cost, extended process breakdown time and related financial losses.

To eliminate these problem a continuous, predictive maintenance of industrial ventilators should be applied. To implement this innovative idea a dedicated microcomputers system has been developed. The block diagram of this system is presented on the figure below (Fig.1.).

The system is furnished with the set of sensors measures relevant parameters, like vibrations, noise, current, voltage, temperature, pressure, flow or other values depending on the application. Data is processed on site, machine state indicators are calculated and the results transferred to the local workstation. Machine state indicators are transferred to the preventive maintenance database server. Data are analyzed by the diagnostic software, machine failures are predicted and warnings are communicated to the appropriate persons and systems. Machine state indicators are archived for future use.

The Fast Fourier Transformation (FFT) is performed by the system onsite and the results are transmitted to the monitoring station. All the results can be viewed there. The sample result presenting the acceleration and FFT results is presented on the figure below (Fig.2).

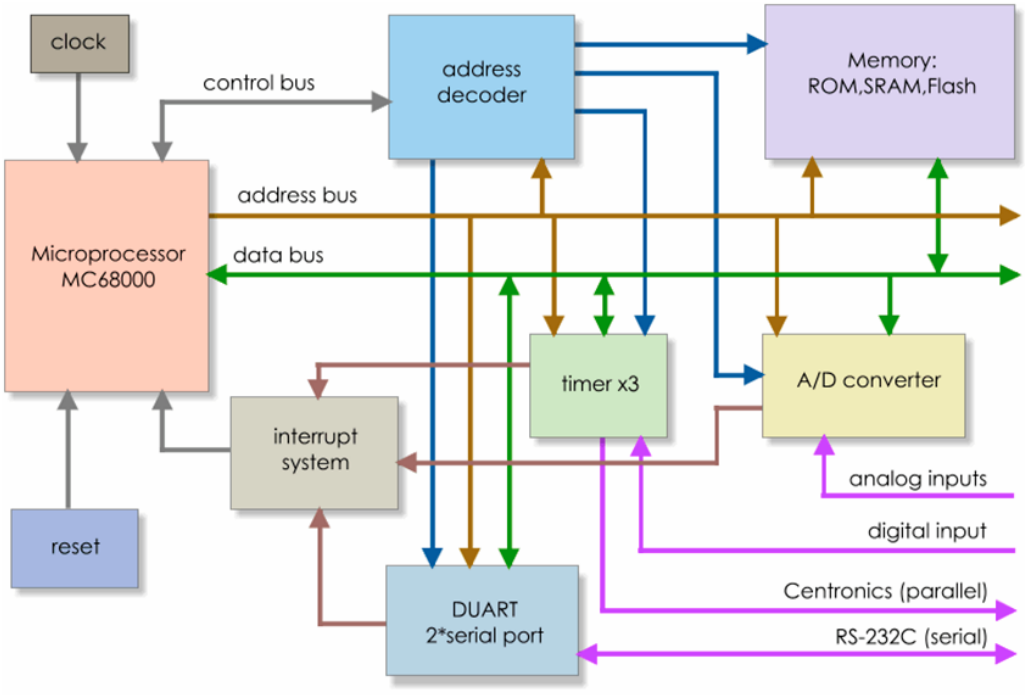


Fig. 1. Block diagram of the diagnostic system.

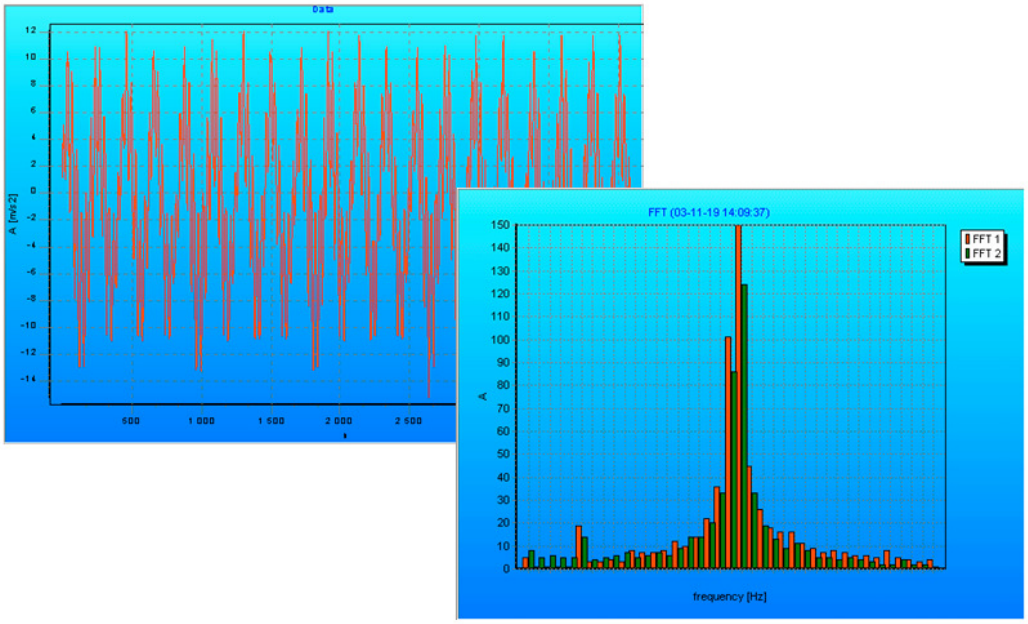


Fig. 2. FFT analysis of vibrations - sample result.

All the data generated by the system are stored at the database for the analytical purposes. The structure of the database is presented below.

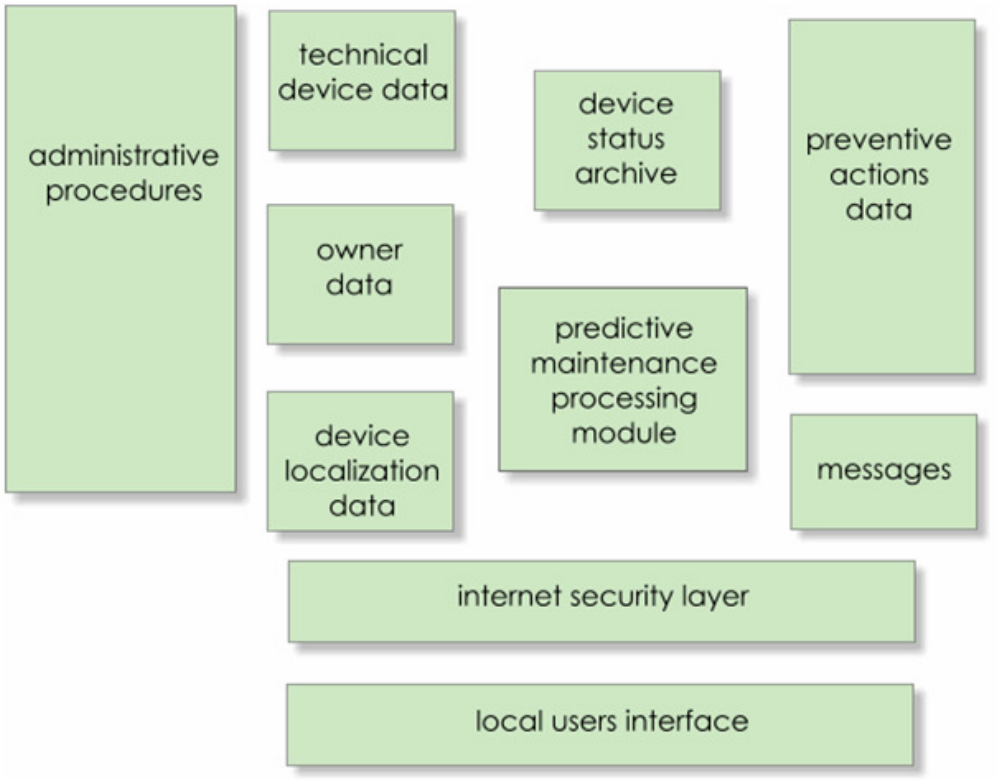


Fig. 3. Components of predictive maintenance database.

Based on these data a forecast process generating the predictive maintenance curve is carried out. The state of the equipment and the time of recommended maintenance action are resulting from this curve.

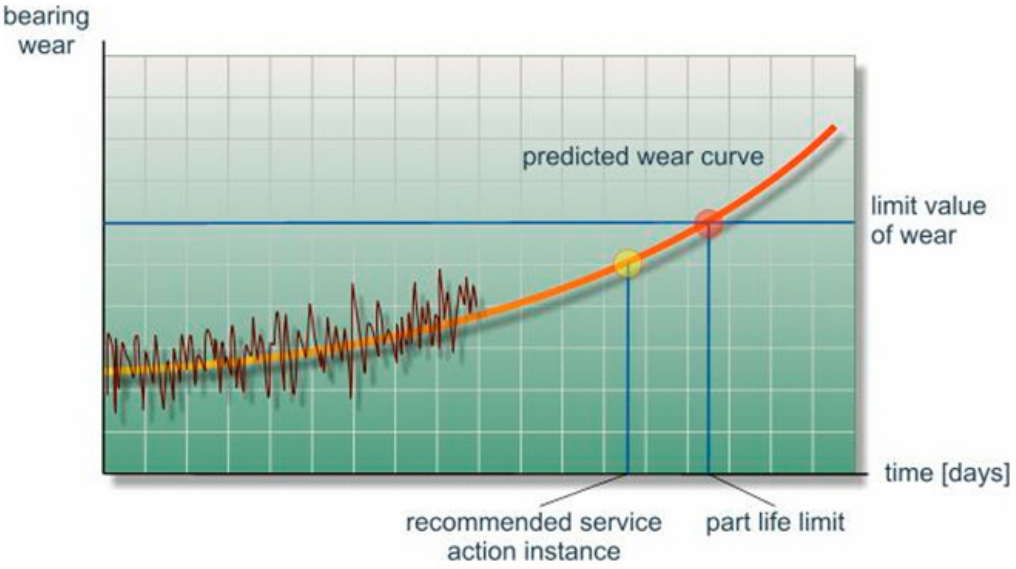


Fig. 4. Predictive maintenance curve.

In case of rapid deterioration of any of the monitored parameters the alarm messages are distributed over the Internet to the appropriate recipients like: owner's tech support, external tech support, manufacturer and any other person or unit indicated.

Hardware structure of advanced robot control system

A. Staszulonek

Between the basic requirements set on advanced robot control systems one can mention the following:

- High precision of robot arm positioning and tracking,
- High speed of motion,
- Rich set of interfaces to the sensory systems,
- Trajectory repeatability in the presence of various disturbances,
- Simple design and maintenance,
- High reliability,
- Lack of overshoots during the transient processes.

Last of the above mentioned requirements is critical. Due to these requirements the robot control system has to perform simultaneously and in real time large number of tasks. Between these tasks are following: desired trajectory planning and generation in presence of variable work space, elimination of inertial cross couplings, acquisition and processing of sensory information, control of multiple degree of freedom

servomechanisms, robot motion visualization and general system monitoring. These tasks represent significant computational load and by far exceed the power of single processor. Due to the nature of the calculations performed robot control system's task can be classified into group performing the floating point operations and, the group performing the integer calculations. For the above-mentioned reason the robot control system can be divided into two dedicated subsystems. First of these subsystems is loaded with task planning, decomposing and execution supervision. The output from this subsystem is the desired robot trajectory specified as the point-to-point or continuous motion. In the first case one has to deal with the set point control problem while in the second with the tracking problem. For both cases the methods the methods used to solve the problem differ significantly. Second of the above mentioned subsystems, in a way subordinate to the first is the one whose task is the execution of the generated trajectory. It usually consists of one or more dedicated computers, controlling each of the manipulator's servomechanisms. The figure below presents the hierarchical, multilevel, multiprocessor hardware structure of advanced robot controller reflecting the task assignment between the two subsystems. Presented structure incorporates two single board computers: MVME2604 and MVME162 cooperating over the standard VME bus. Each of these computers has the set of interfaces and peripheral devices appropriate for the performed tasks. The information exchange between both computers (and subsystems) is carried out via the shared area of system memory. The access to this memory is coordinated by an appropriate set of semaphores. At the upper, supervisory level of the system the RISC processor based machine MVME2604 has been applied. The particular tasks performed at this level are: desired trajectory generation, reverse kinematics problem solution, pseudoinertial matrix calculation, inertial decoupling, motion visualization, system monitoring and robot program storing. This level of the controller is provided with SCSI CD-ROM and Hard disk to enable easy system software installation and storage of the application software. The operator communicates with the system via the SVGA monitor connected to MPMC graphic card, standard keyboard and mouse. The users access the system via the local area network Ethernet. This level is controlled by the AIX R4.3 operating system.

The software development is carried on with the C++ programming language, while as the graphic environment the X-Windows system is used.

Embedded computer MVME162 has been applied at the lower level of system. Its major tasks are: servomechanisms control and sensory data acquisition. To increase the speed of system, the calculations at this level are mostly performed on the integer numbers.

All activities of the system at this level are interrupt driven. Due to the high data sampling rate required, the computational load at this level is very high. In particular, high sampling rates are required for manipulator links position and velocity acquisition. This justifies the necessity of multiprocessor structure of the whole system.

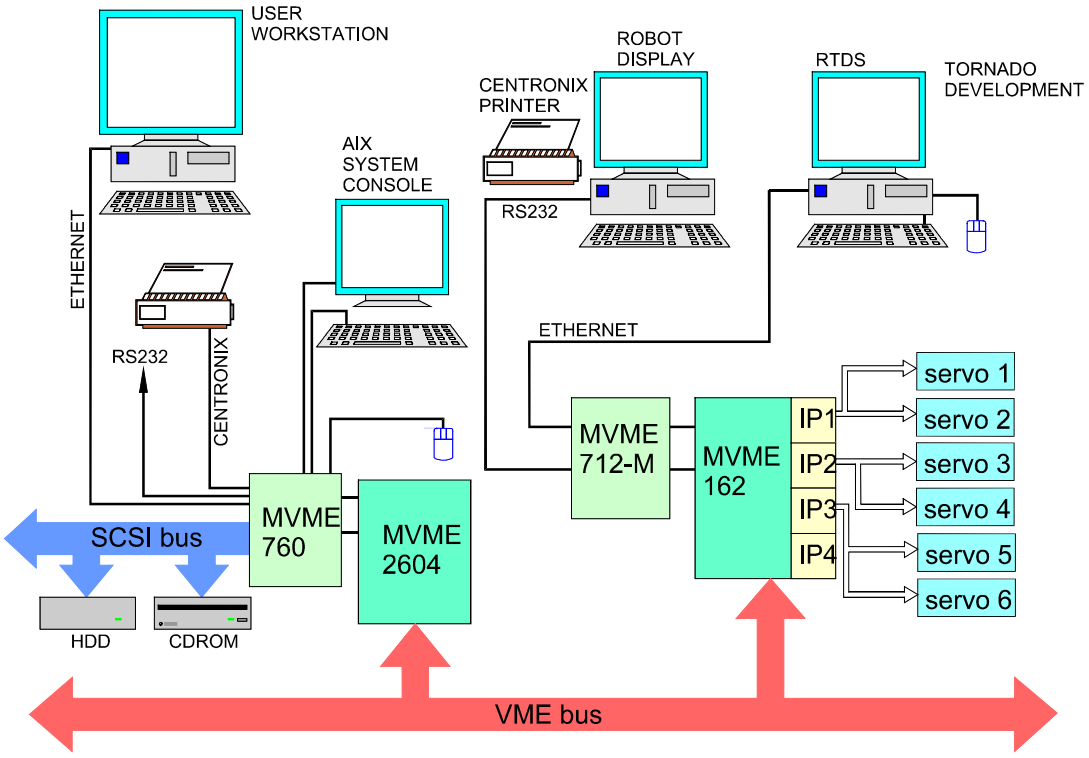


Fig.1. Hardware structure of robot control system.

To achieve high sampling rate, the embedded controller at the trajectory execution level has been provided with six dedicated servocontrollers based on specialized motion controllers LM628 organized into three Industry Pack standard modules. Real time operating system VxWorks is responsible for the system coordination at this level. The application software for the trajectory execution level is created in assembly language, high-level C, and object C++.

The development process is carried on in the Tornado and Windows environment on common PC computer. The communication between development system and embedded controller is carried on via the Ethernet. Additionally the terminal can be connected directly to the embedded controller. This terminal can be used as the low-level system console, displaying various information concerning the task performed and current trajectory execution.

GRADUATE COURSES

- Control theory (lectures, classroom exercises, laboratories), Polish, English,
- Optimization theory (lectures, classroom exercises, laboratories), Polish, English,
- Pattern recognition (lectures, classroom exercises, laboratories), Polish, English,
- Introduction to system dynamics (lecture, classroom exercises), Polish, English,
- Quality Control (lecture, laboratories), Polish, English,
- Probability theory and mathematical statistics (lectures, classroom exercises), Polish, English,
- Artificial intelligence for robots (lectures, laboratories), Polish,

- CAD of control systems (lectures, laboratories, project), Polish,
- Control and estimation in uncertain environment (lectures, laboratories), Polish,
- Control of large - scale systems (lecture, classroom exercises, laboratories), Polish,
- Object programming (lecture, laboratories), Polish,
- Internet technologies (projects), Polish,
- Modelling and Simulation (lecture, laboratories), Polish,
- Foundations of Robotics (lectures, classroom exercises, laboratories), Polish,
- Manipulator Systems (lectures, classroom exercises, laboratories), Polish
- Power Transmission Systems and Industrial Robots (lectures, classroom exercises, laboratories), Polish,
- Robot Control Systems (laboratories), Polish.

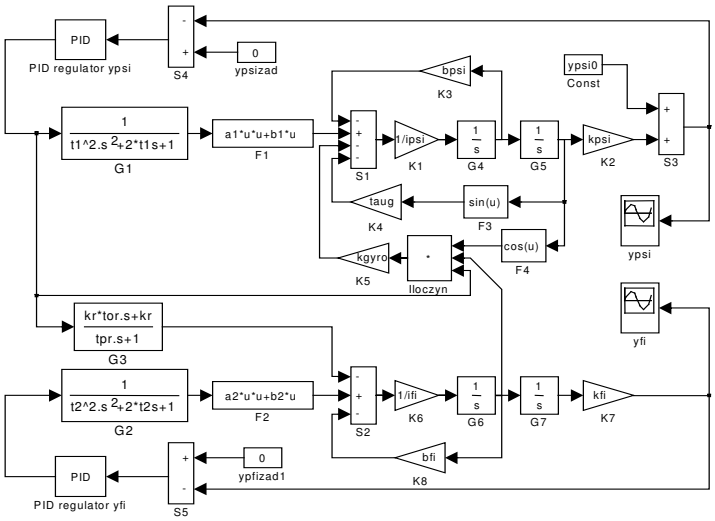
LABORATORY AND RESEARCH EQUIPMENT

Helicopter Model.

Helicopter model is a laboratory and research station manufactured by TQ International in cooperation with Humusoft. The model, with two degrees of freedom, is moved by two propellers (main and side) driven by DC engines, (photo below). Its configuration enables control by a PC computer. It is equipped with the software interface enabling real-time control from Matlab.

The plant provides a wealth of control system design and analysis features that make it very useful for education and research purposes. The mathematical model of the helicopter exhibits natural nonlinearitiy, instability and significant cross-coupling between two control channels. The range of possible experiments covers such areas as dynamical systems study, derivation of the mathematical model, linearization, simplification, identification, state feedback design, decoupling, robustness analysis and design etc.

During the experiments in the Department the system was enriched with additional software for Matlab and Simulink that enable solving some problems of controllers design and control system analysis as well as simulating closed loop or open loop systems or their elements. The figure below presents the Simulink block diagram of the helicopter model with two PID controllers driving its main and side propellers.



Simulink block diagram of the helicopter model with two PID controllers

Laboratory stand for regulation in ABS car system

The ABS car setup is a laboratory stand designed for the theoretical study, practical investigation of basic and advanced control engineering principles, and fast prototyping of designed control system. The braking system of a car is one of the key-factor for the driving safety. Anti-lock Braking Systems (ABS) have become an integral part of modern cars, and they have dramatically improved vehicle handling in braking maneuvers. System has contributed to improve the security of modern cars decisively by automatically controlling the brake force during braking in potentially dangerous conditions (braking on iced or wet asphalt, panic braking, etc.). The wheel slip control is a highly nonlinear problem. Moreover, it depends on a set of parameters that cannot be exactly a priori known and on the type of road surface and tyre.

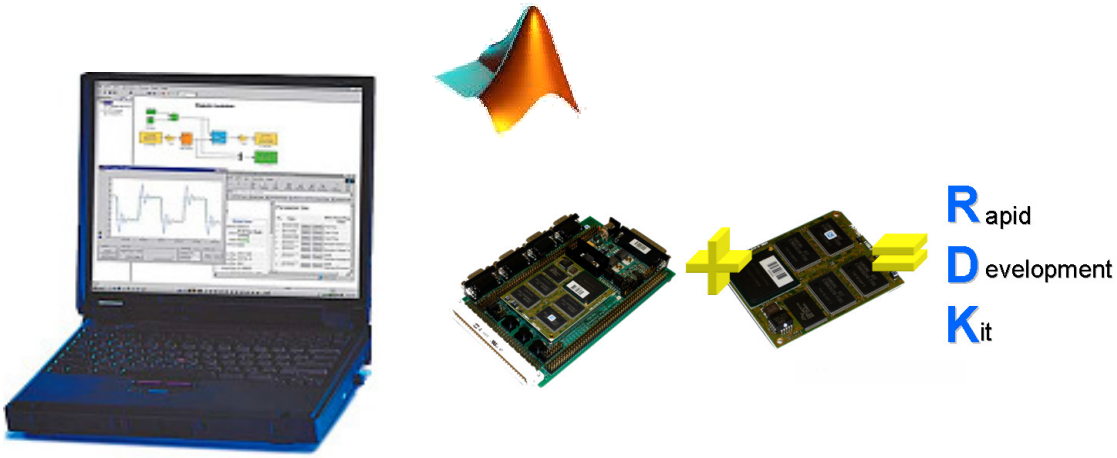
The basic assumption of the project was to use elements of a real car (Fiat Panda parts), which was much closer to industrial solutions. The students will acquaint with the principles of operation of ABS also implement their own control algorithms on a real plant. The laboratory stand construction consists of a vehicle wheel resting on the shaft with flywheel, driven by a three-phase induction motor controlled by inverter. Stand was modeled in simulation environments in order to verify the validity of the overall concept. It was designed in Autodesk Inventor software where the vehicle components are modeled and matched to the elements of the framework or other parts. As a result

the successful prototype of the stand has been achieved. All calculations related to the control algorithm are implemented on the Freescale MPC555 microcontroller. The development kit, integrated with the software Matlab / Simulink provides an environment for rapid prototyping controllers in real-time HiL (Hardware in the Loop) structure. The setup has full hardware feedback (the inertia of rotating parts, inertia and delays in actuators), so that control system operates in conditions close to real.

Implemented control system has been tested for different settings and external conditions (different surfaces and pressure). Conducted experiments showed the validity of established concepts and the proper functioning of all components of the ABS system.

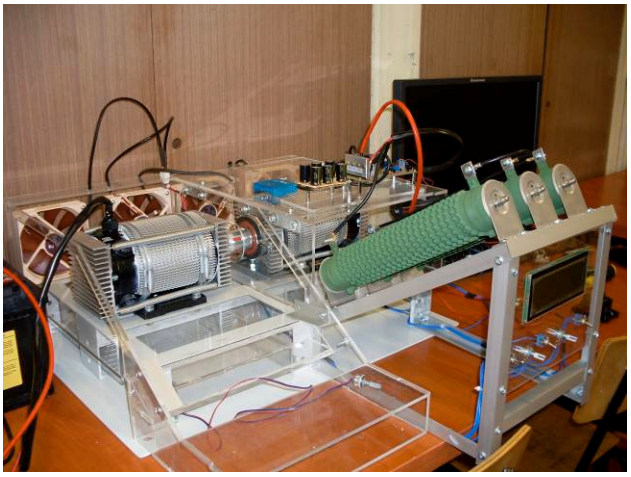
Embedded Control System Design and Fast Prototyping Laboratory

Embedded systems are widely used nowadays in many different areas of industry, such as sensing, control, communications etc. These systems can measure many physical quantities, perform actions on the actuators and other devices. The possibilities of the embedded system design seem to be endless and are only limited by the creativity of the designer and novel technologies. The aim of the laboratory course is to teach relatively new approach in the design process of the control systems and their practical verification. The idea is to transfer program written as a block diagram into the selected hardware platform. The great advantage of presented approach is the possibility of omitting the low level firmware programming, that sometimes causes lots of confusion. Another advantage of this method in the area of control algorithm synthesis is reducing the design and the controllers parameters tuning time, but not only. The further possibility of the control unit development or adding extra features are also attainable.



The Matlab/Simulink environment is the main software platform, which is used in the laboratory. It is traditionally applied for the simulation of systems dynamics, but now it is also equipped in tools meeting the principal objectives of model-based design. Simulation model in the form of Simulink block diagram can be supplemented with additional blocks representing I/O operations allowing the measurement and control to be implemented in the real object. The equipment of the laboratory consists of the Freescale MPC555, Infineon C166 and C167 RDK, Microchip Explorer 16 with the digital signal processors rapid development kits. The Freescale MPC555 is a 32-bit PowerPC core microcontroller with 40 MHz CPU speed and the 64-bit floating point unit. The Infineon microcontrollers are the 16-bit microcontrollers with the very similar

to Freescale MPC 555 inputs and outputs. The Explorer 16 is a low cost, efficient rapid development board to evaluate the features and performance of Microchip's new PIC24 Microcontroller, and the dsPIC33 Digital Signal Controller (DSC) families.
The rapid development kits are fully integrated with the Mathworks Matlab/Simulink software. The microcontrollers peripherals are accessible from the Simulink models via the Simulink toolboxes or libraries. The Embedded Target for Freescale MPC5xx, and the Target for Infineon C166 from Mathworks allows to deploy code generated from Real-Time Workshop Embedded Coder directly onto the selected family processors for real-time execution. The Microchip Device Blocksets for Matlab/Simulink provide a set of interface-compliant configuration and run-time peripheral blocks for the dsPIC30 and dsPIC33 DSCs.



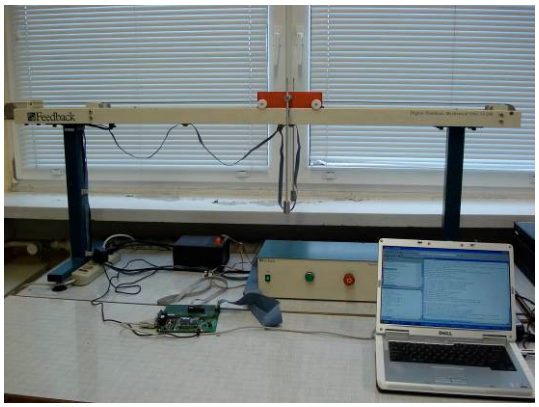
Another development platform is LabVIEW software from National Instruments. This development platform is for a visual programming and it is commonly used for data acquisition, instrument control, and industrial automation. One of the laboratory hardware which is fully programable with LabVIEW is a CompactRIO, a programmable automation controller (PAC). This device is highly configurable and used for control and acquisition system designed for applications that require high performance and reliability. NI CompactRIO is powered by reconfigurable I/O (RIO) FPGA technology. Other device similar to CompactRIO is a Single-Board RIO platform which combines deployable, embedded devices that feature a real-time processor, reconfigurable field-programmable gate array (FPGA), and analog and digital I/O on a single board.

Coupled Tank Apparatus

The Coupled Tank Apparatus is a laboratory station designed for the theoretical study and practical investigation of basic and advanced control engineering principles. It relates specifically to fluid transport and liquid level control problems as they would typically occur in process control industries. It may also, however, be used as a practical introduction to the design, operation and application of control systems in general.
The system configuration for the Coupled Tank Apparatus is shown in the figure. The apparatus is controlled by PC computer with LabView software and was updated under master's thesis.

The station provides a safe, adaptable and self-contained facility for students of control engineering so that they may practically investigate and compare a wide range of functional control system configuration using analogue and/or digital techniques. The scope and content of performed experiments correspond with the usual development sequence used in industry. Starting with the calibration of transducers and actuators, leading to static characteristics and dynamical response testing and, finally, controller design. Full access to the sensors actuators and power supplies is provided. In this way it is also possible to make use of any other available laboratory instrumentation, such as oscilloscopes, plotters, etc.

Digital Pendulum System



Pendulum model is a laboratory and research station designed for theoretical study and practical investigation of non-linear system that has complex dynamic behavior and creates serious control problem. The pendulum - cart set-up consist of a pole mounted on a cart in such a way that the pole can swing only in the vertical plane. The cart is driven by a DC motor (photo below). The apparatus has been reconfigured and updated. This new configuration enables control by rapid development kit phyCORE-167CS with microcontroller Infineon C167 using Matlab & Simulink software. Additionally, in the feedback loop is used 12-Bit voltage output digital-to-analog converter. The system architecture is open and allows a user to modify and change implemented control algorithms.
A wealth of control system design and analysis features that the plant provides, make it very useful for education and research problems. The cart - pendulum model shows the natural nonlinearity and instability that make it very difficult for control. It also provides wide range of possible investigations such as derivation of the mathematical model, linearization, simplification, identification, dynamic system analysis and design.

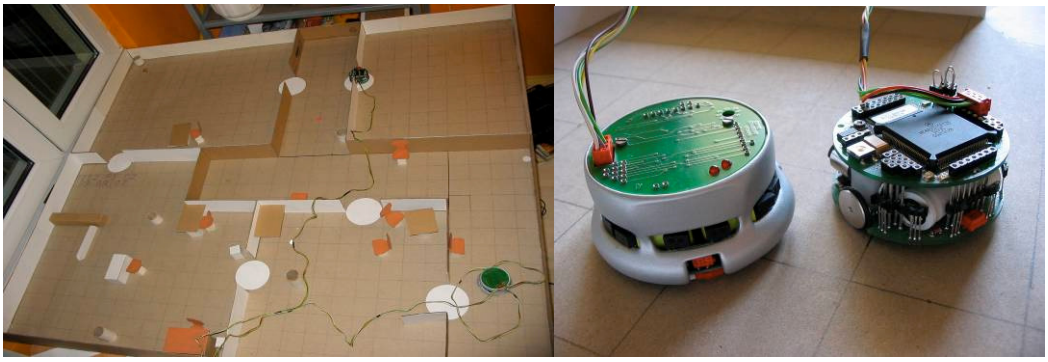
Laboratory Setup for Examining Mobile Robots Navigation Problems

The laboratory setup consists of two miniature laboratory, mobile robots *Khepera* and the model of a complex structured, human made workspace. The robots are controlled by the PC computer with the use of serial communication protocol RS232. The robots are miniature, differentially driven platforms equipped with infra red proximity sensors and with optical encoders associated with each of two DC motors. The robots reflects all the features of real, large dimensional mobile robots.

The setup so far, has been exploited for developing and testing algorithms for multi robot coordination based on elements of the Theory of Games. The example is the algorithm of an exploration of complex structured office like environment by the two mobile robots, that was designed and verified with the use of presented setup.

The setup provides a wealth of multi robot motion planning algorithms design and analysis features that make it very useful tool for the research purposes. All the

algorithms can be easily applied in the *MATLAB* environment, what makes it also ideal for an education.



(a) (b)

The model of the office like workspace (a) and two mobile robots (b)

Mobile robot systems

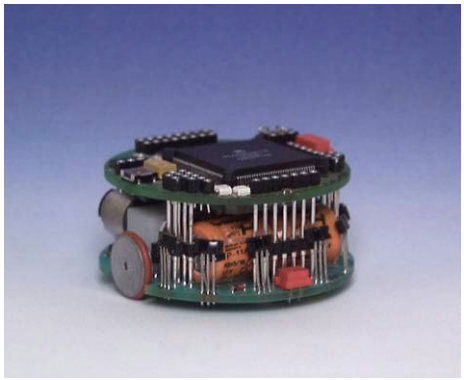
The laboratory is equipped with two *Khepera* robots, two sets of *LEGO MindStorms - Robotic Invention System*, two colour CCD cameras, ultrasound and IR sensors, six soccer robots. We also have special development tools like MPLAB ICE 2000, MPLAB ICD 2 Debugger and dsPIC Development Board.

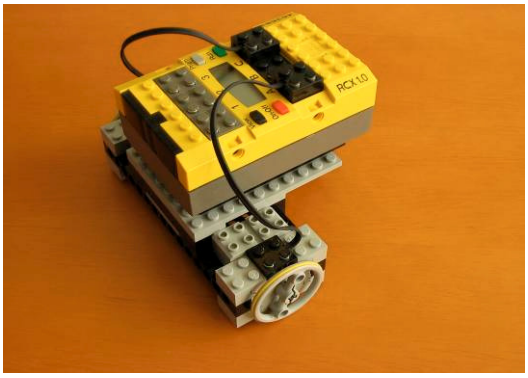
MPLAB ICE 2000 is a full-featured emulator system providing full speed (up to 25 MHz) emulation, low voltage operation, 32K by 128-bit trace, and up to 65,535 breakpoints. It is small, portable and lightweight. Interchangeable processor modules allow the system to be easily configured to emulate different processors. Complex triggering provides sophisticated trace analysis and precision breakpoints. The trace analyzer captures real-time execution addresses, opcodes and read/writes of external data. It also traces all file register RAM usage showing internal addresses and data values, as well as all accesses to special function registers, including I/O, timers and peripherals. Triggers and breakpoints can be set on single events, multiple events and sequences of events. The MPLAB ICE 2000 analyzer is fully transparent and does not require halting the processor to view the trace.

MPLAB ICD 2 is a low cost, real-time debugger and programmer for selected PICmicro® MCUs. Using Microchip Technology's proprietary In-Circuit Debug functions, programs can be downloaded, executed in real time and examined in detail using the debug functions of MPLAB. Watch variables and breakpoints can be set from symbolic labels in C or assembly source code, and single stepping can be done through C source line, assembly code level, or from a mixed C source and generated assembly level listing. MPLAB ICD 2 can also be used as a development programmer for supported PICmicro MCUs.

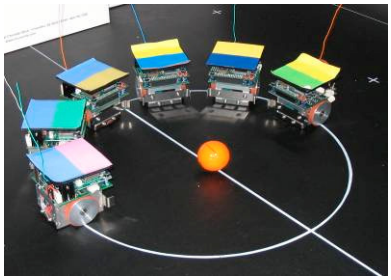
The dsPIC® Digital Signal Controller (DSC) from Microchip is a powerful 16-bit (data) modified Harvard RISC machine that combines the control advantages of a high-performance 16-bit microcontroller (MCU) with the high computation speed of a fully implemented digital signal processor (DSP) to produce a tightly coupled single-chip single-instruction stream solution for embedded systems design.

The system is used for research in such areas as: trajectory planning, collision avoidance, on-line control in Cartesian coordinates, vision based control, autonomous mobile robot systems etc.

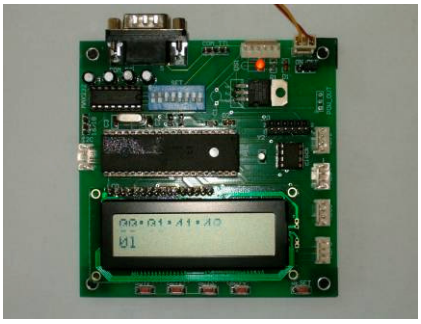




Khepera and LEGO Mindstorms robots



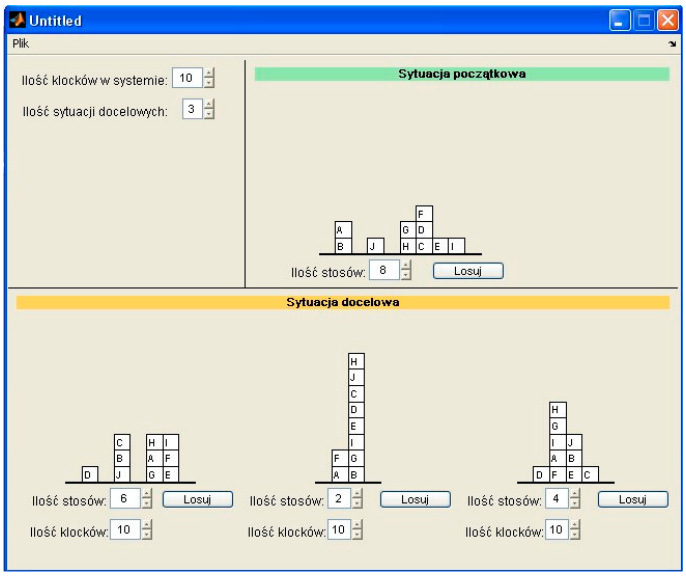
QTeam soccer robots and dsPIC (Microchip) development tool



Our proto board and Turtle robot equipped in wireless color camera

Block World

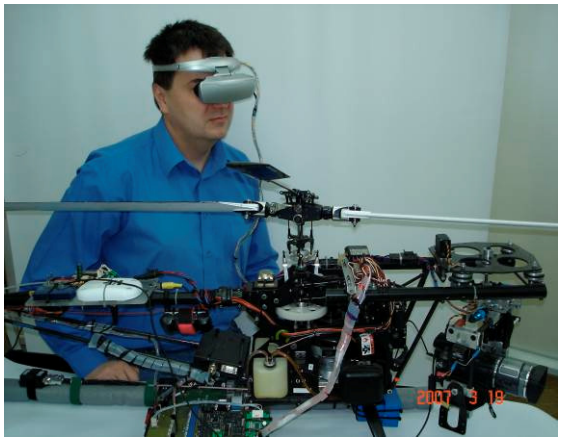
Within the laboratory “Artificial Intelligence in Robotics” classical problems of planning robot tasks are investigated. Part class of these problems can be represented by so called Block World environment (see figure). The environment is modelled by classical for AI methods language - STRIPS system. This environment today stated as an experimentation benchmark for planning algorithms. Also more realistic situations can be presented as Block World problems, where moving blocks corresponds to moving different objects like packages, trucks and planes. The case of Block World problem where the table has a limited capacity corresponds to a container-loading problem. The tools that deals with Block World was developed using MATLAB software and PROLOG language.



Block world environment with one initial state and disjunction of goal states.

Laboratory Setup for automatic control of UAV (Unmanned Arial Vehicle)

The laboratory setup consists of physical helicopter based on the Hirobo SST EAGLE2-GS Long Tail model. Helicopter is fixed to the helicopter stand which allows to perform tests inside the laboratory. It is controlled manually through the radio line. Naturally it can be also controlled by the PC computer with the use of serial communication protocol RS232 and the wireless radio line. Build in hardware-software platform is equipped with Novatel GPS - OEM4 G2L-RT20W with GPS-512 antenna, laser and ultrasound altimeter and AHRS system based on the MEMS Technology (3 gyros and 3 accelerometers).



On the ground of the rich theoretical experience of the group and practical experience in the field of constructing electronically controlled systems of mobile robots, it is build automatic control system of the flying object (helicopter model, airplane model). For this purpose new control algorithms robust for random disturbances (abrupt and unpredictable wind blows) are designed. Moreover the experience of the group in image processing is used to construct active image canvassing system for the flying object, which can be applied together with the automatic control system for realization of the two tasks. The first is on line building of three dimensional ground maps. The

second one is searching objects in the urban terrain (feature of the searching object are transmitted from the ground basis to the UAV, when the UAV is already in the air (flying mission)) and following it. The information about the localization and direction of relocation of the searching object has to be transmitted to the ground basis. Vision system is based on the FPGA matrices. By the research group it was constructed and designed the ultra light vision acquisition platform, which is operated by human observer head movements.

Software

The group is equipped with educational licenses of basic programming tools, such as Pascal, C++ etc. However, the main research activities as well as teaching courses, are supported by the specialized programs for engineering and scientific calculations:

Matlab + toolboxes + Simulink (research and educational licenses). Matlab, elaborated by Math Works Inc., is a specialized software for engineering and scientific computation. It can be enriched with additional toolboxes (control, identification, neural networks, optimization, symbolic calculations etc.) for solving specialized problems. It can also be equipped with Simulink - a package for real - time simulation,

dSPACE – (research license) is a complete software/hardware environment for developing of real time control systems and real time simulation. It is equipped with complete experimental environment with optimal connetion to Matlab/Simulink and $Matrix_{X,}$

$MATRIX_X$ (research licence). $MATRIX_X$ is a sophisticated simulation environment that can be used to model dynamic systems. It handles continuous, discrete, linear, or nonlinear systems,

Mathematica (research license). Mathematica was elaborated by Wolfram Research Inc. It is a specialized software for scientific computation,

PSI (educational license) elaborated by Boza Automatizirung. PSI is a specialized program for simulation of nonlinear continuous and discrete systems,

CC (research and educational license) elaborated by P.M.Thompson, Systems Technology Inc.. CC is a software package for analysis and design of linear control systems,

S-plus – (research license) is a professional statistical software package suitable for acquisition and manipulation of large data sets, as well as performing all kinds of statistical tests and analyses,

Visual.NET (MSDN Academic Alliance) – is a fully development environment for building application for PC computers using C, C++ and C# languages. Visual.NET is a product of Microsoft,

MPLAB – is a professional IDE (Integrated Development Environment) for application development using C or Assembler languages for PIC microcontrollers. MPLAB is a product of Microchip Inc.,

CCS – is a complete software environment for developing control programs in C language for Microchip's PIC (12,14,16 bit) microcontrollers. CCS is product of CCS Inc.

Industrial Robotics Research Laboratory

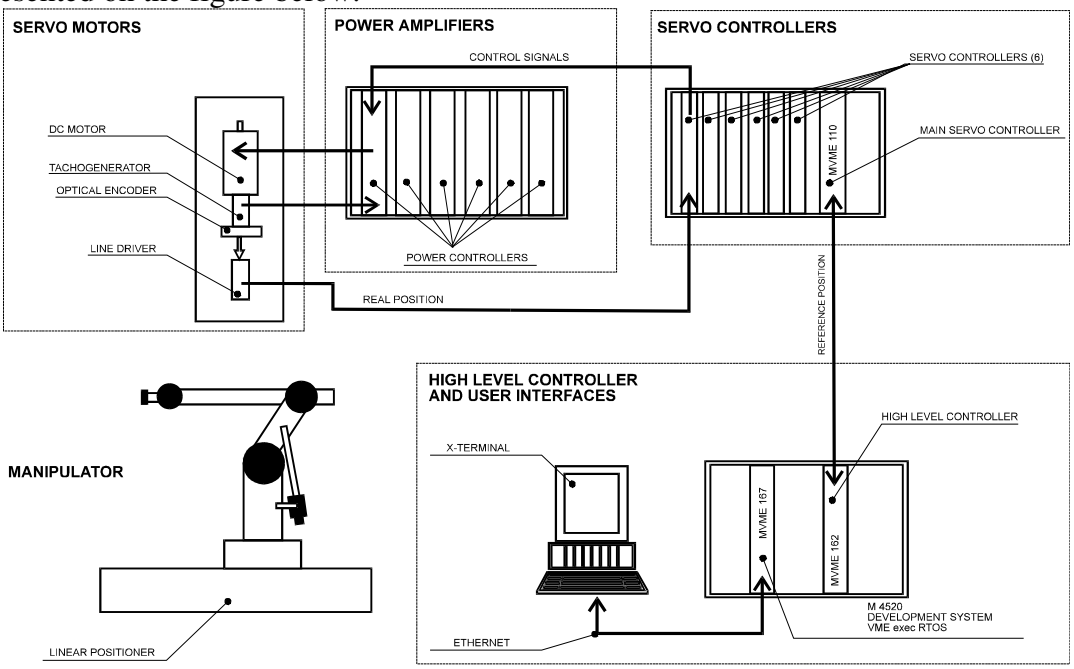
An advanced robot control systems research and development laboratory has been created at the RDEA Group during recent years.

The experimental setup consists of the following components:

- the kinematic and mechanic structure of robot IRb-6,
- advanced, multilevel robot control system,
- X Windows graphic environment,
- VxWorks real time operating system,
- application software under development.

The advanced robot control system for robotic research has been entirely designed and implemented of the RDEA Group. The sensorial part of IRb-6 system has been modified according to the design.

An innovative approach to the problems of servocontrol, trajectory generation and robot programming language has been adopted. This approach results in the unique, high quality control software. The simplified block diagram of the experimental system is presented on the figure below.



RESEARCH STATION

A variety of research works can be carried out at this laboratory. Among these works one can mention the investigations in the following areas:

- servomechanisms control algorithms,
- robot programming languages,
- task planning and decomposition,
- trajectory generation,
- inertial decoupling,
- vision systems,
- sensor information processing.

The laboratory of robot control systems is accessible for researchers active in the above mentioned areas and for the industrial engineers who wish to become familiar with the most advanced microcomputer control systems technology.

DIRECT COOPERATION WITH OTHER RESEARCH GROUPS

1. Cooperation with the Novosybirsk State Technical University, Russia, concerns control law synthesis for continuous dynamic systems based on localization and dynamic contraction methods,
2. Cooperation with L'Universite de Montreal, Canada, concerns the problem of robust control of complex uncertain systems with Markov jumps,
3. Cooperation with L'Universite de Montreal, Canada, concerns the problem of using FPGA matrices to image acquisition.
4. Cooperation with the Nottingham Trent University, Department of Computing, Real-Time Telemetry Systems Group concerns city traffic flows simulation and control,
5. Cooperation with Department of Statistics, Rice University, Houston concerns modeling and control of cancer cell population,
6. Cooperation with Baylor College of Medicine, Houston, USA concerns,
7. Cooperation with A/O ASIF Research Institute in Davos concerns modeling and control in biomedical systems,
8. Cooperation with Baylor College of Medicine, University of Texas, School of Public Health, Human Genetic Center, Houston, USA concerns genetic studies,
9. Cooperation with Universite de Pau, France, Weitzman Institute, Israel and Biomathematics Study Group at Vanderbilt University, Nashville, USA includes biomathematical modeling, control and estimation in cancer cell populations,
10. Cooperation with Institute of Oncology, Gliwice, Poland, concerns radiotherapy protocols for cancer cells and population genetics,
11. Cooperation with Southern Illinois University, Edwardsville and Washington University, St. Louis concerns biomathematical studies,
12. Cooperation with Center for Mathematics and Computer Science in Amsterdam concerns morphological image and signal processing,
13. Cooperation with Institute of Mathematics and Computer Science, Bulgarian Academy of Science concerns selected problems of computer vision,
14. Cooperation with Belarussian Institute of Cybernetics in Minsk concerns image processing in spatial information systems,
15. Cooperation with Lvov Technical University, Ukraine concerns the field of signal and image processing.

MEASUREMENTS AND CONTROL SYSTEMS DIVISION

RESEARCH ACTIVITIES

The research activities concentrate on:

- artificial intelligence and modern education technologies,
- microelectronics and operating systems,
- signal processing and system identification,
- programmable controllers and SCADA systems,
- noise and vibration control,
- energy process control,
- control theory,
- sensors and actuators,
- metrology and measurement systems.

ARTIFICIAL INTELLIGENCE AND MODERN EDUCATION TECHNOLOGIES

Expert Systems

A. Niederliński

Expert systems are computing highest target. „rmes Rule- and Model-Based Expert Systems" [II.11] is a unique book for learning expert systems with the help of four expert system shells freely available at the Internet. It gives the user the possibility to learn while doing. The idea is to allow the reader to test and run all the book examples, as well as individually developed knowledge bases, using *rmes*.

The book contains:

- a user-friendly yet broad introduction to basic rule- and model-based expert systems;
- an in-depth discussion of knowledge-base development for elementary exact, augmented exact, elementary uncertain and augmented uncertain *rmes* expert system shells;
- an exposition of the Modified Stanford Certainty Factor Algebra and its uses for uncertain reasoning;
- a number of real-world Knowledge Base examples, among others how to use expert system to avoid being plagued by sub prime credits, or how to use expert system to manage white-collar employee. Detailed reports of reasoning with those bases are presented.

Professor Niederliński is running a website http://www.rmes.pl on his expert system shells. All *rmes* expert system shells used in this book, as well as PPT presentations of lectures on *rmes* may be downloaded from this website

Scheduling and Constraint Programming

W. Legierski

Scheduling problems are in the core of many real-world applications. They occur in areas of production planning, timetabling or personnel planning. For certain well-defined problem classes there exist efficient algorithms from Operations Research (OR). But these algorithms are often very specific and slight changes in the problem definition raise difficulties in the adaptation of the special purpose algorithms.

There is possibility of instantly changing already defined algorithms and making it adequate for real-world problems, but it is hard and it often lowers their effectiveness. One of the offspring of AI is Constraint Programming (CP), which offers flexibility by the formulation of constraints in a high-level language. Its main advantage is declarativity: a straightforward statement of the constraints serves as part of the program. This makes the program easy to modify, which is crucial in real-world problems.

Constraint Programming has succeeded in solving standard benchmarks and real-world problems from the area of scheduling. The construction of timetabling falls under

the class of scheduling problems. It is large, highly constrained and much more complicated. Problem differs greatly for different schools and educational institutions. Although manual construction of timetables is time-consuming, it is still widespread, because of lack of appropriate programs. This forces from programmer to use a adjustable tool for programming to write a universal program, suitable for all imaginable timetabling problems. Declarativity of CP allows to take into account many cases without effort.

Research in area of Scheduling and Constraint Programming tackle with following problems:

- incorporation of local search into constraint programming
- using nVIDIA CUDA for computational penalization
- visualization of results
- user interfaces for scheduling problems.

During research real-world problems are taken into account such as:

- university timetabling problem (solving Silesian University of Technology problem)
- airport staff rostering (Module for Flight Information System applied in Pyrzowice Airport)
- instruction list scheduling (cooperation with ST Microelectronics).

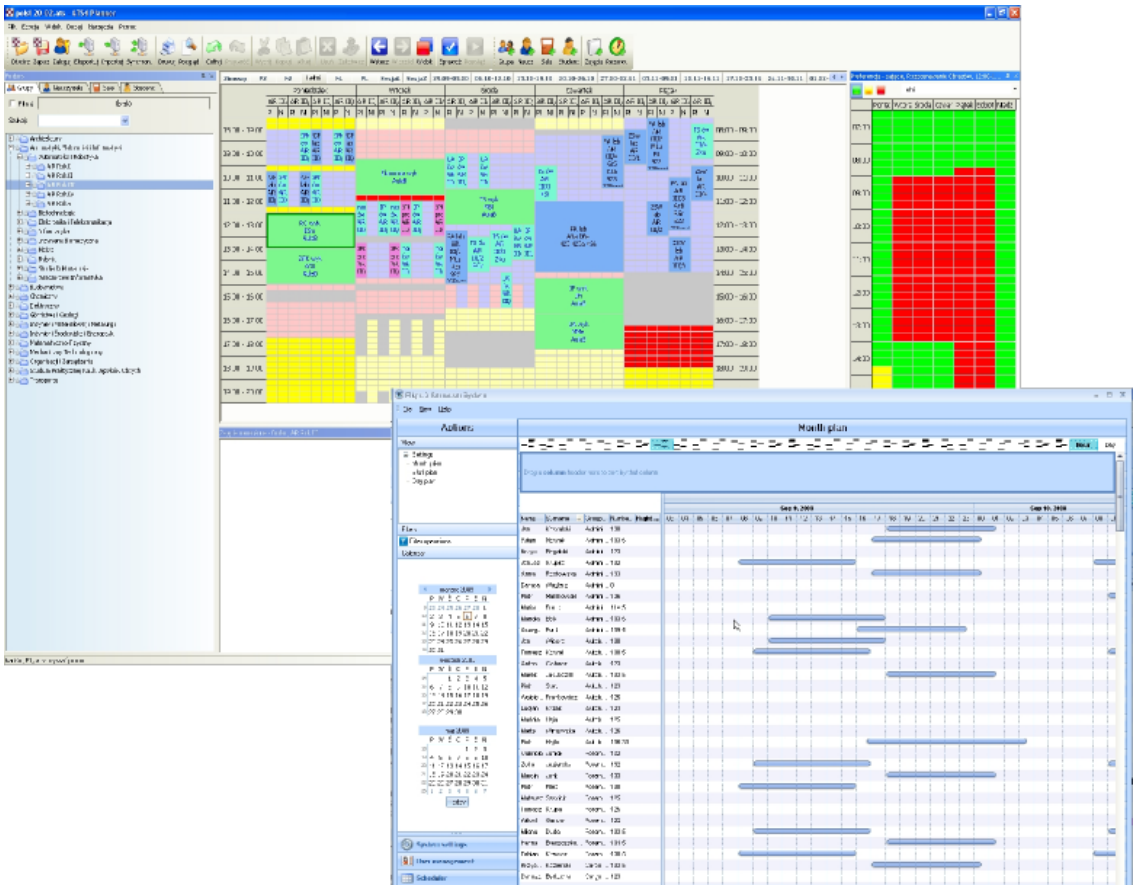


Fig. 1. Visualization of scheduling problems – timetabling and airport staff rostering.

E-learning and education methods

J. Mościński

The Division staff members are involved in e-learning oriented research and education methods development for several years, in many cases including extensive international cooperation. Among other, in 2007-2008, the group was involved in the second phase of the curricula harmonisation project in the form of Thematic Network project called EIE-Surveyor (Reference Point for Electrical and Information Engineering in Europe). The project concerns establishing the reference point for general and specific competences in the project field, especially with respect to methodologies and tools that would ensure reaching specific teaching quality level. The project focuses on international cooperation, real and virtual mobility including e-learning concepts implementation, as well as recognition issues including higher education institutions accreditation and certification issues.

The Division e-learning oriented activities concern also the active participation in the International Network for Engineering Education and Research, iNEER. This networking organisation, with more than 30,000 members from all over the world, aims at promoting the international cooperation in engineering education and engineering research to substantially higher level, with respect to the scale of individuals and organisations involved in such cooperation, and types of projects and bilateral contacts that result in enhancing methodologies and tools for engineering education. iNEER prepares yearly books in the series of "iNEER Special Volume – Innovations", concerning innovations in engineering education and research, especially e-learning methods development and implementation. The group was involved in preparing and editing two special volumes of iNEER Innovations in 2007 and one in 2008.

The Division members are also involved in practical development of tools that are used for e-learning systems purposes. Many years specialisation in estimation and adaptive control simulation area resulted in the development of several version of simulation software – mainly using Java platform – that can be used within e-learning methodology for accompanying lecture material, for self-study work and as stand-alone systems used as part of laboratory exercises in adaptive control, also in the virtual and tele-laboratory framework. Other examples of e-learning oriented systems built in the Division concern specialized Learning Management System type of software – like Electronic Catalogue and Electronic Results Documenting System.

The Electronic Catalogue (EC) system has been prepared primarily in order to replace the paper catalogue cards used for checking the presence of students at laboratory exercises and – more importantly – for documenting the results of students' work during the exercise and after it – while working on the laboratory report. The efficient flow of information in such system is sometimes difficult to achieve and both teachers and students could face delays and inconsistencies problems. The other problem concerns the data archiving. The EC system seems to solve efficiently all problems mentioned above. First of all this is a multi-user and multi-access system which means that all laboratory exercises tutors have theoretically simultaneous access to the same electronic catalogue card concerning specific laboratory. The teacher can input his grades and comments to the system as soon as student get it and such grades and comments are instantaneously available to the laboratory manager. This makes the work of all laboratory exercises tutors and laboratory manager much easier and faster. The system is also student-friendly in this respect because every student is informed immediately about each grade issued by the teacher, he can also check at any time

which grades of him are missing, which reports still await evaluation, is it possible for him to get the final laboratory grade and what grade is it going to be. Every student is allowed to get information from the EC system only with respect to his grades.

The EC system is also an important tool for efficient archiving of students grades – with respect to their laboratory exercises work, reports contents and laboratory final grades. The system is based on popular database system and all grades, comments and reports are added to the database once issued or uploaded. There is an administration part of the system that is used for intelligent proceeding from one semester to the next one with changing links between students, groups, curricula and courses and archiving the old data. With appropriate backup tools and procedures the EC system enables secure and efficient way of saving laboratory exercises data with possible recall when needed. As all grades are stored in the EC system database it becomes possible to export it from the system in several possible formats for subsequent analysis of statistical kind. The grades data can be analysed with either specific course in mind, or specific students and groups of students' results, or with respect to different teachers and laboratory exercises, all data possibly with multi-year horizon. Such analysis is an important tool of data-mining type which can reveal interesting relations among students' grades, courses and teachers.

The Education Results Documenting (ERD) system has been designed for slightly different and broader task concerning computer and network support for communicating and archiving students' grades at the university. The immediate reason for decision to design such system was university wide adoption of European Credit Transfer System (ECTS), which is a popular basis for transferring results of studying between universities in different countries. Credit transfer and accumulation system implementation caused shifting from giving grades to students with respect to all components of courses towards one cumulative grade for the whole course which may include from one to four components – such as lecture, classroom exercises, laboratory exercises, project work and other. There are several teachers who deliver lecture, conduct classroom exercises and play the role of laboratory manager for some course and for some group or several groups of students. What we need is precise and fast communication among these people which would allow as a net result for efficient issuing of so called final grade for the whole specific course at the end of semester. Other important tasks of the ERD system include current documenting of students' attendance and performance with respect to course components as well as all data archiving.

Other systems based on internet technologies and built for enhancing education at the Division concern tests/quizzes/exams generation and running systems. Computer networks and internet technologies enable building versatile systems for generating contents of tests that are going to be taken by students at various stages of their studying – at the beginning of the course, while self-studying, and as intermediate and final tests. The test contents can be individually adjusted, the students can access the tests individually and grading can be to some extent automatic and provide basis for statistical analysis enabling further research concerning e.g. teaching methodologies.

The Division staff was also involved in developing more general event registration systems that could include substantially more complex organization of grading/reviewing uploaded material and more sophisticated registration/reservation scheme. Such systems can be used for enrolling students to specific courses, for

matching students and projects topics proposed by teachers and even as general conference registration systems.

All systems mentioned above were developed using e.g. PHP/MySQL platform, ASP.NET/Microsoft SQL Server platform and XML technology. It should be stressed that research work in the Divison with respect to internet technologies in education concentrated on building small and medium scale, flexible systems, whereas for general e-learning oriented education the Moodle based university platform is used.

SCADA systems in education

R. Jakuszewski

SCADA systems use many modern programming technologies. The amount of knowledge needed to use them steadily grows. In the Institute of Automatic Control was developed the application called *Lessons*, which shows the user how to solve many industry problems using modern programming tools. The application has been developed in Proficy HMI/SCADA – iFIX v5.0 Software for Efficient Manufacturing made by GE Fanuc firm and is used during iFIX training courses. It consists of almost 1500 pictures, which include many programs and present step by step how to use iFIX tools by examples in graphical way. Many pages of iFIX documentation are shown on only several pictures, which enables easily to memorize even complex algorithms.

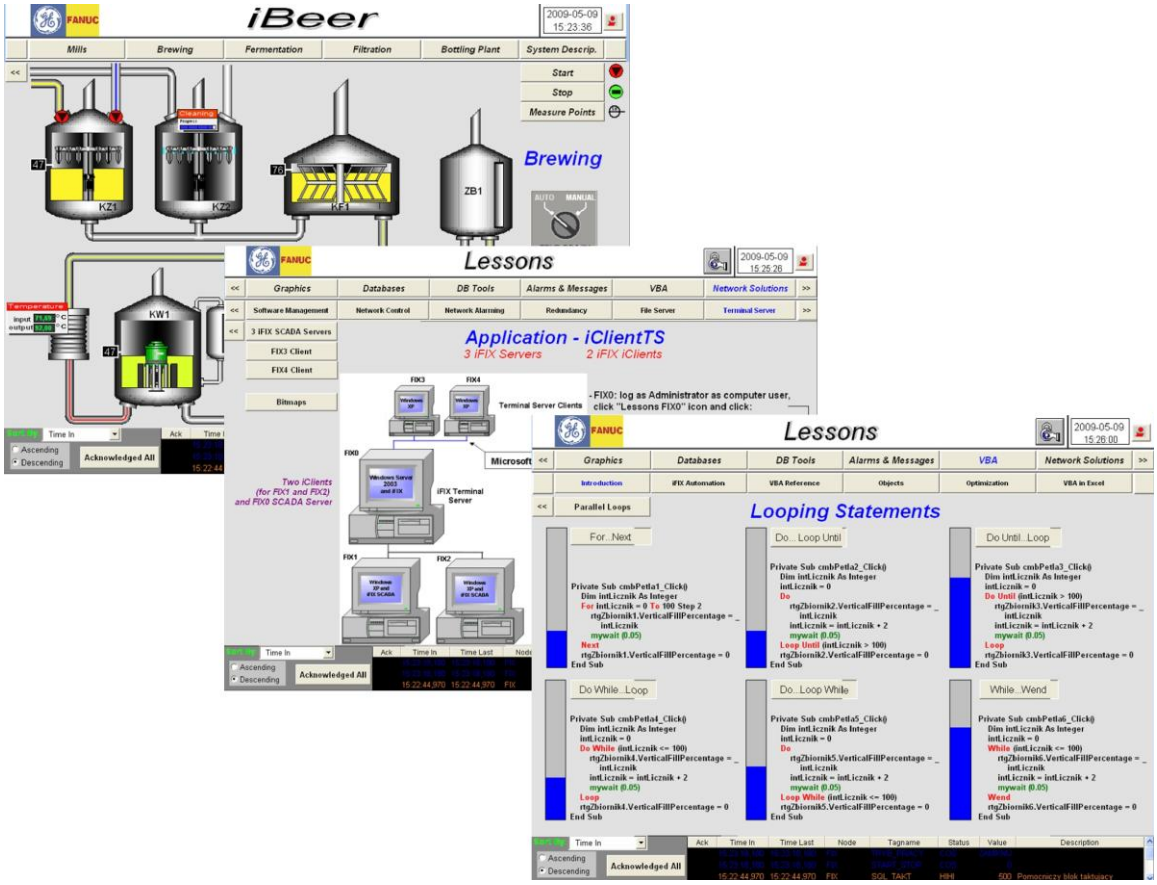


Fig. 2. *Lessons* application for teaching students SCADA systems.

Graphical methods of solving industry problems, e.g. creating sliders, utilization of threshold tables to change the colour scheme of the whole application, utilization of

timer blocks in pump maintenance, use of recipes in beer production, presenting binary alarms are shown in this system. The problem of simultaneous running of scripts written in VBA is introduced as well.

Remote laboratory stand for distance education on metrology

D. Buchczik

Remote laboratory is also referred to as WebLab or Online Laboratory. First WebLabs can be dated at the 1990's, but real development began after the year 2000. Virtual laboratory (simulation) usually does not require any resources. Remote laboratory in contrast to the virtual laboratory allows users to perform real experiments by accessing functional hardware that is set up in some distant location.
Remote laboratory for distance education on metrology is aimed as a demonstration and testing platform. Average number of simultaneous users is assumed to be less than one, so no user queuing or user management is required.

The most important part of the project is an application created in LabVIEW environment with a use of the virtual instruments (VI) technology [II.182, II.60]. There are utilized G Web Server and Common Gateway Interface (CGI) functions provided in LabVIEW Internet Toolkit. The application is used to publish web pages that allow to control virtual instruments of any kind. Those web pages are constructed with use of HTML and CGI commands.

Data flow between LabVIEW server, Web Server and WebLab user is presented in Fig. 3. The only application of Web Server is publishing of the laboratory website. It does not communicate with LabVIEW PC in any way. All functions directly connected with remote control of VI's are performed on LabVIEW PC.
LabVIEW PC can be any computer which features the following:

- Built in LabVIEW Web Server is a simple web server that is available in each LabVIEW version. It can provide images of application front panel, and it is used in remote laboratory only for that purpose.
- G Web Server is provided with LV Internet Toolkit. It has CGI functionality and allows LabVIEW applications to communicate with Users PC by means of WWW.
- The most important part on the LabVIEW PC is Main Control VI Application which receives user input, translates it into LabVIEW commands and variables which are passed to Controlled Virtual Instrument. It also generates HTML forms through which users can control VI's.
- Controlled Virtual Instrument can be any VI that has an available HTML page created according to application requirements.
- Users PC represents any computer with web browser that has connection to the Internet.

The scheme presented in Fig. 4 shows measuring instruments and connections between them. LabVIEW PC is used to control devices through GPIB interface. Function generator is connected to analog input of the DAQ card and analog output of the card is connected to oscilloscope and multimeter.

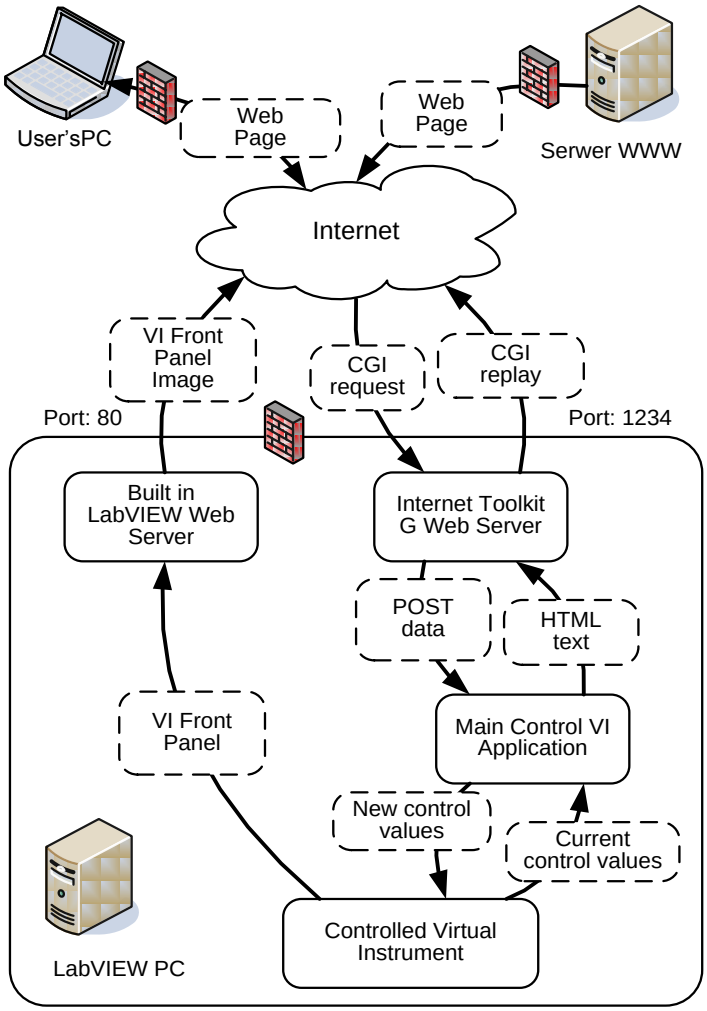


Fig. 3. General data flow diagram.

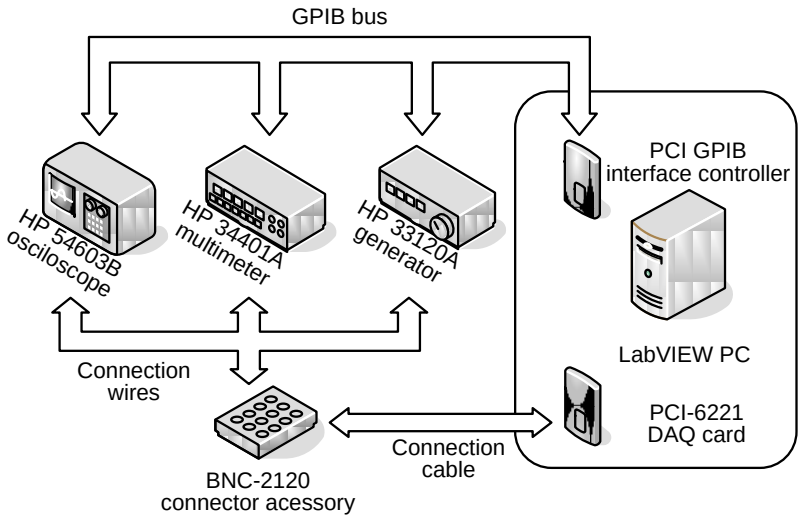


Fig. 4. Remote laboratory setup.

Currently the laboratory setup are configured to allow performing of two laboratory exercises on testing of a DAQ card. However the laboratory setup can be also simultaneously used to perform other exercises – it is only required to create and publish VI's for those.

The Voltage Acquisition Laboratory allows to test operation of the DAQ card analog input. Users are able to configure external function generator connected to the DAQ card analog input. Then parameters of a signal acquisition can be set. Those include a sampling rate and a number of samples to read. Such features allow students to learn how basic voltage waveform measurement system works.

The Voltage Generation Laboratory allows to control the DAQ card analog output. First part of that laboratory webpage allows users to set parameters of the waveform generated by the DAQ card analog output. Next the user can configure parameters of a signal acquisition for the external oscilloscope. Finally there is a screenshot of the LabVIEW virtual instrument at the bottom of the webpage on which two plots are visible. First one shows the waveform that is sent to the DAQ card analog output and the second one presents a true shape of the waveform measured by the oscilloscope.

Educational suit of microprocessor systems

K. Czyż, M. I. Michalczyk

The well equipped Digital Signal Processing Laboratory is used both for research and educational purposes. To meet students needs special educational boards were designed in Institute of Automatic Control. New courses were prepared to let students learn about microprocessor systems, basing on the owned hardware. The can students also work with microprocessors and digital signal processors taking part in research and engineering tasks by their Master of Science theses preparation.

The starter kits for Renesas SH7619 microcontroller (Fig. 5) have full functionality necessary to setup first projects by students and enabling them to go into SuperH architecture. Starter kits include evaluation board, JTAG emulator, GNU C compiler, on-chip debugger, Eclipse IDE, eCOS real-time operating system and examples. The starter kits contain all the necessary hardware to design, develop and test applications with following peripherals: GPIO, Timer Counter, PWM, Watchdog Timer, Real Time Clock, Interrupt Controller, I2C, SPI, UART, Audio Codec, Ethernet, Video DAC and Xilinx FPGA.

Fig. 5. Evaluation board of educational starter kit for Renesas SH7619 microcontroller.

Courses on microprocessor systems:

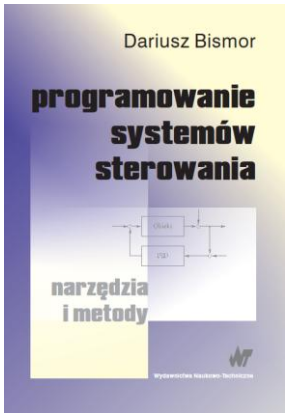
- Fixed-point signal processing on Texas Instruments TMS320C6713
  The course on fixed-point signal processing was prepared for fifth year students. Currently, the digital signal processors are used in numerous applications. They are the most popularly used for telecommunication purposes – for GSM systems and for

rapidly expanding VoIP communication. Students learn about the unique features of fixed-point digital signal processor architecture on the example of Texas Instruments TMS320C6713 processor. Their laboratory tasks are to implement simple digital signal processing algorithms (FIR filtration, Goertzel algorithm) firstly using C language and next, using assembler language. By optimization of a code a knowledge about the dedicated architecture of digital signal processors with the stress on fixed-point arithmetic is gained. The architecture of TMS320C6713 processor allows also for evaluation of compromise between the algorithm accuracy in floating-point and effectiveness in fixed-point arithmetic that is necessary in DSP algorithms implementations.

- Signal processing on FPGA
  The course prepared for fifth year students is concerned on signal processing on FPGA. Digital signal processing algorithms usually have very strong computational requirements. Substituting of some parts of processing algorithms by hardware operations using e.g. FPGAs may radically improve the DSP application performance. Current generation of FPGAs can perform multiplication and addition operations at speeds exceeding 200 MHz, this is why they are suitable for intensive computations like fast Fourier transform, FIR filtering and other multiply-accumulate operations. It does not mean, that all DSP operations may be easily implemented in FPGAs. Floating-point operations are quite difficult to implement due to the large amount of resources needed in the device. Such operations are more suited to a DSP or even general purpose processor (GPP). This is why FPGAs and GPPs could coexist and create a flexible platform for signal processing purposes. During the laboratory course practical experience in implementation of digital signal algorithms on FPGAs is gained.
- ARM microcontrollers
  The course prepared for third year students concerned on the fundamental concepts of ARM architecture and internal hardware structure of Atmel SAM7 series microcontrollers. Nowadays the ARM processor is the processor of the choice for embedded and mobile systems found in PDAs, mobile phones, media players, hard drives and routers. During the laboratory course practical experience in the ARM architecture is gained with respect to internal hardware as serial communication controllers, timer-counters, and analogue signal converter. Furthermore, the course is conducted on dedicated educational starter kit based on Atmel AT91SAM7S256 microcontroller.

Teaching object-oriented programming for control science students

D. Bismor



Modern technique for teaching of object-oriented programming has been developed over the last few years [II.3]. The technique is addressed for students in control science and is based on examples from control sciences and information technology only. The technique emphasizes the most important object-oriented programming components: encapsulation, composition, inheritance and polymorphism, but also puts stress on the use of standard library.

There are a couple of advantages of teaching by examples from control sciences. First, there is no need to invent abstract

problems and examples. Second, students can extend the knowledge of the issues they have to program and simulate. Furthermore, students learn how to divide complex problems from control sciences into smaller and easier to understand parts – this skill can be applied in fields far from programming. Apart from gaining experience, during the process students develop their own software platforms and software components that can be further used during their education in control.

MICROELECTRONICS AND OPERATING SYSTEMS

Research on Operating Systems

D. Bismor, J. Wyrwał

The Measurements and Control Systems Division has developed an approach to process control focusing on both theoretical and practical issues related to this increasingly important topic. An approach covers methodology for creation of kernel-related parts of operating system as well as design techniques of applications for real-time systems.

The work on kernel programming has been induced by the existence of free and open source code of the Linux system. First, the modular structure of Linux kernel has been recognized. This allowed for small modifications of the existing kernel rather than writing new, dedicated kernel versions. Next, the development started with writing small, dummy kernel modules, but led to writing full-fledged and functional modules allowing for connection with DSP boards and other hardware. The first application was the communication with EIB network system. This work continues with the goal of creating soft&hard real time platform, where Linux applications are responsible for the soft part, while the modified (extended) Linux kernel communicating with DSP board is able to fulfil hard real time system requirements.

Real-time control systems impose stringent time deadlines for delivering the output signals. Sufficiently immediate responsiveness of computer system to rapid changes of controlled process is in most cases unsatisfactory when the system is managed by the standard general-purpose operating systems since their services can inject random delays into application software and thus cause slow responsiveness of an application at unexpected time instants. That is why, Real-Time Operating Systems (RTOS) that are deterministic and have guaranteed worst-case interrupt latency and context-switch times have been used in the research. However, it should be emphasized that RTOS facilitates the creation of a real-time system, but does not guarantee the final result will be real-time. RTOS provides facilities that, *if used properly*, guarantee deadlines can be met deterministically. Therefore, to meet all the requirements imposed by real-time control systems particular attention has been paid to correct development of the software implementing different types real-time control strategies.

Taking into account above-mentioned issues a QNX Netrino operating system has been included to the research. It is the RTOS based on the true pre-emptible microkernel architecture and priority-based pre-emptive scheduler offering advanced memory protection and distributed processing. With its microkernel architecture, the QNX Neutrino RTOS has modular structure and offers large scalability providing a comprehensive set of technologies for development of robust and reliable embedded systems. QNX Neutrino is also certified for conformance to the POSIX standards that assures both the real-time determinism and high predictability needed for real-time systems and the code portability which allows quick migration of applications from/to

other open source systems supporting this standard (e.g. Linux). It has been also introduced into educational programme to show the students important issues related to operation of RTOS and implementation of real-time applications.

The use of ordinary PC computer for real-time tasks is also possible if the computer is equipped with dedicated DSP board containing real-time microkernel. The PC can be used to supervise the real-time tasks while the DSP board is responsible for preserving constraints imposed by real-time processing. The applications of this setup are widely used for active noise and vibration control by the whole group.

DSP technology

K. Czyż, M. I. Michalczyk

Digital Signal Processing Laboratory in Institute of Automatic Control is equipped with a wide range of microprocessors (Renesas H8, Atmel ARM7) and digital signal processors (Analog Devices Blackfin BF561, Texas Instruments TMS320C31 on dSPACE board, TMS320C6713 and TMS320C6416 on Spectrum Digital DSK, Renesas SH4) and other processors (Motorola/Freescale PowerPC MPC8240 on dSPACE board). These processors are used both for educational purposes (especially for Master of Science theses preparation) and as tools in research activities.

Designed DSP algorithms, especially these used in active noise control systems, have to be implemented in hardware to carry out real-world experiments. This requires a careful hardware choice and often also low-level code optimisation. To evaluate the hardware and gain reliable knowledge about its capabilities independent benchmarks of the owned processors in DSP tasks are being developed.

Specific character of research activities generates a necessity to equip the existing processor boards with additional functional units and to develop dedicated software. The dedicated daughter boards (for TI TMS320C6713, TMS320C6416 and AD BF561 DSKs) for specific DSP tasks are designed and realised in the Institute of Automatic Control. One of them is daughter board for TI TMS320C6713 and TMS320C6416 DSKs equipped in AD73322L analogue front-ends for general-purpose applications, including speech and telephony, and SMSC LAN9218 Ethernet module optimised for high performance applications including VoIP.

For more sophisticated problems, the new processor boards with expanded functionality were designed and realised: educational low-cost starter kits with ARM7 and efficient Portable ANC platform (Fig. 6) destined for creation of spatial zones of quiet in enclosures. The PANC platform consists of two modules: signal processing core and additional analogue front-end board. The core board contains SH7750R CPU aided by the Spartan IIE FPGA, 64 Mbytes of SDRAM memory, flash memory and fast Ethernet controller. The analogue board is equipped with 8 analogue input channels for reference and error microphones, and 8 analogue output channels for control loudspeakers.

Moreover, in the Digital Signal Processing Laboratory emulators and real-time data exchange libraries for various processors (ARM, Blackfin, TI TMS320C6xxx, SH2, SH3-DSP, SH4) are developed. These tools enable efficient data tracking during code development and algorithm testing.

Fig. 6. One of the DSP platforms designed and realised in the Measurements and Control Systems Division in the Institute of Automatic Control.

Circuit of multichannel ion-meter

J. Wiora, A. Kozyra

Simultaneous determination of several ions in potentiometric way not only allows to determine several ion concentration, but also to lower measuring uncertainty. For this purpose, a matrix of ion-selective electrodes (ISEs) is applied. Investigations of multi-component static measurements by the matrix require the multi-channel ion-meters characterised by very high input impedance, possibility of connecting the ISEs and acquisition data on PC, voltage uncertainty below 1 mV and sample rate of 1–10 Hz. Commercially available ion-meters do not satisfy all of the requirements simultaneously.

The block diagram of elaborated ion-meter is presented in Fig. 7. Signals from up to five ISEs and reference electrode (RE) go to the input amplifiers with very high input impedance. Analogue signals are measured by the 24-bit Σ-Δ analogue-to-digital converter (ADC) embedded in the ADuC845 microcontroller (μC). Software runs on the μC sends values of voltages expressed in mV to PC via RS-232 in raw ASCII format, so data acquired can be easily analysed by any program.

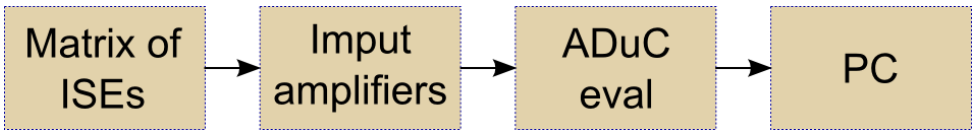


Fig. 7. The block diagram of elaborated ion-meter.

The block of input amplifiers has signal-conditioning function (Fig. 8). It consists of six AD8231 chips, introduced to market in 2007. Each chip has one instrumentation amplifier (IN-AMP) and one operational amplifier (OP-AMP). For each channel, the RE potential is subtracted from ISE potential at the IN-AMP. The Ref inputs of IN-AMPs allow to shift their output voltages and the unipolar power supply of the whole system can be used. The high input differential impedance and low input bias current assure almost zero current conditions of measurement of ISEs. The OP-AMPs are used

as followers and their outputs are connected with cable shields of ISEs, minimizing signal disturbances.

The uncertainty of voltage measurement was analyzed according to the *Guide to the Expression of Uncertainty in Measurement*, ISO, Geneva 1995. Type A and B evaluation of uncertainty was applied to determine the potential deviations. Long-term stability tests with ISEs immersed in solutions allow determining type A evaluation of concentration uncertainty. Using on-chip temperature sensor connected with temperature investigations make it possible to improve the measuring accuracy.

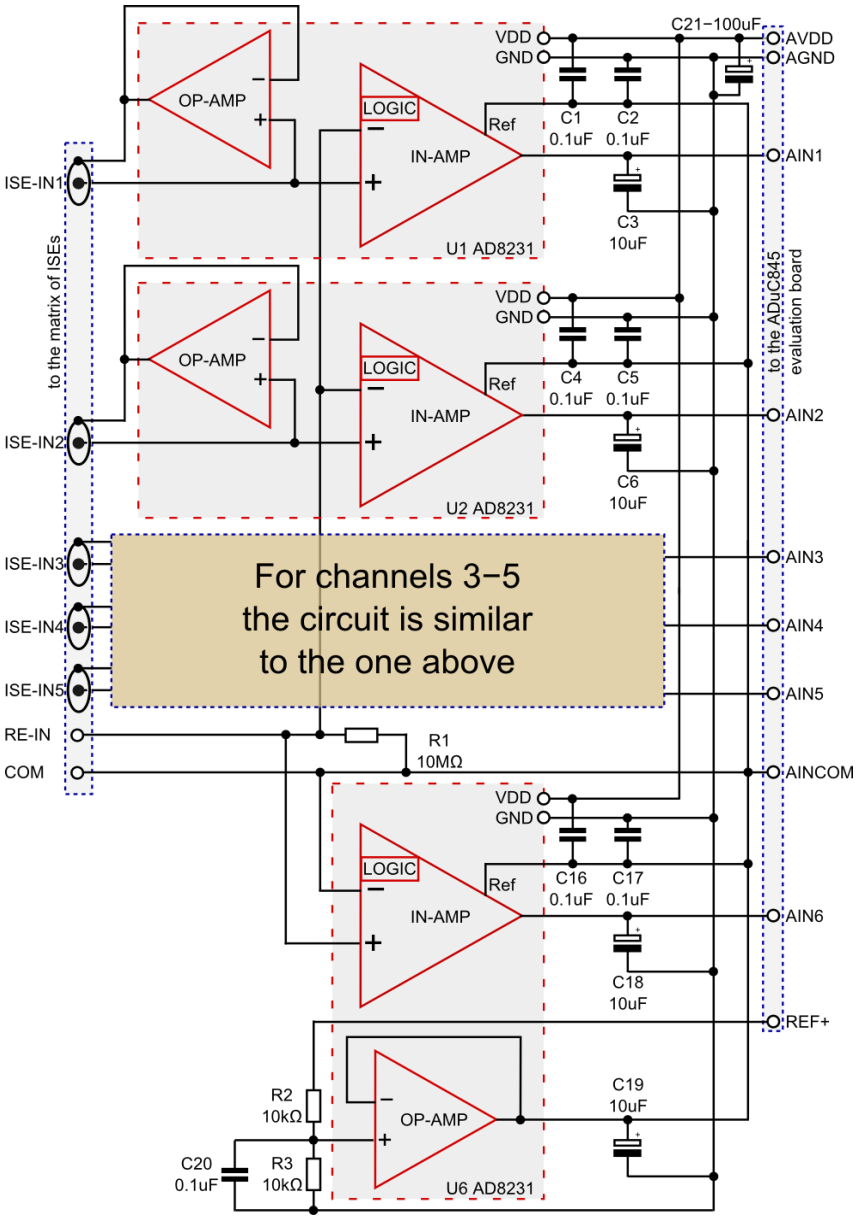
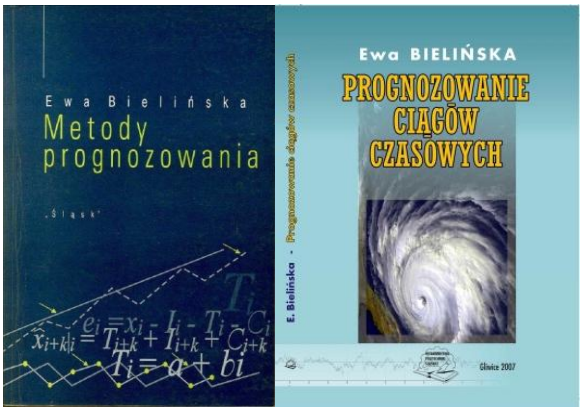


Fig. 8. The circuit of the input amplifiers.

SIGNAL PROCESSING AND SYSTEM IDENTIFICATION

Time series prediction and analysis

E. Bielińska



Prediction is an important stage in process control of complex systems both, in open as well as in closed loop. The open loop control is usually realised in large systems, and is the more efficient, the more precise is forecasting, used for the decision undertaking. In the closed loop control, the prediction of disturbances or the set point changes is a part of the control algorithms.

Basic research is directed towards development, testing and comparison of different prediction methods. The classical prediction based on time series smoothing and decomposition is compared with the advanced methods (e.g. neural, minimum variance or Kalman prediction) [II.12].

Methods of a'priori estimation of the prediction efficiency are developed, and compared with an ex post prediction efficiency measure, obtained with the use of a particular prediction algorithm.

Time series models are functions of accessible process outputs, observed as a set of uniformly sampled data, which are one and the only information on the process. Time series analysis covers wide area of data processing, and may be described as a set of the following procedures:

1. Checking data correctness.
2. Data transformation.
3. Data scaling
4. Series decomposition.
5. Descriptive statistics
6. Series modelling.
7. Model identification
8. Series prediction.

The research on time series analysis refers to all mentioned above stages. The variety of the real time series causes that only a general methodology, and not an unique technique or concluding, can be proposed. Hence, the research goes towards designing a general computer system, that is a comfort tool for the user working on a particular series analysis, and contains different methods of data processing, modelling and identification [II.1].

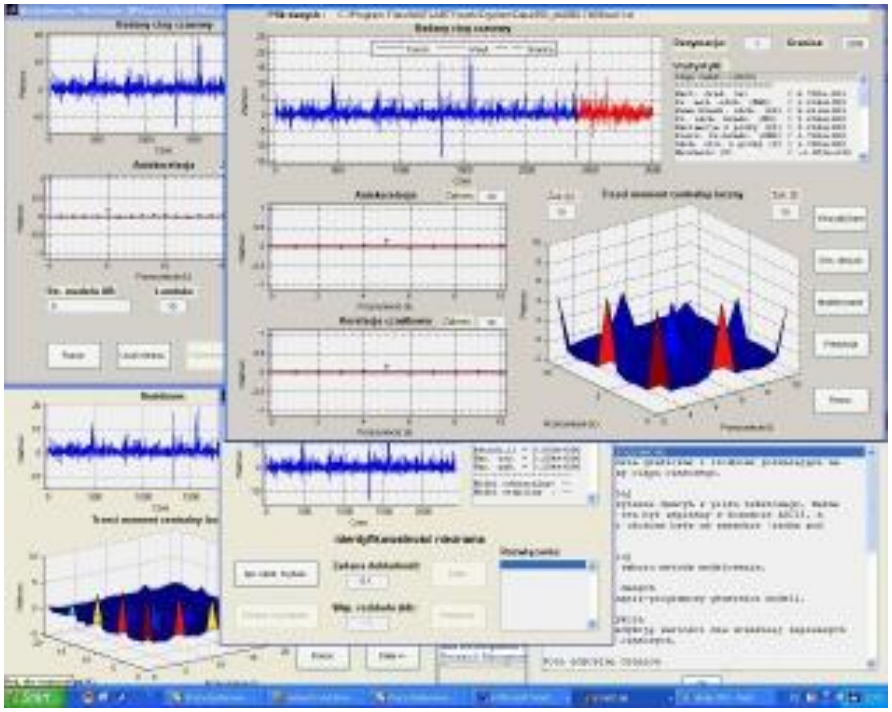
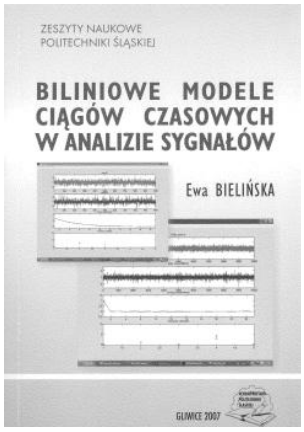


Fig. 9. Example of a program window.

Bilinear time series models in signal processing

E. Bielińska



Basic research is directed towards elementary bilinear time series analysis, identification and prediction. Such aspects as identifiability, methods of identification, prediction flexibility and prediction efficiency were considered and published in [II.23].

A new idea of Hybrid Linear Bilinear model was proposed and discussed in [II.2]. Prediction algorithm designed on the basis of the HLB model was published in [II.98] and [II.27].

Applied research directs the results of basic research toward the application in signal analysis. Up to now, conclusion is that there are events, for which bilinear modelling brings no improvement in comparison with linear modelling. However, there are events where bilinear modelling gives more accurate models than linear modelling. The results were presented on IEEE Human System Interaction Conference, HIS'08 [II.99].

Multisine random number generator

J. Figwer

Uniformly distributed random number generators play an important role in many areas of research and engineering activities. Considerable research effort has been put into developing various uniformly distributed random number generators and to compare

their properties. The objective of this research was an application of the multisine transformation to uniformly distributed random number generation [II.4].

The algorithm of uniformly distributed random number generation is based on a recursive synthesis and simulation procedure of multisine time-series with the multisine transformation. In the presented algorithm N-sample multisine time-series from the (r-1)-th iteration is used as phase shifts and amplitudes to synthesize and simulate the corresponding new N-sample multisine time-series, i.e. in each iteration, the finite discrete Fourier transform of a multisine time-series is synthesized and next the N-sample multisine time-series is simulated by performing the inverse discrete Fourier transform of the synthesized spectrum. The corresponding uniformly distributed random numbers are calculated from the obtained N-sample multisine time-series by using a modulo operation. Properties of the proposed uniformly distributed multisine random number generator are analyzed from the chaos theory point of view.

The numerical complexity of generating uniformly distributed random numbers using the multisine transformation can be reduced by using the FFT algorithms. In multiprocessor systems the efficiency of the proposed random number generation procedure may be also increased by parallel implementations of the FFT algorithms. The strong sensitivity on initial conditions of the multisine transformation is a feature of the proposed uniformly distributed random number generator that additionally allows to parallelise the proposed random number generation procedure in multiprocessor systems. A simple way to do this is to generate simultaneously the uniformly distributed independent random numbers on separate processors starting from different initial conditions.

The proposed approach to random number generation may also be a tool for enhancement of classical random number generators. Random numbers generated by these generators may be used as initial conditions in the proposed algorithm.

The generated random numbers belong to the set of real numbers. It is obvious that they can be transformed into natural numbers and corresponding binary sequences.

Nonlinear dynamic system modeling

J. Figwer

In the last two decades, fast development of microprocessor control systems and necessity to control plants in which nonlinearities have a substantial influence on a quality of control contributed to development of nonlinear dynamic system modeling methods. In the presented research a new approach to nonlinear dynamic system modeling with excitations being wide-sense stationary random processes is proposed. In this approach any nonlinear dynamic system is approximated by a linear dynamic system in which nonlinearity is represented by a disturbance at the linear dynamic system output that is uncorrelated with the system input as well as with the undisturbed linear dynamic system output. Such nonlinear dynamic system modeling is a tool that allows to look from another point of view on many digital signal processing problems like for example: identification problems implied by nonlinearities of digital measurement systems (e.g. finite precision of quantizers used in D/A and A/D converters), continuous-time system identification with data coming from identification experiments in which plant is excited directly from continuous-time excitation signal reconstruction system based on D/A converter with zero-order filter without additional analogue signal reconstruction filtration, model identification in the case of input and output signal levels comparable with data acquisition system accuracy, estimation of

input and output signal values in between single multiplicities of A/D converter quant, controllers working without expensive analogue antialiasing filters.

Methods for three dimensional measurement data conversion

S. Budzan

With the increasing use of 3D scanner and the growth in complexity of this models, the necessity of robust method for de-noising points cloud preserving the fine features in the surface has increased. Point clouds are one of the most primitive and fundamental representations. One of the most popular sources of point clouds are 3D shapes acquisition devices, such as laser range scanners e.g. laser scanner with digital light projection, with applications in many disciplines.

Often the noise source are optical elements from the 3D scanner. The 3D analysis methods are applied often to eliminate the groups of bad points – noise data, segmentation and filtration – smoothing, also classification objects in cloud of points. The elimination of bad points is commonly realized by manual selection of the groups of bad points. However, several methods are based on semi-automatic 3D grouping - based on calculation of Hausdorff distances. Main idea of applied algorithm depends on maximize distance – distance between points in three dimensional space – nearest neighbours in sliding 3D window [II.62].

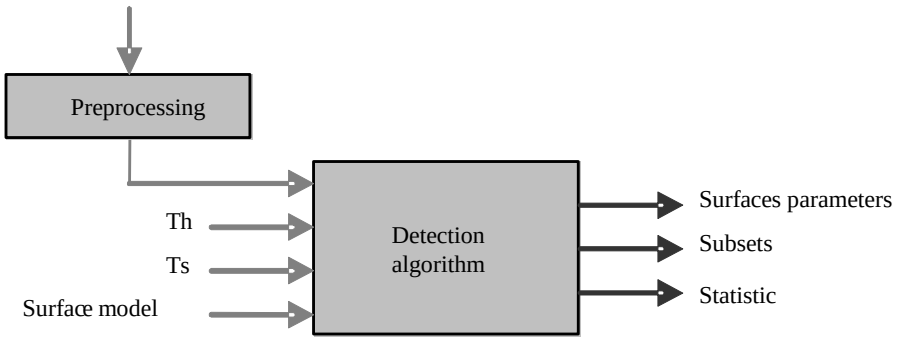


Fig. 10. Block diagram of the proposed algorithm.

The Segmentation cloud of points is realized by combining growing methods and 3D Hough Transform (HT). Thereupon object in 3D Data are classified, e.g. planar, elliptical or more complicated surfaces. The application of Hough transform for parametric surfaces in 3D is the natural extension of the Hough transform for 2D digital images, where it is used for detection of e.g. lines and ellipses. With reference to a specific pattern model, the Hough transform examines each point and finds all possible model parameters that agree with it. By collecting all such parameters in a properly defined parameter space we can determine data patterns that comply with reference model through cluster identification in the Hough Space. A implementation of the Hough transform is based on the definition of a proper 3D Hough Space – cumulation array. Here are some problems, like discrete data space, discrete parameter space, or non-perfectly planar shape in fractures. This and other weakness of the Hough transform stood themselves cause the proposing of the new hybrid algorithm [II.63] for detection of the parametric surfaces in 3D measurement data, as well as some major problems connected with 3D data acquisition and processing. The algorithm is based on

3D Hough transform and segmentation with the region growing which increase the efficiency of the algorithm (Fig. 10). The hybrid algorithm uses only the input two parameters, Th – Hough threshold and Ts – segmentation threshold, also the surface model, which must be searched. The parameters of the detected surface, subsets of the surfaces and 3D image statistics are the algorithm output information.

Face detection algorithms in 2D images

S. Budzan

Human face and eyes detection is often the first step in applications such as video surveillance and face recognition. The goal of face detection is to determine whether or not there are any faces in the image and, if present, return the image location and extent of each face. In fact, the methods of the face detection are classified into four categories: knowledge-based, feature invariant, template matching and appearance-based methods. Face detection is a part of the face recognition system. There are many closely related problems of face detection (Fig. 11). Face localization aims to determine the image position of a single face. Feature detection aims to detect the presence and location of features, such as eyes, nose, mouth, lips or ears. Face identification compares an input image against a database and reports a match. The purpose of face authentication is to verify the claim of the identity of an individual in an input image.

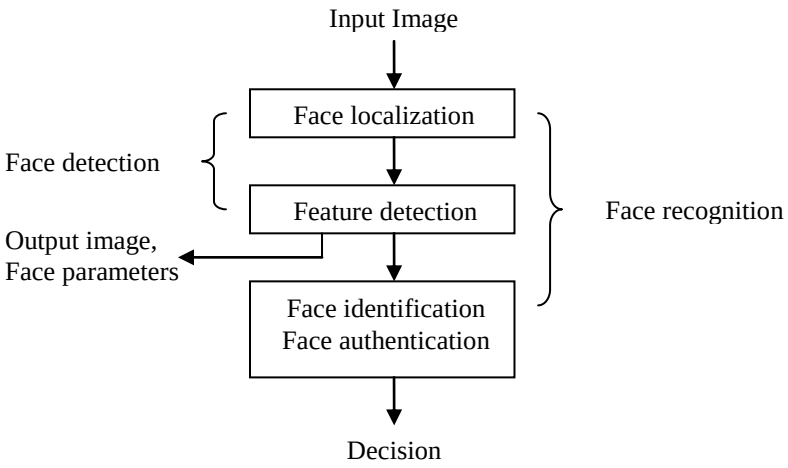


Fig. 11. Block diagram of the face recognition system.

The main problems connected with face detection can be attributed to the factors like pose, background of the image, facial expression and imaging condition. The main idea of the investigation is development of the effective method for face detection based on the template matching method like Hough transform (HT). The proposed algorithm [II.64, II.184] is based on Hough transform for ellipses detection and segmentation with region growing which increase the efficiency of the algorithm. With reference to a specific pattern model, the Hough transform examines each point and finds all possible model parameters that agree with it. By collecting all such parameters in a properly defined parameter space (Hough space) we can determine data patterns that comply with the reference model through cluster identification in the Hough space. In practice, the HT converts a complex pattern detection problem in the image space into a more manageable peak detection problem in the parameter space. There are many concerning problems, the most important is size of the Hough space – the ellipse detection need

five parameters to describe the position and the dimension of the face and the eye ellipse. Use of the growing segmentation reduce the compute complexity.

For future research the use proposed algorithm for images with more than one face and use of the fusion thermovision and vision images will be investigated.

Software for process identification

J. Kasprzyk, J. Figwer

It is generally accepted that some form of computer support is a necessary prerequisite for successful process identification, as the result of identification depends on a considerable extent upon the availability of a user-friendly system giving access to robust and high-quality numerical identifications software, some data base tools and some tools for producing graphical output. Part of the staff of the Measurements and Control Systems Division is traditionally engaged in research on various aspects of process identification and its applications, particularly to adaptive control. As a result of these activities a software package for process identification called Multi-EDIP was developed and its scope is continuously enlarged. It is used in education and research and commercialised on a small scale.

Multi-EDIP (Fig. 12) is a user-friendly software package for Windows 9x/NT/XP that intelligently aids the user in process identification. It can be used in identification and validation of scalar or vector time-series, like e.g.:

- parametric, stochastic, time-invariant as well as time-varying models (AR, MA, ARMA and their integrated instances),
- deterministic models (polynomial trends, sinusoidal components),
- nonparametric models – correlation and frequency-domain models

and single-input-single-output or multi-input-multi-output systems:

- parametric, stochastic, time-invariant as well as time-varying models (ARX, ARMAX, transfer function, FIR, output error model, etc.),
- nonparametric models, like correlation and frequency-domain models (cross power spectral density, coherence functions, frequency response function, etc.)

Multi-EDIP supports also data preparation, including:

- data checking and correcting (dealing with outliers, stationarity tests, statistical parameters, etc.),
- data editing (decimation, interpolation, taking out a sub-series of interest),
- data pre-processing (filtering, normalisation, removing a periodic component, etc.).

The user is released from doing any computer programming because Multi-EDIP provides a full control on all functions and services by means of a system of pull-down menus and windows. Besides, it supports the user during process identification by:

- providing automatically the most appropriate numerical procedures for model calculation and validation,
- offering expert advice in model structure selection and its validation [II.117],
- providing data-base capabilities to store and retrieve data samples, results of processing data and identified models,
- offering services for accumulating identification experience by providing a set of defaults values for some parameters,
- providing a system of context sensitive helps.

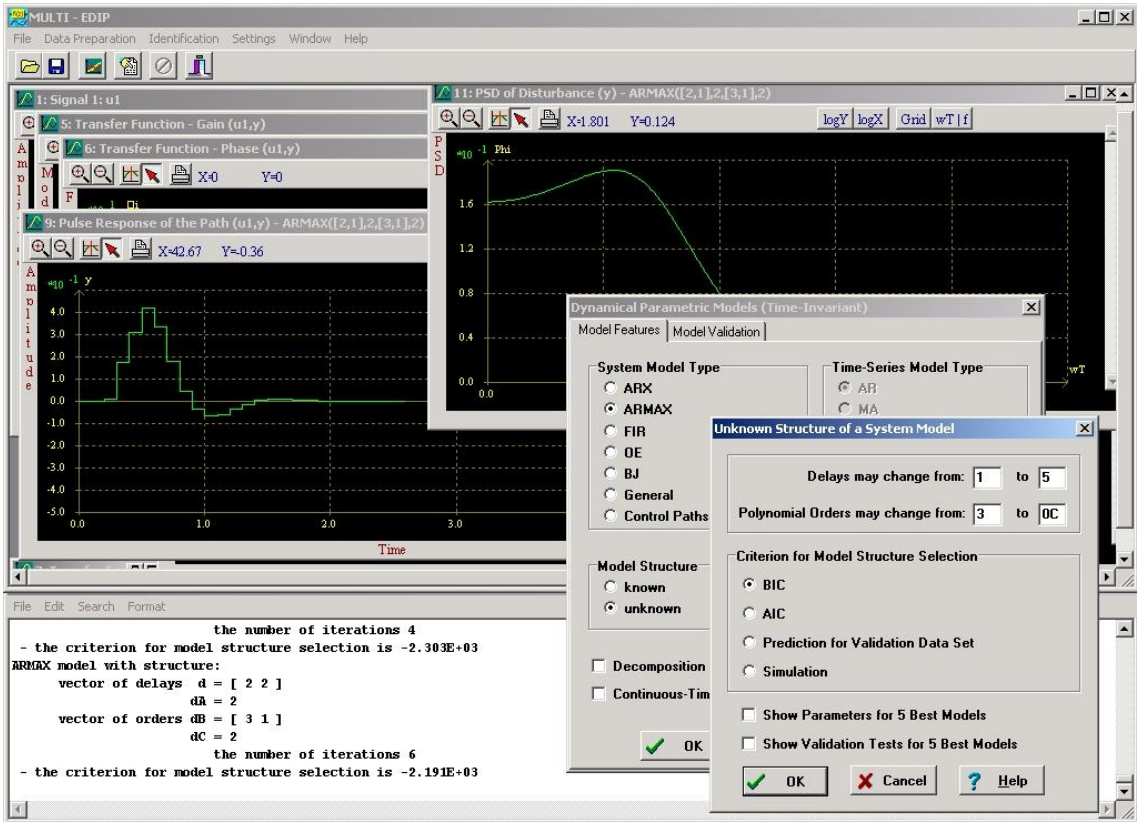


Fig. 12. Multi-EDIP windows.

The Multi-EDIP environment has been exhaustively tested for a large number of laboratory projects by groups of students reading process identification and signal processing as well as in research on active vibration control and active noise control.

Non-linear identification

T. Główka

The researches in the field of input-output system identification with higher-order spectra (HOS) are conducted. It is an unique approach, as there are very little references presenting HOS-based solutions for input-output identification problems; the literature dedicated to HOS concentrates almost exclusively on time-series identification. The proposed algorithms allows for identifying error-in-variable systems, in which noise disturbing the system input may be (via the feedback and feedforward loops) or not correlated with noise disturbing the system output [II.196].

The main motivation for using higher-order spectra (HOS) instead of second-order ones (i.e. power spectral density) in system identification is that they are identically zero for Gaussian processes. Thus, if the additive noise is Gaussian, it theoretically does not influence identification results, and in practice this influence is significantly reduced. The proposed approach requires a special non-Gaussian excitation signal. The main drawback of HOS is their computational complexity and long data series requirements, therefore we focus mostly on methods based on integrated HOS, particularly of the 3rd and 4th order (i.e. integrated bispectrum (IB) and integrated trispectrum (IT), respectively) [II.31]. An additional modification of those methods has been also proposed; it helps to reduce the variance of obtained estimates especially if the

disturbance is concentrated only in some frequency ranges. In the proposed approach the estimator (so called mixed-order estimator) is calculated as a linear combination of both: second-order and HOS-based estimators, with weights dependent on the coherence function. The idea of this approach is as follows: for strongly-disturbed frequencies (low coherence) the estimator is based rather on the higher-order estimates, otherwise second-order estimates are weighted more.

A part of our work is oriented on searching the methods for more efficient reduction of variance of frequency response estimates than in conventional approach, based on estimates smoothing using frequency window functions. We propose an alternative way of estimates smoothing, and consequently variance reduction; it is based on the iterative identification algorithm, in which a single identification procedure (based on second- or higher-order spectra) is repeated several times. The proposed method causes smaller flattening of estimates than the conventional approach; this is important if the true frequency response of identified system has a lot of peaks and notches [II.115].

Continuous-time dynamic system identification

J. Figwer

Models of linear continuous-time dynamic systems are important in many areas of research and engineering activities. Basic principles of their identification are not very much different from these for the discrete-time linear dynamic system identification case. In the literature of linear continuous-time dynamic system identification based on input and output signal samples a necessity of additional low-pass analogue antialiasing filtration of continuous-time dynamic system input as well as the corresponding output signals prior to their sampling with the constant sampling interval is stated. It is argued that such analogue filtration allows to reduce an influence of disturbances not satisfying the Shannon's sampling theorem on identification results. It is also emphasised that these filters should be identical taking into account dynamic characteristics to remove their influence on identification results. When this very restrictive and unrealistic condition is not satisfied, like it takes place in real-world applications of identification techniques in which additionally the same initial conditions of these filters are necessary, there is no possibility to remove the influence of these filters on identification results - a bias in obtained estimates may appear and identification errors implied by aliasing may be amplified.

The main aim of this research is to present a new, revisited and unified approach to nonparametric and parametric linear continuous-time dynamic system identification with a specially designed excitation of the form of a continuous-time multisine random excitation and data processing based on input and output signal samples acquired with a deterministic constant or random sampling interval without prior analogue antialiasing input and output signal filtration taking into account excitation signals generated directly from D/A converter equipped only with zero-order hold filter. A focus on model identification in the case of input and output signal levels comparable with data acquisition system accuracy and almost sure convergence of obtained identification results to *true* plant is given. Different methods reducing influence of the disturbances (including aliasing) as well as nonlinearities of the excitation generation and data acquisition systems on obtained identification results are proposed, too.

It is also worth to emphasise that in the presented research only finite variance of disturbances is assumed. Its power spectral density may be not bounded – periodic disturbances are taken into account. It is a class of disturbances that is more general that

this discussed in classical books on system identification and the corresponding publications based on them.

The approach presented in this research is a tool that allows to enhance properties of existing measurement systems and introduce superposition principle in a nonlinear world. It is also a background for a new generation of digital measurement systems, like for example very precise spectrum and system analyzers as well as discrete-time controllers working without expensive analogue antialiasing filters. Special cases of the presented approach are a closed-loop system identification and discrete-time model identification.

Speaker identification

E. Bielińska

The aim of speaker identification is to recognize an actual speaker among set of possible speakers, on the basis of a particular utterance. At the stage of trials end experiments speaker identification is an iterative and multi-stage process of speech signal pre-processing.

Research on speech signal processing, designed for speaker recognition, need large amount of data. Large amount of information often makes working with data difficult hence logical or comprehend arrangement of data is of great importance, and flexible system of data operating dedicated for speaker identification is really helpful at the stage of research of the problem. A structure of a system of data operating is presented in the Fig. 13.

Important stage in speaker recognition is a feature vector selection. Basic research is directed toward effective algorithms for feature selection. Some results are published in [II.100]. Applied research directs toward the effective system of speaker recognition.

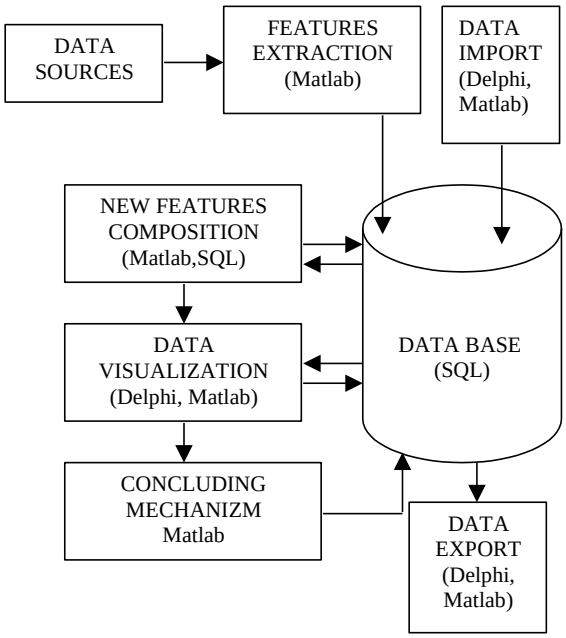


Fig. 13. Structure of data operating system.

Speech enhancement

M. Latos, M. Pawełczyk

There are many industrial environments which are exposed to a high-level noise, sometimes much higher than the level of speech. Verbal communication is then practically unfeasible. In order to increase intelligibility of speech being sensed with a microphone and then transmitted to another person, appropriate speech enhancement algorithms can be used. It is sometimes impossible to filter off the noise completely from the acquired signal by using a conventional filter, because of two reasons. First, the speech and the noise frequency contents are overlapping. Second, the noise properties are subject to change.

For increasing intelligibility of speech distorted by noise a number of algorithms based on the general idea of spectral subtraction have been developed in the literature. For this algorithms a voice activity detector is usually used to distinguish between time frames where the speech together with noise are present and those where the noise exists only. The frames with noise only allow to estimate its properties and then use them to eliminate the noise from the speech. If the signal to noise ratio is low, what is the case for industrial environments, the voice activity detection is poor and the remaining part of processing fails. Improperly subtracting the noise from a composite signal may even reduce speech intelligibility.

The problem undertaken in the Measurements and Control Systems Division refers to real conditions existing in power plants, assembly lines, etc., where noise level may exceed 100 dB. Communication between people is of utmost interest for safety and job efficiency. Therefore, another approach to speech enhancement, which does not involve employment of voice activity detection and spectral subtraction has been used. The adaptive realisation of the Wiener-based approach has been applied. Two structures have been considered. One is the line enhancer, where the predictive realisation of the Wiener approach is used. The benefit of using this structure it that it does not require additional apparatus. The second structure takes advantage of the high level of noise present in industrial environments. Under such condition, placing another microphone, even close to that used for speech sensing, can provide a reference signal well correlated with the noise disturbing the speech, and lacking the information about the speech. Then, the classical Wiener filter can be used, to produce an estimate of the noise based on the reference signal. That noise estimate can be then subtracted from the disturbed speech. Both algorithms can be supported by a bandpass filter limiting frequency content of the signal to that used for telecommunication. All approaches have been verified based on the data obtained from the real industrial environment, using the G.R.A.S. artificial head [II.43].

The problem of speech enhancement is a part of a larger project leading to development of a personal hearing protection system with integrated enhancement of speech intelligibility.

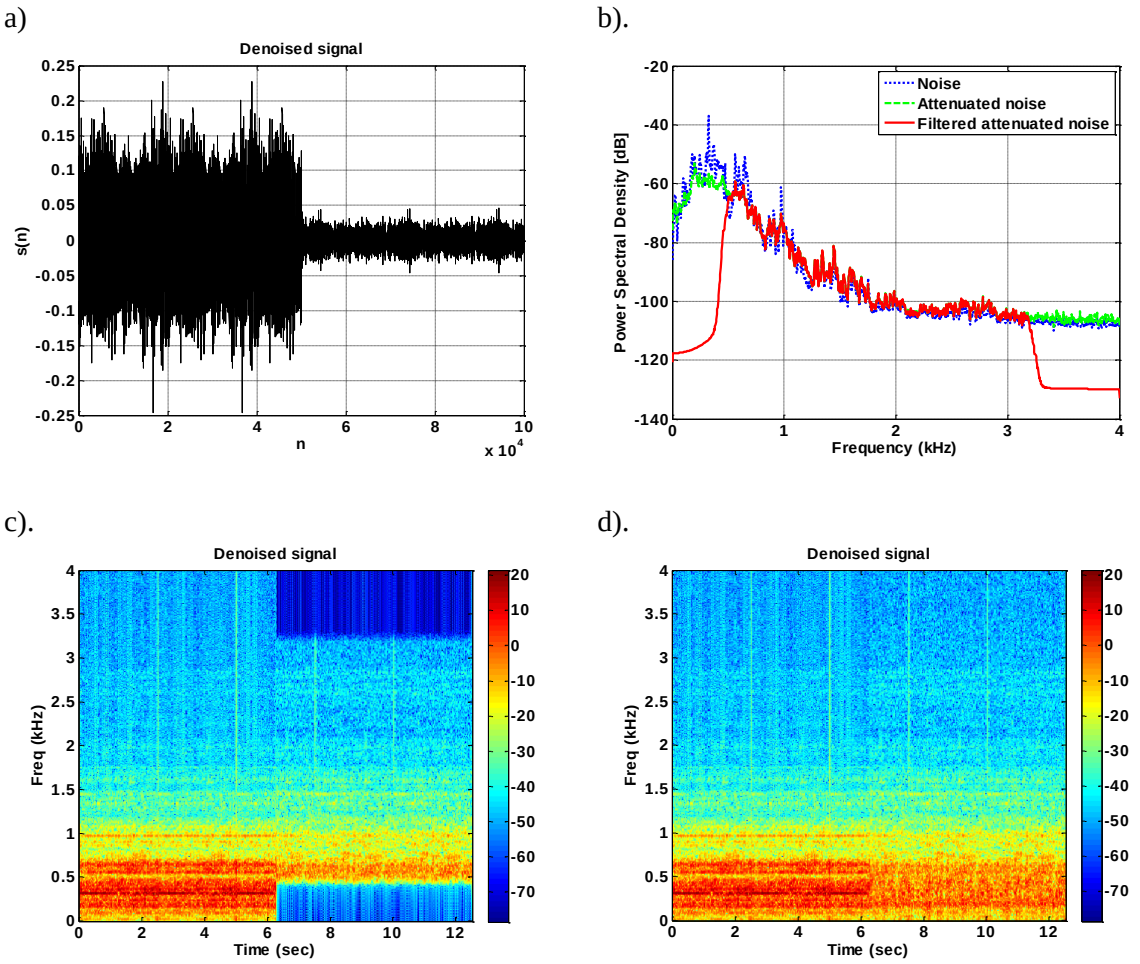


Fig. 14. Results of speech enhancement: a) noise attenuation in the time domain (system starts at 50000 sample); b) noise attenuation in the frequency domain; c) speech with noise in the time-frequency domain in dB, without bandpass filtering (system starts at 6 s); d) speech with noise in the time-frequency domain in dB, with bandpass filtering (system starts at 6 s).

Research on adaptation algorithms

D. Bismor, M. Pawełczyk

Many active sound or vibration control applications need adaptation to achieve their goals. Nowadays there are two algorithms that are generally used to perform adaptation in such applications: Recursive Least Squares algorithm (RLS) and Least Mean Squares algorithm (LMS). The former, however computationally more expensive, is better known from theoretical point of view. The latter, very simple to implement, still lacks complete theoretical analysis.

Among the adaptation algorithms based on the idea of local iterative descent, *the method of steepest descent,* or the method of deterministic gradient, plays very important role, because it allows for theoretical analysis and formulation of convergence conditions. This method, however, assumes the statistical properties of processed signal are known, or can be estimated. As estimation of statistical properties of unknown signals is usually time expensive, the method of steepest descent is rarely used in practice.

The algorithm that can be considered to be a simplification of the method of steepest

descent is known as Least Mean Squares (LMS) algorithm. The simplification depends on replacing statistical properties of the signal by their instantaneous estimates. Among the properties deciding the LMS algorithm is probably the most frequently used one can find:

- no need to estimate statistical characteristics of the signal, like autocorrelation,
- no need to do matrix inversion,
- general simplicity,
- low computational cost.

The LMS algorithm has also some drawbacks: despite its simplicity the exact mathematical analysis of its stability and steady-state performance is still not known. Indeed, due to highly non-linear nature of the LMS algorithm some even argue such analysis will never be possible. Theoretical results regarding LMS algorithm presented so far are mainly based on small step size assumption. According to this assumption, when the step size approaches zero, the LMS algorithms acts like low-pass filter with extremely low cut-off frequency. Using this assumption some results for the convergence necessary condition can be obtained.

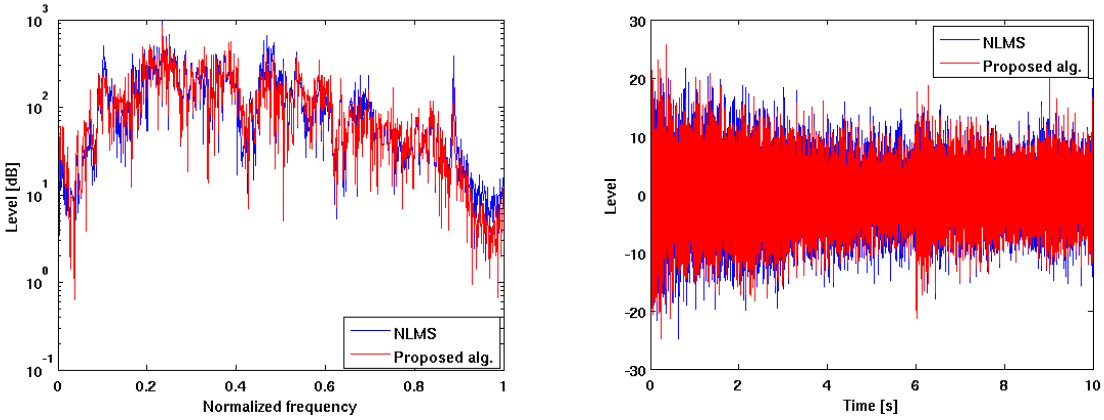


Fig. 15. Comparison of performance in simulations of NLMS and LMS with automatic step size adjustment algorithms.

The work on the convergence analysis of LMS algorithm is one of the areas of interest, too. Although the work just begun, the first results allowed to formulate a new necessary condition on the convergence of LMS algorithm [II.102, II.103]. It must be emphasized that this condition was obtained without small step assumption that is crucial in many theoretical LMS analyses presented so far. Moreover, the condition proved to be relatively easy to use in practice. Based on the new convergence condition the algorithm was derived allowing for fast adaptation with the guarantee of convergence. The algorithm proved to be effective in many simulations, see Fig. 15. The work will be continued to apply the new algorithm in active control of sound.

The LMS algorithm is commonly used to update parameters of a feedforward control filter. In such structure it is known as the Filtered-Reference LMS algorithm, or FXLMS. It aims at reducing the instantaneous square system error signal. A reference signal correlated with the error signal is also required as the input to the control filter. A product of this two signals supervises the adaptation. However, there are some applications, where measurement of the error signal is unfeasible due to lack of space for the sensor or other reasons. In the Measurements and Control Systems Division a modification of the FXLMS has been developed, which does not require measurement of the error signal. Instead that signal is estimated. Such approach is particularly useful

if the control system should react to disturbance nonstationarity and the plant changes marginally. Properties of this algorithm, including convergence, have been analysed. Its performance in terms of acoustic noise control has been verified. The tests demonstrated potential of this algorithm [II.158].

Fuzzy models for hazard assessment

T. Grychowski

Fuzzy hazard models can be used for assessing the safety condition of a mine. The models are created based on mine regulations and the experience of mine personal responsible for monitoring the mine atmosphere. Fuzzy inference is carried out on linguistic data and the analysis rules are defined by the mining industry regulations or by the empirical interpretations of the applied data by the supervising personnel in monitoring regions of the mine. The formation of the fuzzy models is diverse and depends on the monitored hazard, accessibility of the measuring devices and environmental conditions. The formation of the models may be broken up into several stages [II.32]:

1. Selecting the input variables linked to the sensors in the monitoring system and determining the range of their actions (creating linguistic variables).
2. Division of entrance variables into sectors. A sector represents the way a dispatcher is identifying measurements (creating linguistic values).
3. Selecting output variables by classifying hazard values and decisions made by the dispatcher. This is a function of the way the zone is supervises by the dispatcher.
4. Creating "if-then" rules base to link the qualitative information with decisions made by the dispatcher.
5. Selecting suitable patterns of deduction for individual mathematical computations of the system for the fuzzy analysis.

The measured parameter regions of the air in the fuzzy models are described by their associated trapezoid or triangular membership functions. The division of the input and output variables in this program for aiding the decision-making process is based on experience of the dispatcher and on modifications made during testing the fuzzy models. Studied fuzzy models used mainly in conjunction with interpretation of the rules that are based on Mamdani inference model with the centre of gravity method.

The flow of signals example in a multidimensional 3 rules fuzzy model is illustrated on Fig. 16. Such models provide concrete information regarding the degrees of hazard.

Fuzzy models allow analysis many correlated parameters of the mine's air and for faster and reliable control of the hazard levels compared to the existing threshold approach. The structure of the fuzzy models allows for easy adjustment of the result module when the hazard situation is changed. The hazard scale introduced into the model can be normalized. The level of every hazard can be evaluated between themselves. This approach provides new way of analyse and control different type of hazards for example associated hazards [II.60].

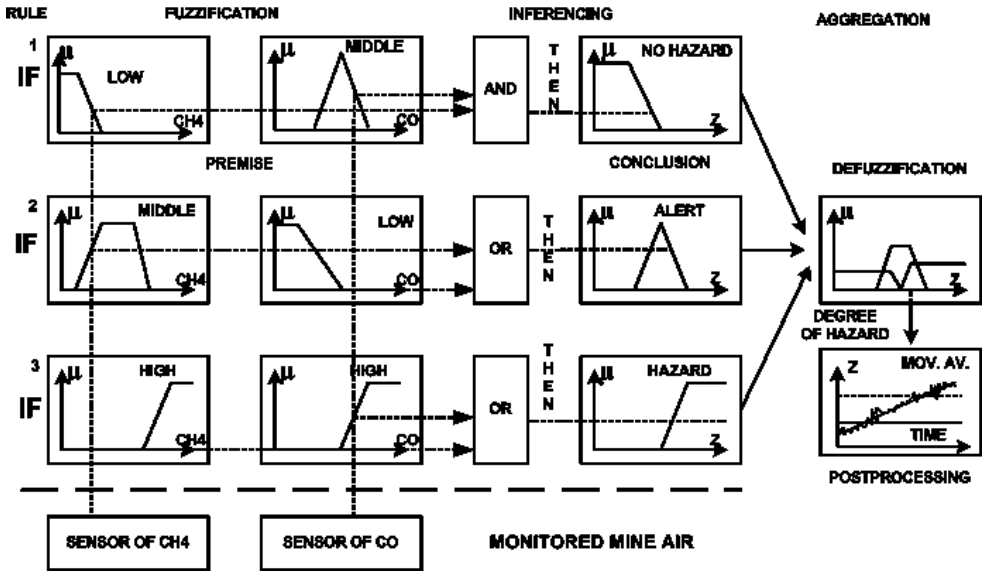


Fig. 16. The flow of signals in fuzzy hazard assessment model.

Adaptive synthesis and generation of random fields

J. Figwer

In many areas of engineering techniques applications in macro- and micro-scales like for example radar, sonar, telecommunication, biological, heat transfer, acoustic, nuclear physics and cryptography signal processing systems there is a need to synthesise and generate piece-wise wide-sense stationary random local as well as distributed fields. In this research, an adaptive approach to synthesis and generation of these fields based on a synthesis and simulation of wide-sense stationary multisine random time-series with the multisine transformation was proposed [II.5].

In the proposed approach to piece-wise wide-sense stationary random local field synthesis and generation, the multisine transformation is used to synthesize and simulate wide-sense stationary multisine random time-series recursively. First, in each iteration, the finite discrete Fourier transform of a multisine random time-series is synthesized using the power spectral density and providing phase shifts with some well defined random properties and next the corresponding multisine random time-series is simulated by performing the inverse discrete Fourier transform of the synthesized spectrum. Spectral properties of the synthesized multisine random time-series are changing, in the corresponding iterations, due to changes in time of the power spectral density of the piece-wise wide sense stationary random local field to be synthesized and generated. The corresponding piece-wise wide-sense stationary random local field may be generated using realizations of the synthesized and simulated multisine random time-series and special algorithms of continuous-time signal reconstruction with for example oversampling or analog low-pass filtration through high-order filter with sharp cutoff characteristic of the multisine random time-series transformed to continuous-time signal by D/A converter . In the proposed approach adaptive active noise control system may be used additionally as a support to attenuate an unwanted background noise coming from the environment.

The adaptive synthesis and generation of piece-wise wide-sense stationary random distributed field is a merge of the adaptive synthesis and generation of piece-wise wide

sense stationary random local field with a decentralized implementation of multi-channel adaptive active noise control systems based on a constellation of cooperating single-channel cross coupled adaptive active noise control systems. To synthesize and generate piece-wise wide-sense stationary random distributed field the cooperating single-channel adaptive ANC systems are equipped additionally with a software for synthesis and generation of piece-wise wide-sense stationary random local field.

The presented approach to adaptive synthesis and generation of random fields was extended to distributed field shaping that is understood as an adaptive synthesis and generation of the piece-wise wide-sense stationary random local or distributed field with properties similar to the given pattern being space distribution of power spectral density function.

PROGRAMMABLE CONTROLLERS AND SCADA SYSTEMS

Industrial Controllers

J. Kasprzyk

Programmable Logic Controllers (PLC) have become an integral part of control systems and process control. Therefore, to deal with a broad scope of today's manufacturing challenges, engineers' education should involve training in the areas of programming and designing control systems based on PLCs. It is assumed that students should get experience in programming various PLC families so as they can compare modern solutions in hardware and software proposed by different manufacturers. Such education should also include other elements associated with control system design, like e.g. communication with SCADA systems, reliability of the systems, etc.

Part of the staff of the Division deals with the development of control systems using PLCs. They are the authors of the textbook "Programming PLCs" (the first one in Poland) [II.9] and the book on programming according to the IEC 61131-3 standard [II.8] in which the author attempts to present a uniform, complete and coherent concept of PLC programming. The Laboratory of Programmable Controllers has been equipped with PLC families of different manufacturers, like: *Allen Bradley's CompactLogix, Simatic S7-300, GE Fanuc 90-30* and *VersaMax, Schneider's Modicon TSX Compact* and *Momentum*, industrial PC embedded *Beckhoff CX1000* and *WAGO IPC*; as well as software that provide a common development environment for configuring, programming, testing, monitoring, simulating and troubleshooting PLCs.

It is also important that students are able to create and test their own projects in situations resembling practical applications. Thus, the laboratory has been fitted with didactic panels to simulate many different real installations. These are, e.g., emulators of simple binary objects that enable for training on-off control together with time constraints, as well as emulators of batch processes that allow students to test sophisticated control strategies. The emphasis is put on the typical tasks met in the industry, like sequential relay control (e.g. drive control, see Fig. 17), motion control using frequency inverters, process control, etc.

Contemporary control applications are often designed as distributed systems. Therefore, the laboratory is also equipped with popular industrial networks, like Profibus DP, CANOpen, Ethernet, Modbus, ModbusPlus and Genius, that allow students to make acquaintance with typical solutions, or to be engaged in scientific research in this area. The concept of the laboratory corresponds with the state of the art that is observed in the scope of industrial automation comprising control systems,

measurement systems, executives and SCADA systems. For this reason, the laboratory is equipped with distributed input and output modules being flexible decentralized I/O products that can be connected to the PLCs by the industrial networks mentioned above.

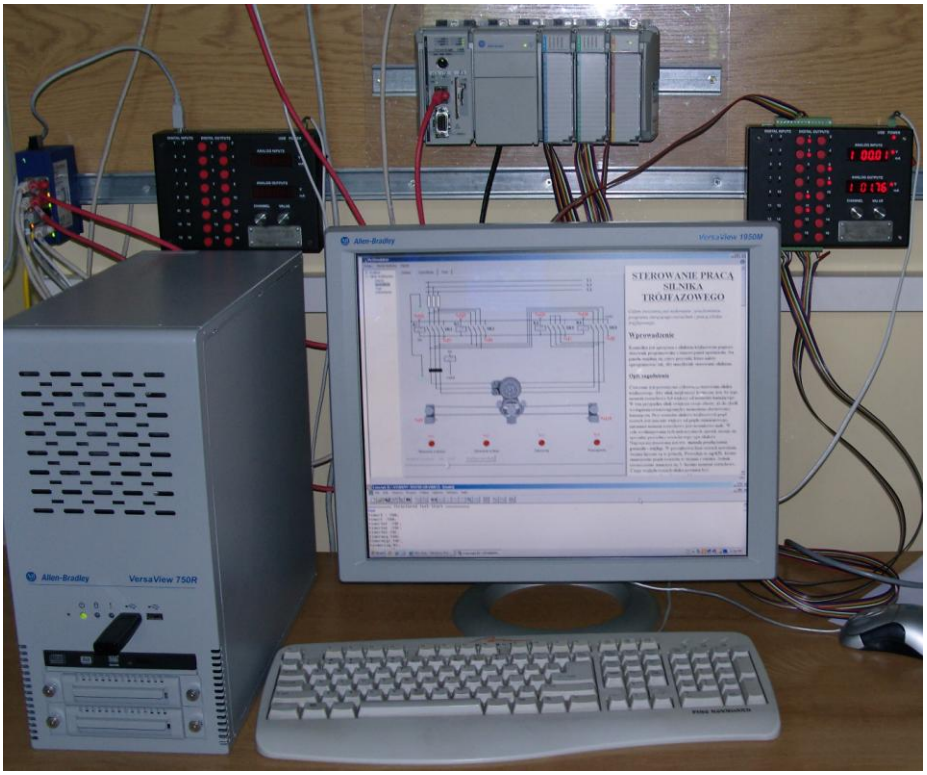


Fig. 17. Laboratory set-up with a process emulator

Often operators need to communicate with PLCs in order to modify parameters and configurations, display messages, variables, report alarms and so on. To meet these requirements, PLC installations need to be equipped with Human Machine Interface (HMI), so students are trained in designing and programming various HMI applications using textual and graphical operator panels, as *PanelView*, *Magelis* and *EasyView*.

Consequently, software and hardware that are available in the laboratory enable students to create modern distributed control systems providing advanced diagnostics and redundant configurations.

Industrial networks

J. Hajda

Industrial Communication Networks, also known as control networks, are groups of devices working in a peer-to-peer fashion to monitor sensors and actuators, communicate reliably, manage network operation, and provide complete access to data transmitted in the network. Industrial networks are a very important part of the modern control systems.

The research area concentrate on networks efficiency and reliability. The aim is to propose the best solutions for different cases by comparison strengths and weaknesses of various solutions on each level of the network ISO model.

The next issue is possibilities and constrains estimation of Ethernet TCP/IP network with various protocols and media to use in fast and slow as well as small and big industrial control systems.

In the scope area are the Modbus, Interbus, Uni-Telway, Profibus-DP, Modbus Plus, ControlNet, CAN, DeviceNet, ASi, FIPIO and Ethernet TCP/IP networks (Fig. 18). Also LonWorks, BACnet and KNX networks for building automation and M-bus and HART-bus for meters are tested and assessed.

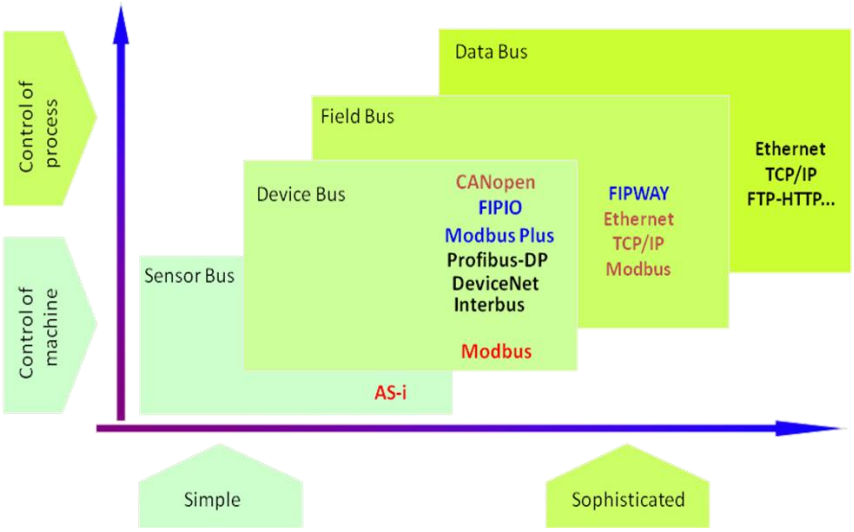


Fig. 18. Requirements and positioning of the main networks.

SCADA Systems

R. Jakuszewski

The Laboratory of SCADA Systems is equipped with the most popular SCADA software:

- *Proficy HMI/SCADA* – with the following software:
  - *Proficy Historian* – industry database,
  - *Proficy Real Time Information Portal* – raport environment Rusing Internet technologies,
  - *Proficy Change Management*,
  - *Windows Server 2003*,
  - *Microsoft SQL Server*.
- *Wonderware Intouch* – component of Wonderware Development Studio using modern technology *ArchestrA*.
- *WinCC*.

The laboratory uses additionally PLCs and industrial networks mentioned above.
Students have developed many industrial simulators, e.g. power plant, sewage treatment plant, car body assembly line, sugar plant, blast furnace.

Polish version (translation, verification and supplement) of the Proficy HMI/SCADA -iFIX v4.5 system made by the GE Fanuc firm has been worked up. This version was published on a CD by GE Fanuc in USA and is distributed by VIX Automation in Katowice, Poland. The packet consists of the following items:

- 159 programmes of the iFIX system – total 35.1 MB,
- contextual help of the iFIX system and VBA (*Visual Basic for Applications)* programming language,
- technical documentation in the form of textbooks (25 textbooks – total 4880 pages) and compact disks.

Proficy iFIX made by GE Fanuc is a leading SCADA software all over the world. It fulfils all functions of visualization, data acquisition and supervisory control of technological processes in industry. Proficy iFIX enables precise monitoring and parameters audit of manufacturing processes as well as devices and supplies in order to: increase output and production flexibility, decrease waste of materials, raise quality of production, shorten the introduction time of new articles into market, and enlarge production profitability. The system contains all tools, which are necessary to quick application development of any type and size, beginning from individual HMI (*Human – Machine Interface*) station, and finishing with complex many-station SCADA system network. Proficy iFIX uses object-oriented core iCORE, which joins innovative technologies of GE Fanuc and Microsoft firms to programme industrial automation systems - DNA - M, OPC, COM / DCOM, ODBC / SQL, VisiconX, DDE, Backup & Restore, Plug & Solve, Secure Containment. Built in VBA programming language it additionally gives unrestricted possibilities to control industry process and data handling. Proficy iFIX offers the protection of data access, which uses extended security systems of Windows NT/2000/XP as well as enables full redundancy in LAN network and emergency switching between SCADA servers.

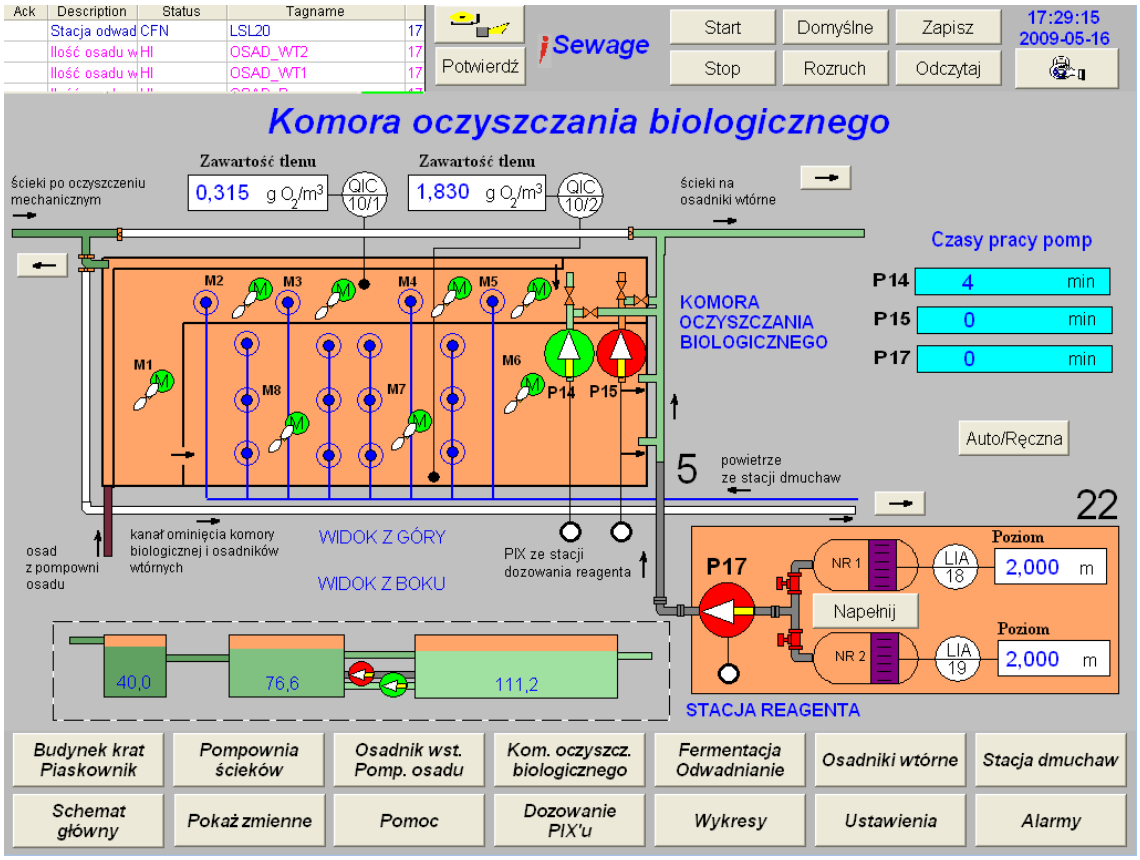


Fig. 19. Sewage Treatment Plant – Industrial Simulator.

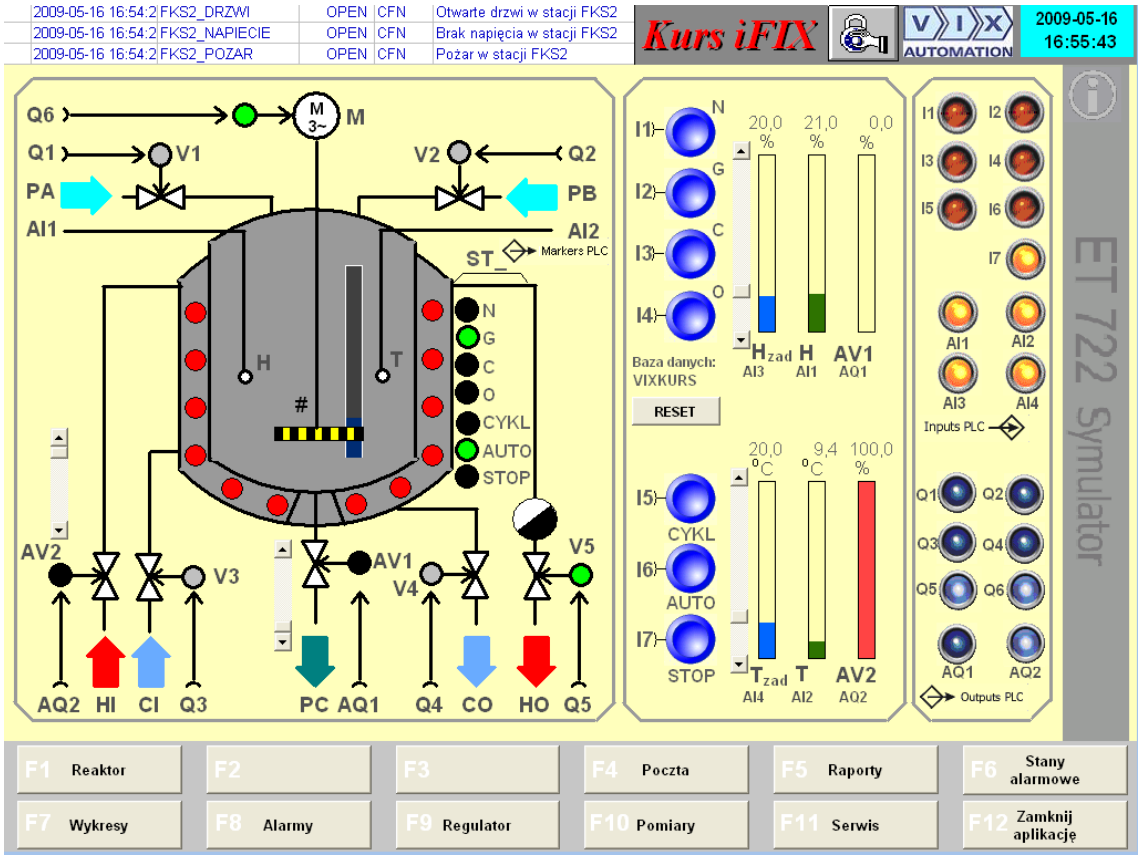


Fig. 20. Chemical Reactor – Industrial Simulator.

All over the world applications which use mechanisms included in this system control and supervise thousands of manufacturing processes, both discrete and continuous ones, in chemical, food, pharmaceutical, electronic, machine, metallurgy and power industries, and in many other branches. There are over 2500 such applications in large plants in Poland. The developed system is also used in the Silesian University of Technology in the SCADA laboratory by students as a basic tool to prepare their M.Sc. theses and during lectures related with SCADA subjects.

NOISE AND VIBRATION CONTROL

Active Noise Control

J. Figwer, T. Główka, M. I. Michalczyk, D. Bismor, K. Czyż, M. Latos, M. Pawełczyk, J. Staniek, M. Wilk, K. Mazur

Research performed in the area of Active Noise Control (ANC) in the Measurements and Control Systems Division of the Institute of Automatic Control concentrates on the following topics:

- ANC in a duct (D. Bismor)
- Local zones of quiet (M. I. Michalczyk K. Czyż)
- ANC for time-varying plants (M. I. Michalczyk, K. Czyż)
- Optimal fixed-parameter ANC at desired locations (M. Pawełczyk)
- Integrated personal hearing protector with capability of communicating in an area subject to high level nonstationary acoustic noise (M. Pawełczyk, M. Latos)

- Multichannel and distributed ANC systems (M. Pawełczyk, M. Wilk)
- Decentralized Adaptive Multichannel ANC (J. Figwer)
- ANC system identification (T. Główka)
- Structural control of sound (M. Pawełczyk, J. Staniek, K. Mazur)

The acoustic duct laboratory station consists of the duct, microphones, loudspeakers and amplifiers. The duct is made out of wood, it is four meter long, and of 20x40 cm in diameter (see Fig. 21). It must be emphasised that in order not to idealise the laboratory conditions the duct was not covered with sponge; neither inside, nor outside.

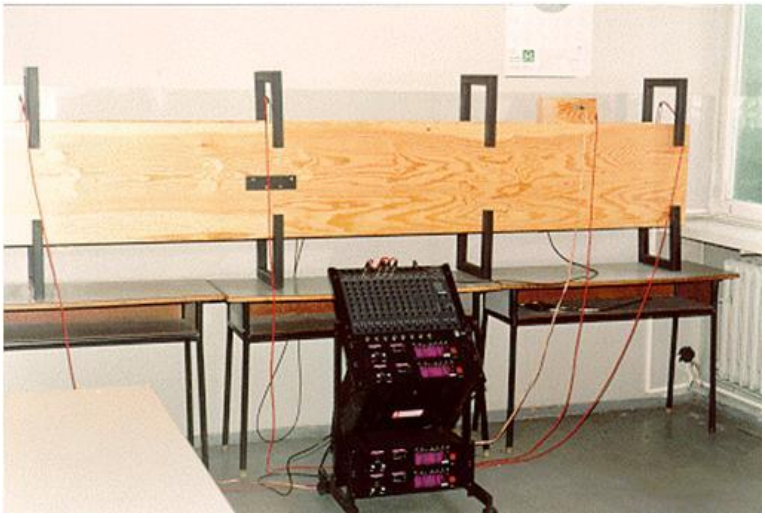


Fig. 21. Acoustic Duct Active Noise Control Laboratory.

The latest development of active noise control for acoustic duct has been inspired by problems with acoustic feedback phenomenon. So far it was cancelled by appropriate processing of reference signal (so-called feedback neutralisation). Such method involves estimate of electro-acoustic transfer function of acoustic feedback. As this estimate may be inaccurate, it may introduce error to the processing.

Virtual unidirectional source of sound (VUSS) is another approach to the problem of acoustic feedback. The idea of VUSS is to use adaptive signal processing algorithm to drive two loudspeakers in such way that the sound produced with them virtually propagates only downstream the duct. Virtually means that in fact the sound generated by each loudspeaker propagates in both directions, but the processing algorithm assures that the sound waves propagating upstream the duct are actively cancelled by themselves, while those propagating downstream the duct are amplified.

The overview of the virtual unidirectional source of sound system is shown on the Fig. 22. The process value for the VUSS algorithm is the control value produced by the active noise control system. In this case both VUSS algorithm and ANC algorithm use the same microphones M1 and M2. The virtual unidirectional source of sound algorithm uses multi-channel FXLMS algorithm to adjust appropriate adaptive filters it contains. Thus it is fully adaptive. However, as the goal of VUSS is in opposite to the goal of ANC system, it is not possible for both the VUSS and ANC adaptive algorithms to operate "on-line". Therefore VUSS usually adapts itself on the beginning of operation (after switching the system on), and then the adaptation of VUSS is turned off allowing the ANC system to operate properly. The virtual unidirectional source of sound proved to be very efficient. It attenuated the sound propagating upstream the duct on average

level of 60 dB in frequency range between 100 and 600 Hz. On the other hand, the level of sound propagating downstream the duct was very effectively equalised over the same frequency range [II.28].

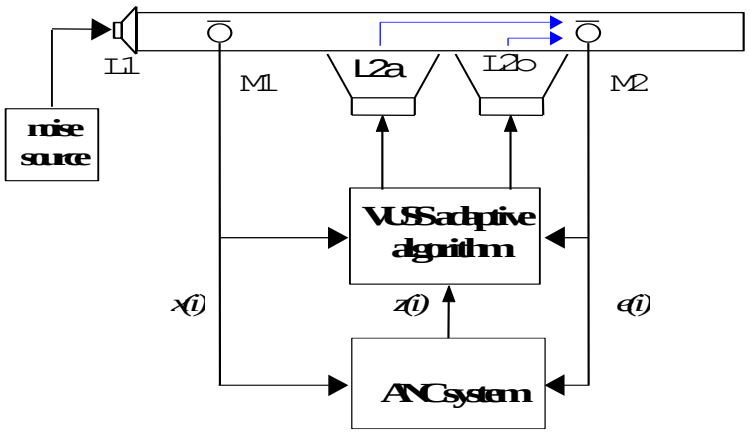


Fig. 22. The ANC system containing Virtual Unidirectional Source of Sound.

To explore possibilities of creation of local zones of quiet in determined spatial locations the real-world experiments were performed in reverberant laboratory enclosures. Depending on the spatial configuration of error microphones and control loudspeakers of the multi-channel ANC system, one bigger zone or many smaller zones distributed over the enclosure can be obtained.

In the initialisation phase of the adaptive ANC system the numerous parameters should be given. These are: an adaptation parameter of the FX-LMS algorithm, controller structure and electro-acoustic plant models, that are identified in this phase. The influence of adaptive control algorithm parameters on ANC system performance was observed in simulation and real-world experiments [II.29, II.136, II.45, II.135]. The observation conclusions allowed to formulate the rules of the ANC system parameterisation that were applied in further research.

Two kinds of control structures of three-channel ANC system were examined in the experiments: the feedforward control structure, parameterised as full as well as diagonal system, and the IMC (Internal Model Control) structure implemented as a set of diagonal one-channel systems [II.110]. The IMC ANC system of distributed structure can be simply transformed into a decentralized system, built of independent single-channel units, that is a cheaper alternative for classical multi-channel systems.

A new approach to real-world implementation of multichannel ANC was developed. In the proposed approach the multichannel adaptive ANC system is decomposed into a constellation of single channel autonomous adaptive active noise controllers. They exchange models of electro-acoustic cross-interaction paths by broadcasting them over the local Ethernet network. These models are used to estimate signals used by each of single channel autonomous adaptive controllers in the constellation to compensate their mutual cross-interactions. The presented idea enables to implement the multichannel adaptive ANC system as the constellation of single channel autonomous adaptive active noise controllers [II.104].

Results of real-world experiments showed the efficiency of ANC system in creation of one large or a few distributed local zones of quiet for random disturbance (Fig. 23). Maps of attenuation distribution show shapes of zones of quiet created in the small (a) and large (b) enclosures using 3-channel ANC system based on FX-LMS algorithm during random disturbance attenuation. The spatial configuration of microphones and

loudspeakers determines if one large zone of quiet (a) or a few, distributed zones are created (b). Attenuation obtained using full and diagonal feedforward controllers was similar. Attenuation in the IMC ANC system was slightly worse for random disturbances, however, showed the possibility of implementation of decentralized ANC systems creating local zones of quiet in enclosures.

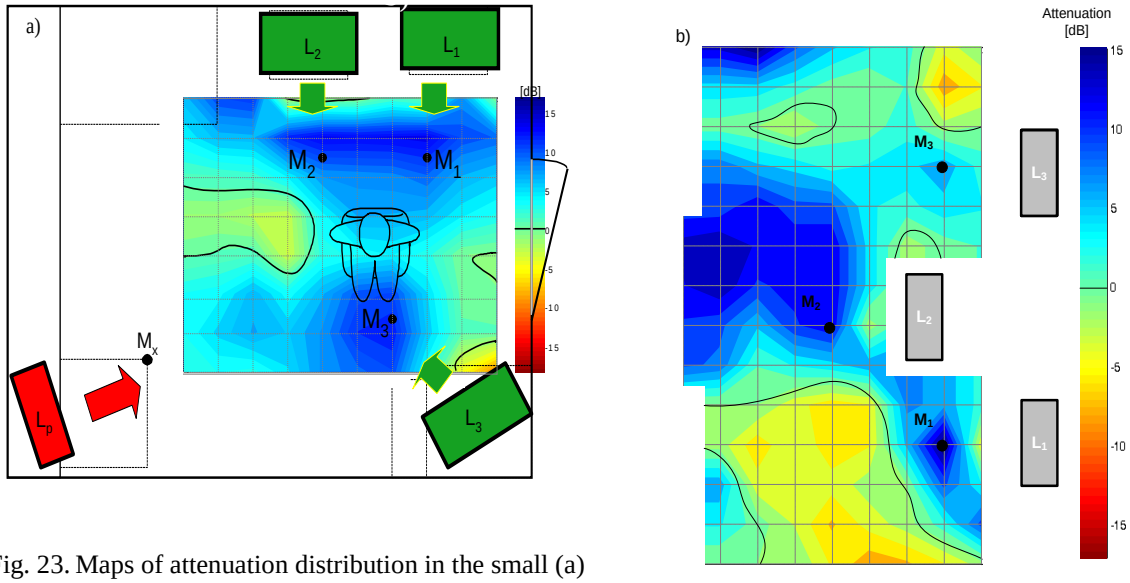


Fig. 23. Maps of attenuation distribution in the small (a) and large (b) enclosures using 3-channel ANC system.

The supporting research on adaptive control algorithms behaviour was conducted. RLS-based algorithms were shown to be effective but very difficult to parameterise [II.45]. The application of non-uniform sampling techniques proved to prevent some chaotic behaviour in active noise control systems [II.136].

The above work considered stationary acoustic plants. The following paragraphs describe research carried out in the area of time-varying ANC plants**.** The electro-acoustic plant controlled by the ANC system includes electronic elements and an acoustic space. The acoustic space can change very significantly, especially if it is the inside of enclosure. Every change of the enclosure spatial configuration causes an inevitable large change of electro-acoustic plant dynamic properties. These plant properties time variability can be split into three groups:

- weak changes, caused by variability of air temperature and humidity, mains supply frequency fluctuations, etc. They do not introduce significant changes of electro-acoustic plant dynamics and therefore do not influence ANC systems performance.
- strong changes, caused by externally introduced changes to the ANC system environment: any movements of persons in the enclosure, location changes of furniture, opening or closing of door or windows. Transducers (microphones and control loudspeakers) locations are assumed to be fixed. Door opening and person movement inside the enclosure, which cause strong nonstationarities of the acoustic feedback path can also serve as an example. The FX-LMS algorithm is robust on such changes of the secondary path.
- severe changes, caused by movements of the error microphone around that the zone of quiet is created. Such movements cause huge changes in the plant

dynamics, especially changes of the phase shift. The increase of the phase estimation error, if exceeds $\pm\pi/2$, results in divergence of the adaptive control algorithm.

Severe changes can be caused by large dislocations of the error microphone or by significant changes of the plant dynamics. In such case the electro-acoustic plant models should be additionally identified *on-line*. If the severe changes are caused by small (in comparison with the disturbance wavelength) dislocations of the error microphone it was shown in [II.110, II.136, II.134] that this case can be dealt with the use of standard adaptive control algorithm. The Fx-LMS algorithm is characterized by rather slow convergence. Therefore, many modifications to accelerate the convergence of the control algorithm were developed. Several of them were evaluated: (1) normalized Fx-LMS algorithm (NFx-LMS) where the adaptation parameter is weighted by the estimate of the filtered reference signal power; (2) modified Fx-LMS algorithm (MFX-LMS) using error signal calculated in the way neutralising the secondary path dynamics.

The main drawback of standard ANC algorithms implementations is the necessity of analogue anti-aliasing and reconstruction filters. Because of their high-order, these filters introduce additional dynamics to the electro-acoustic plant. Thus, eliminating filters from the signal processing path is beneficial for improving disturbance attenuation as well as increasing convergence rate of control algorithms. In order to accelerate control algorithm convergence and improve tracking capabilities of the ANC system various modifications of Fx-LMS algorithm were considered. One of them is non-uniform sampling technique, due to which analogue filters can be omitted and the reference and error signals are irregularly sampled [II.105].

The real-world experiments were conducted on specially designed laboratory setup [II.105, II.44, II.133] that allows introducing in time severe changes of electro-acoustic plant properties, by the movement of the error microphone (Fig. 24). The laboratory setup is used for testing of different modifications of adaptive control algorithms to compare their speed of convergence for time-varying properties of controlled electro-acoustic plant. The experiments results confirmed that the increasing intensity of the error microphone movement deteriorates the ANC system performance expressed by the disturbance attenuation. However, even for the velocity as high as 3.5 m/s the zone of quiet can track the error microphone. The results of the preliminary experiments showed how powerful the adaptation can be if properly applied for fast-varying ANC systems.

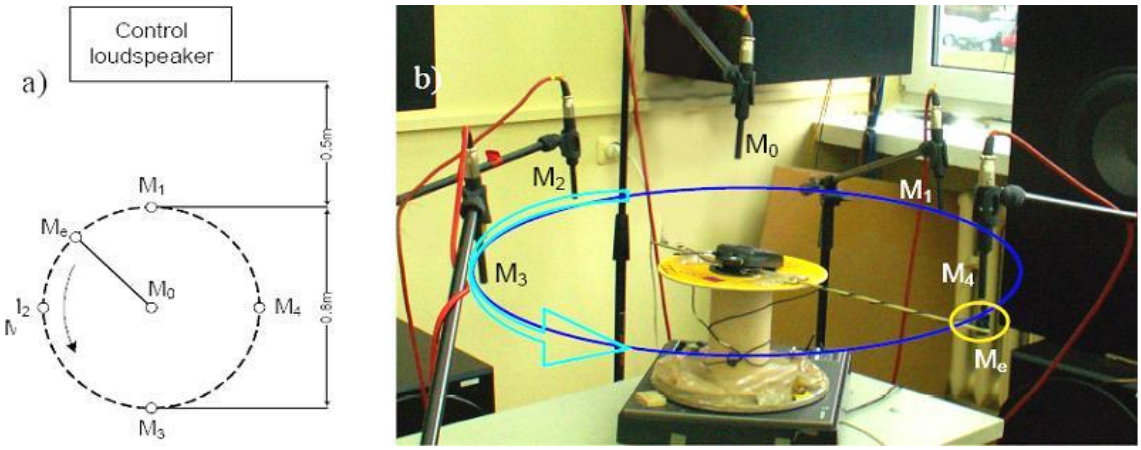


Fig. 24. The laboratory setup enabling the movement of the error microphone and the observation microphones positions: a) scheme and b) photo (error microphone trajectory denoted with blue circle).

Further work at the Measurement and Control Systems Division refers to creating local zones of quiet at desired location [II.185, II.51]. For many electro-acoustic applications there is a need to design control systems capable to shift the zones of quiet to desired locations. Such systems are referred to as the Virtual-Microphone Control systems. They employ different techniques to estimate the residual noise at the desired location and then minimise it using a relevant criterion. Three systems have been proposed. The first system does not require identification of the virtual path, which is usually time-varying. It has two stages of operation [II.48, II.174]. In the first stage knowledge of the system state is gained in additional filters when noise reduction at the desired location is obtained. In the second stage the filters are used to synthesize a command signal for the measured/controlled signal. Another Virtual-Microphone Control system requires models of the virtual and real paths to estimate the residual signal at the virtual microphone based on the measurements of the real microphone. The use of a single pair of microphone and loudspeaker does not frequently suffice to obtain satisfactory performance, i.e. generate a zone of quiet of acceptable dimension. Moreover, for some applications, presence of an obstacle, e.g. the head for an active headrest system, constitutes a barrier for the zone of quiet at one side to propagate to the other side (see Fig. 25). Therefore, more microphones and loudspeakers are often necessary. In the most general case a coupling between subsequent channels should be taken into account resulting in a fully coupled multi-channel system. A formal derivation and analysis of the multichannel control system has been performed [II.53]. The Wiener approach has applied. It has required spectral factorisation of the matrix PSD of the disturbance, inner-outer factorisation of a polynomial matrix and extraction of a casual part [II.155, II.157]. The presented control system has been experimentally verified by reducing acoustic noise at the user's ears in the active headrest system. The zones of quiet are correctly located, i.e. the highest attenuation is obtained at the nominal position of the head, for which path models had been obtained. Both lateral and forward practical head movements are allowed without leaving zones of significant attenuation for the given noise.

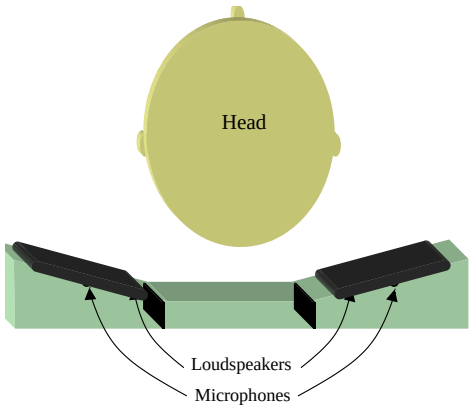


Fig. 25. Active headrest system.

Another Virtual-Microphone Control system has been designed as an analogue one. It has been applied to a phone (see Fig. 26) and aimed at generating the zone of quiet directly [II.52] at the user's eardrum. Such location is different than the real microphone location. The integral of the sensitivity function over assumed frequency band is minimised. A constraint is formulated to guarantee a sufficient stability margin. Another constraint is responsible for protecting against excessive noise reinforcement for any frequency. Controller parameters are found by solving the optimisation problem. Due to

its high non-linearity the exhaustive search method is used. It follows a preliminary analysis of the solution space. Additionally, a feedforward filter compensating for influence of the control system on the transmitted speech has been designed. The system has verified by means of simulations and real-world experiments. It has demonstrated that road noise is satisfactorily reduced.

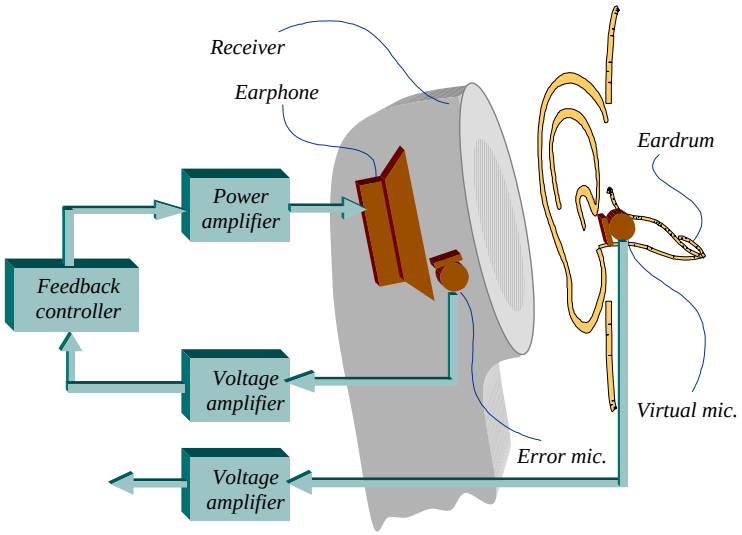


Fig. 26. Active phone system.

Another project has concerned an integrated personal hearing protector with capability of communicating in an area subject to high level nonstationary acoustic noise. The work with personal hearing protector concentrates on creating local zones of quiet directly at the eardrums of a person doing regular job in areas subject to high level acoustic noise, e.g. factories, mines, etc. The device, which is being designed, is very close to market-available solutions taking advantage of both passive and active methods. The novelty of the proposed approach is that the components are of small sizes (earplugs, see Fig. 27) and noise reduction methods are combined with methods of speech enhancement to improve conversation between workers and hearing of alarm signals.

Passive protection is assured due to a tight seal of the insulating material to each of the ear-shell. Level of passive noise reduction depends mainly on properties of the insulating material. Local active noise control near the secondary source deserves particular interest. It is technologically feasible and acceptable. It requires small energy amount and therefore is also economically efficient [II.54].

The person wearing the active earplug may move in a noisy area, a factory for instance, and pass by different working mechanisms, which generate different type of noise, although of a limited frequency band. The noise sources may also be turned on and off, and may generate nonstationary sound. A control system designed for a particular disturbance might then fail. A controller designed based on a disturbance model should be then updated. Solving the optimisation problem is time consuming and is rather avoided on-line. Then, an adaptive approach is usually used.

A drawback of adaptive systems is that they may suffer from convergence problems or some unpleasant transient acoustic effects may be generated. For this system the fixed-parameter approach to control is appreciated. To overcome the problems related to non-stationary noise, dominating frequency components / bands are

distinguished for the acoustic environment and the optimisation is performed [II.128, II.129, II.42].

a). b).

c). d).

Fig. 27. Examples of the used earplugs: Sennheiser IE8 – a), Creative Zen Aurvana – b), Sony MDR-NC022 – c), and the G.R.A.S artificial head with an earplug and microphone – d), used for experiments.

Increasing intelligibility of speech distorted by noise using general idea of spectral subtraction may fail, because if the signal to noise ratio is low, the voice activity detection is poor. Proposed approach to speech enhancement, which does not involve employment of voice activity detection and spectral subtraction is based on filtering. The filter-based approach is particularly effective if the noise to be reduced is periodic or narrowband, what is fortunately the case for most industrial environments due to working of rotating or reciprocating machines.

Multichannel control systems, in the case of a small number of control channels determined by the number of plant under control possible inputs and outputs, are mainly designed and implemented as a centralized control algorithms. Effectiveness of such solution is decreasing with an increase of the number of control channels. Lack of centralized computing power, problems with multichannel control algorithm parameterisation, fast development of very low cost signal processing units and control problems of plants having hundreds or thousands control channels imply necessity of a decentralized control algorithm application. One of such problems is the problem of a single (global) or many separate local zones of quiet creation in an enclosure using adaptive multichannel active noise control (ANC) system. In this research, a new approach to this problem, in the case when the corresponding centralized adaptive control algorithm taking into account all control channels cannot be implemented was proposed. In the proposed approach, the problem of centralized adaptive multichannel ANC is substituted by a set of cross-coupled local adaptive ANC problems but each one with much less number of control channels. Such problem reformulation results in a

constellation of cooperating local adaptive (single- or multi-channel) ANC systems that solve their individual adaptive control problems depending upon locally accessible information about acoustic field in which noise is controlled and about the remaining local adaptive ANC systems in the constellation. Cross coupling of the resulting local adaptive ANC problems implies necessity of their coordination. A coordination strategy based on *on-line* correction of the corresponding individual local adaptive ANC goals was proposed and its influence on structures of the cooperating local adaptive ANC systems in the constellation was discussed. The presented above decomposition of the centralized adaptive multichannel ANC algorithm is a two level control system (Fig. 28).

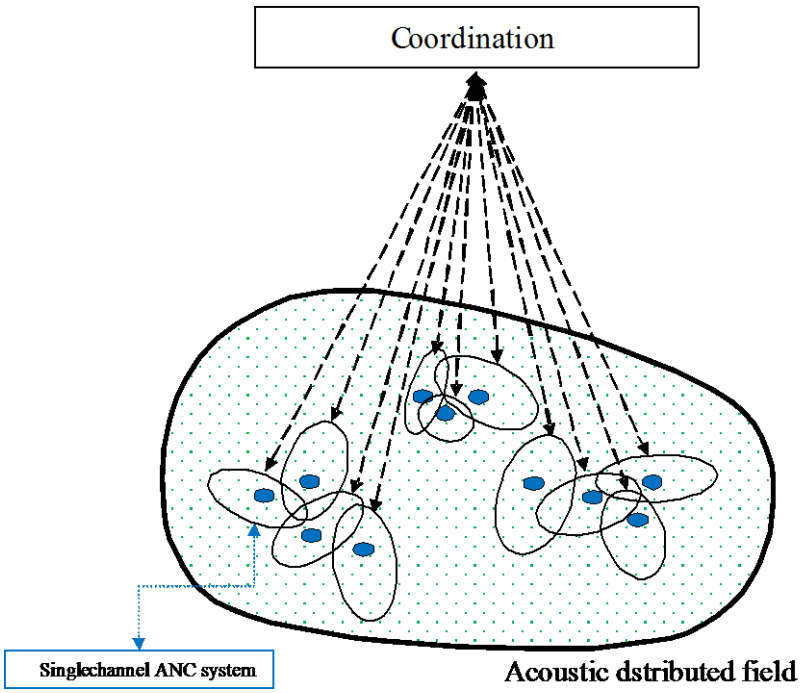


Fig. 28. Decentralized adaptive multichannel active noise control system.

The problem of protecting a human being from noise can be also approached by the means of a distributed ANC system. For successful implementation of ANC systems several conditions must be met. As people move, the zones of quiet should follow their heads. Due to the movement, contribution of noise generated by subsequent noise sources, if they are distributed over a large hall, changes (see Fig. 29). Likewise, while the person is getting closer or farther from a particular secondary source, its contribution to the overall noise reduction is getting stronger or weaker, accordingly.

In a response to such situation classical adaptive algorithms try to compensate the gain loss by increasing the controllers gain, what can be dangerous for system stability and high power consumption. The aim of the project is to propose a modification of the classical multi-channel FXLMS algorithm in order to protect against unpleasant sound effects due to the above problems. It is obtained by applying a time-variant, mutually dependent weight parameters in the multi-channel system. Additionally, when elements of the system are far enough from the position where the zone of quiet should be generated, their adaptation is stopped in order to reduce the computational load. [II.162]

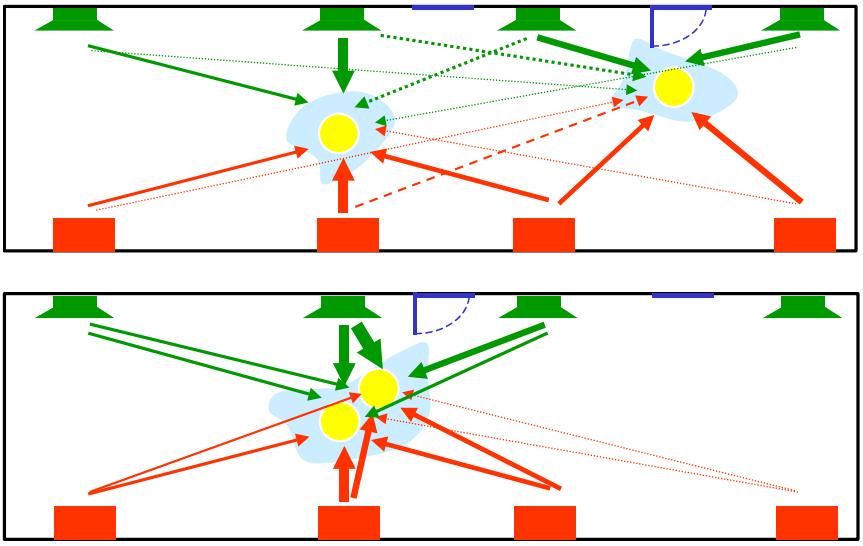


Fig. 29. The idea of active noise control in a large hall.
Red rectangle – noise source; green loudspeaker – secondary source; yellow circle – user's head; red and green arrows – source contribution (thickness indicates the strength); blue segment – door; cyan area – zone of quiet.

Adaptive ANC systems are parameterised with models of secondary and feedback paths. If these paths are time-varying, the models have to be updated during ANC system operation. Solutions proposed for on-line identification problem have to deal with several difficulties:

- (inherent) feedforward and feedback loops, it implies that the input and output of the identified path are correlated, and both signals are correlated with disturbance (attenuated noise). Moreover, if the system works well, the identified path is not excited sufficiently, therefore the external excitation has to be introduced into the system and added to the control signal;
- low signal-to-noise ratio, because the variance of the external excitation has to be very small to avoid significant deterioration of the noise attenuation.

In this case classical identification algorithms often give biased and inconsistent estimates. Therefore, we propose to perform the indirect method, in which at first frequency response (FR) models are estimated using higher-order spectra (HOS), supported by signal averaging. Next, rational transfer functions are calculated to approximate the obtained frequency responses. They are used to design suitable filters for ANC systems.

The proposed method is based on a direct estimation of integrated bispectrum (IB) or together IB and classical spectral analysis. This novel approach helps to improve the quality of obtained estimates in the following way. Firstly, HOS–based identification methods allow for reducing an influence of additive Gaussian disturbance on identification results, as HOS of Gaussian processes are identically equal zero. Secondly, signal averaging allows for improving signal-to-noise ratio without deteriorating noise attenuation, and additionally makes averaged disturbance to have better statistical properties (closer to Gaussian) than non-averaged original disturbance. The proposed solution together with results from simulation and real-world experiments are presented in [II.29, II.31, II.116].

In the Measurements and Control Systems Division a novel approach to sound control has been undertaken. Noise damping is done via structural sound control. In classic active noise control systems membrane loudspeakers are used as the secondary sound source. These loudspeakers are doing very well when used in laboratories or

rooms with clean air and stable temperature conditions. It's common that in industrial halls where many machines are running the air temperature varies in a broad range, air humidity and pollination reaches often high values. Under such conditions a normal loudspeaker is unable to operate. The second problem with classic loudspeakers is their thickness, which makes often almost impossible to use them under industrial conditions. Because of these problems different control sources are investigated. One of them are flat metal plates mounted in a frame and excited by force or bending actuators. In this research two exciting methods have been evaluated – MFC (Macro Fiber Composite) elements and inertial actuators. MFC actuators in contrast to classic PZT (piezoelectric) actuators generate larger strains, have higher directivity, and are easier to mount and control because of the lower capacitance value. Under certain conditions the MFC-plate system behaves non linear. This is due to fixed boundary conditions of the plate and temperature variations. Metal plates expand/contract when the temperature changes. Because of this the frequency characteristics of the system are non-stationary. An ANC system has been successfully developed which uses MFC elements for the attenuation of tonal disturbances in fixed temperature conditions [II.175]. The research focuses now on the investigation of temperature influence on the MFC and plate system with the target of compensating the temperature changes to get stable frequency response of the plate system over the whole industrial operating temperature range [II.131].

Fig. 30. Placement of MFC components.

Active Vibration Control

Z. Ogonowski, K. Plaza, M. Pawełczyk

Research performed in the area of Active Vibration Control in the Measurements and Control Systems Division of the Institute of Automatic Control concentrates on the following topics:

- active vibration control of rotating machines (Z. Ogonowski)
- semiactive vibration damping systems (K. Plaza)

Active vibration control is a challenging problem of magnetic bearings systems for high-speed rotating machinery. Superiority of the magnetic suspension over standard mechanical bearings follows form lack of friction, however, it consumes electrical

energy which appears as a serious problem if large mechanical systems are concerned (e.g. synchronous turbine-generator, motor-driven compressors and turbo-machines). The basic difficulty follows from the shaft displacement constraints which are considerably significant for bending modes and other resonances which can appear due to the control system dynamics. To assure safe performance of the system the diameter of the magnetic gap should be extended. However, consumption of energy grows rapidly. On the other hand the displacements can be reduced by increasing control forces generated with electromagnet. This, however, increases control effort. Thus certain trade-off is necessary.

Different control algorithms have been tested on the laboratory model of magnetic bearing system MBC 500 of Magnetic Moments LLC. (Goleta, USA) – see Fig. 31, since a few years. In [II.46] internal model approach is applied. It is shown that the original IMC methodology does not assure required disturbance rejection. The idea was then to use stabilizing primary controllers and to treat the stabilized system as a new plant for which properly designed IMC is applied. Tests that were carried out proved good performance of the system especially when compare with standard built-in controllers and different linear discrete controller as e.g. minimum-variance.

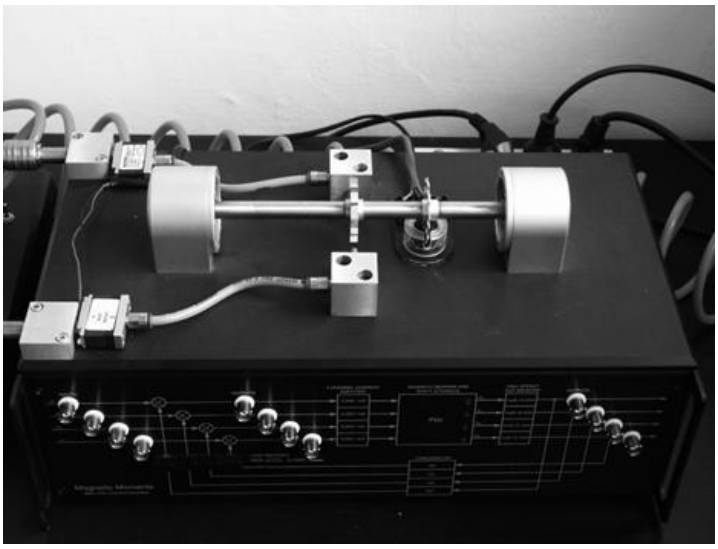


Fig. 31. MBC500 magnetic bearing system.

A similar idea was exploited in [II.149]. Disturbances that excite the system are modelled with generating polynomial with coefficients depending on measured angular velocity of the machine. The rest part of the model can be identified on-line establishing so called Limited Authority Adaptive Control system. Robustness analysis allows, however, for reducing identification problem only to specially designed filter which provides robust stability of the system.

The problem has also been tackled with adaptive Internal Model Control based on the Filtered-Reference LMS algorithm, commonly used for active control of sound and vibration. Adaptive control of such type has generally the potential to well suppress deterministic non-stationary components, which are naturally present in a rotating shaft. However, it has been a high challenge for that algorithm due to instability and hysteric behaviour of the MBC system. Since both convergence of the Filtered-Reference LMS algorithm as well as stability of the structural Internal Model Control feedback loop require stability of the system being controlled and its model, the MBC system has been first stabilised with a Weighted Minimum Variance controller. The proposed approach

to control has proven in simulation to reduce deterministic disturbance components much more efficiently than a PD or Weighted Minimum Variance Controllers themselves. First laboratory experiments has yielded very promising results, although further research is still required [II.161].

A new idea of the control system design is presented in [II.150] namely modified linearization by feedback applied to the MBC500 model. There are electromagnets that generate magnetic force which are linearized. The system itself is not affine in control thus the linearizing element has to be designed in a special way. Results of the experiments illustrate significant improvement of the system response.

A very different approach to vibration control is undertaken in semiactive systems, which are one of the growing domains in vibration control. At the Measurements and Control Systems Division, a semi-active system has been assembled. It constitutes a complete and autonomous measurement and control unit (Fig. 32).

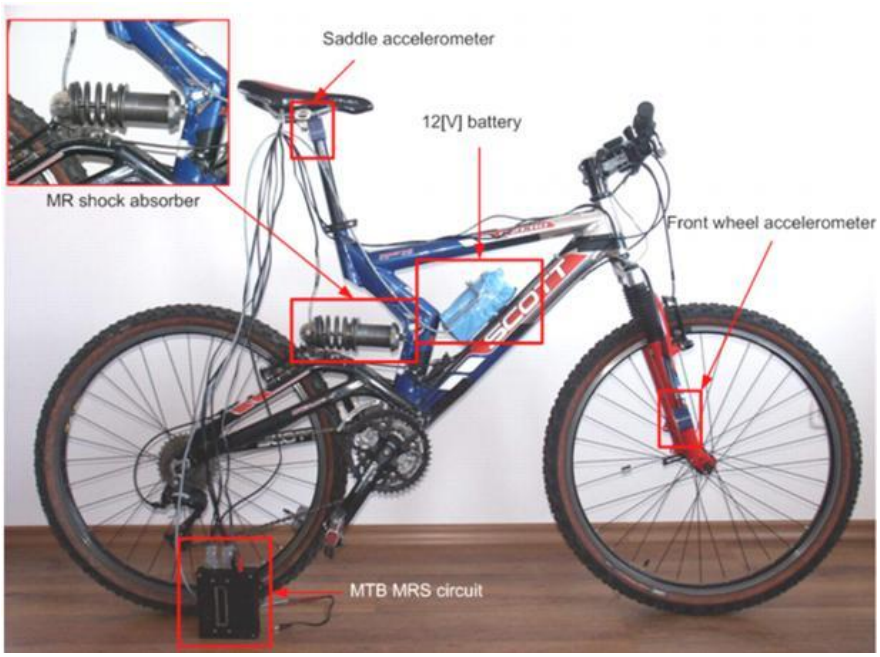


Fig. 32. Semi-active vibration damping system.

The main part of the system is a semi-active magneto-rheological (MR) damper controlled via an embedded control unit. Semi-active systems are inherently nonlinear but stable. Very often the semi-active elements alone are strongly nonlinear. Their control using classical methods is usually highly ineffective, thus they require using nonlinear modern control theory. In semi-active systems vibration reduction is done via control of the energy dissipation process.

Recent work included semi-active actuator modelling and control in real-time. Heuristic models of the actuator have been proposed. These models have been used to synthesize control algorithms. A new approach to semi-active control has been introduced, based on linearization through feedback methods. Linearization is carried out with the use of Lie Algebra. The effectiveness of algorithms has been verified in real-time tests, summarized and documented in a PhD thesis [II.195]. Part of work referring to semi-active vibration damping has been presented in conference papers [II.159] and [II.160].

ENERGY PROCESS CONTROL

Identification, modelling, optimisation and control for energy systems

Z. Ogonowski

Economical issues motivates application of modern control methods in energy distribution systems. Specialized laboratory set up subjects the current research and education interest of the Measurements and Control Systems Division in this area. The laboratory consists of the following parts:

1. Model of the HVAC system (Fig. 33) comprising a cabin with measured temperature of the circulating air. The valve is in-build into the box in recycling pipe. Three sections of electrical heaters, which can be switched independently, heat the circulating air. The fan follows the heater. Additional fans placed in the bottom and the top of the cabin simulate disturbances imposed with wasted air-flow.
2. Stand for distributed parameter heating system (Fig. 34). Heater(s) mounted in one or both ends of the copper bar heats the bar while a set of distributed along sensors measure temperature.
3. Portable system for measurement, monitoring, data collection and control of HVAC units (Fig. 35). The system consists of specially designed agents (servers) that measure and transmit data to the concentrator via standard interfaces, wire-less connections or through Ethernet environment.
4. Stand for application of Constraint Logic Programming (CLP) to control harmonic disturbances in the energy generation network (Fig. 36). All these elements of the set up are used in advanced education concerning identification, modelling, optimisation and control for energy systems.

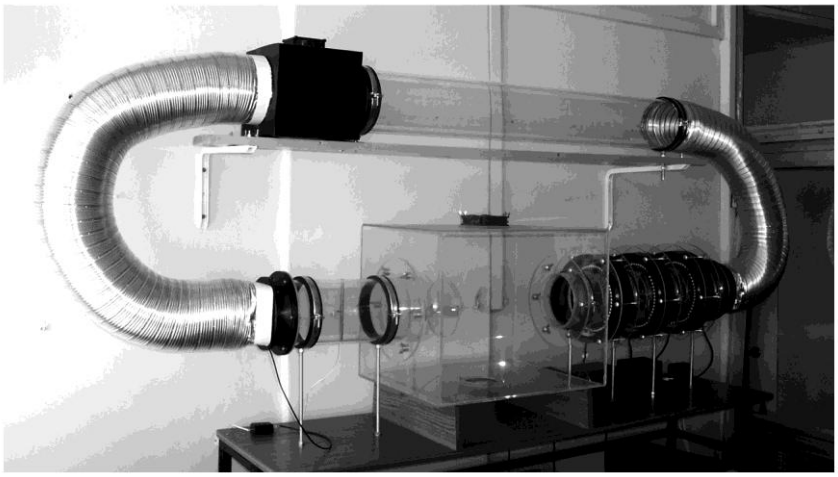


Fig. 33. Model of the HVAC system.

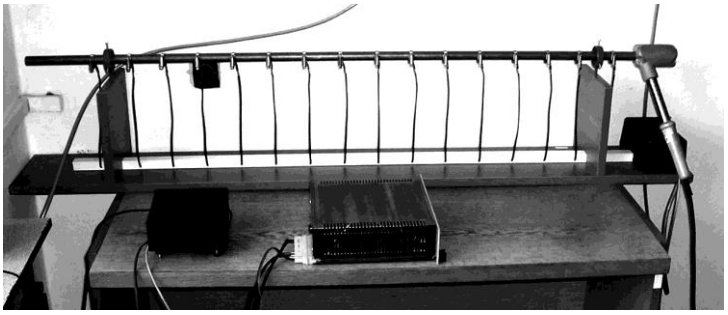
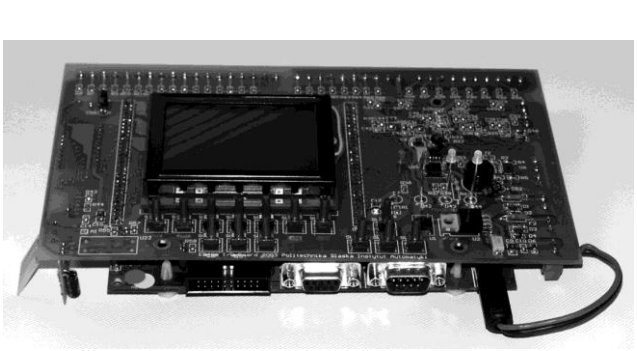
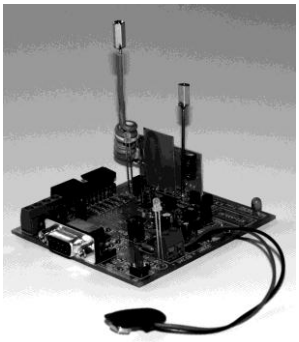


Fig. 34. Distributed parameter heating system.



(a)



(b)

(c)

(d)

Fig. 35. Exemplary elements of portable system for HVAC control: the central unit (CU) – (a), radio module (RM) – (b), Vaisala's system of weather conditions measurements (c and d).

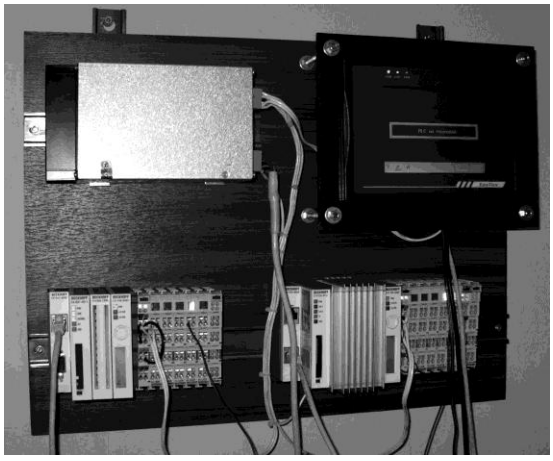


Fig. 36. Beckhoff PLC used to control harmonic disturbances in energy generation network.

Optimising control for the spray booth

Z. Ogonowski

Control problems for HVAC systems have reached great interest especially in the industrial applications due to optimisation aspects. Industrial spray booths serve as one of the example. Modern painting technology needs a few succeeding phases of spraying and drying process. Every phase has to be curried out in a special conditions (air-take and temperature). To keep temperature at the set-point both ventilation and heating system has to be controlled, however, usually simple on-off controllers or manual switching is used and the process is led insufficiently if energy (fuel) consumption is concerned and weak disturbances rejection.

Fig. 37 presents scheme of the Module-Master USI-ITALIA type spray booth which is used for car-painting. Two-layer control system [II.151] is applied to stabilize inner mean *TM* temperature (sensors *T*1…*T*4). The upper layer optimises [II.147] operating points (*TM* and *TI* – temperature of the mixed fresh-circulated air) of the direct control layer to minimize fuel consumption with valve position *VP* and furnace state *FP* being the control signals. The minimization is done on-line on the basis of models which has been identified off-line and measurement of the process variables with specially designed algorithm. The control system has been prototyped with the model of the HVAC system (Fig. 33) using Advantech's GeniDaQ technology. Fig. 38 presents comparison of the performance of built-in controller which uses temperature sensor *TC* (upper curve) with two layer controller (lower curve, controls *VP* and *FP* are presented as the lowest).

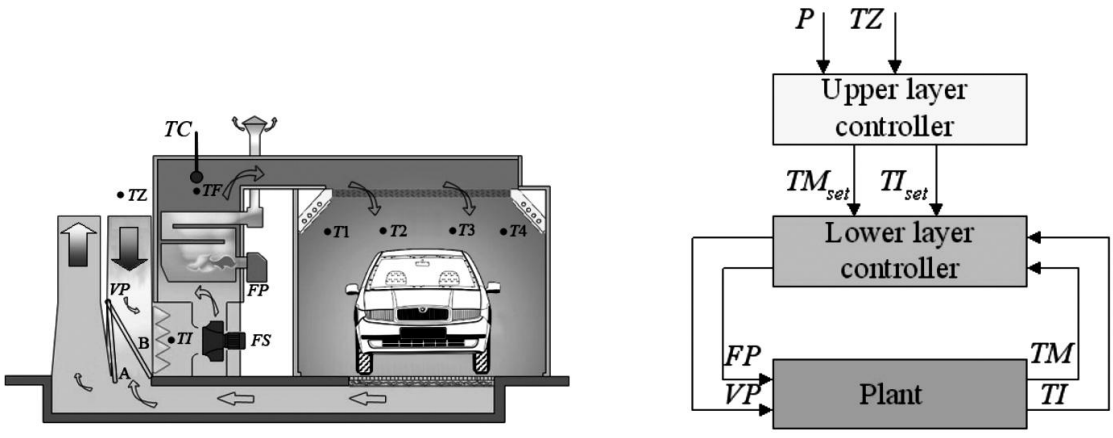


Fig. 37. Module Master USI ITALIA spray booth and control structure scheme.

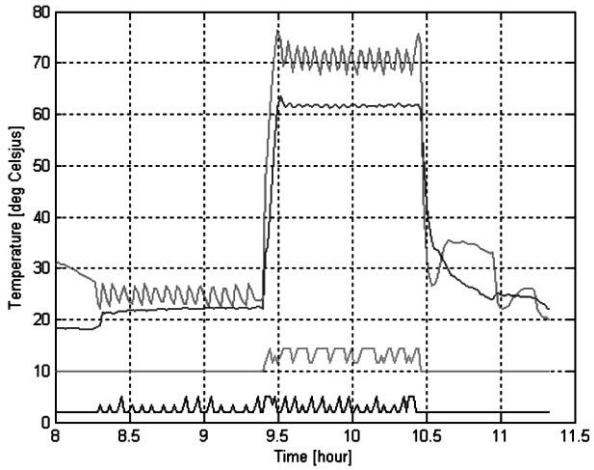


Fig. 38. Example of the control system response for the spray booth.

Heating control system in buildings

Sz. Ogonowski, Z. Ogonowski

Traditional heating control system in small buildings measures only indoor and outdoor temperatures. These measurements serves as the input signals of boiler control or indoor control with possible outdoor temperature compensation. Such control systems are boiler–oriented rather then take into account specific heating demands of a certain building. It would be very difficult to dedicate control system to a specific building due to great variety of building technologies. The robustness is then the main reason for widely applied simple on-off control.

As it follows from the research on heating control systems in small buildings the best way to reduce fuel consumption with no changes made in the heating system structure is to design the control system according to the static and dynamic properties of the heated building. [II.151, II.152]. The goal of the research is also to develop methods of tuning heating control system parameters for typical system of weather compensation structure.

Another important property of the building heating systems is the variety of heat sources and heat consumers. Usually there is one main heat source (e.g. boiler) and additional sources like fire-place, solar panels or secondary boilers. The system heats the building, domestic water, pools etc. Optimal heat distribution between heat sources and consumers reduces the fuel consumption.

To perform necessary simulations proper model has to be identified. The model needs to explain how the weather conditions and the heating system installed in the building influence indoor temperatures and humidity. To simulate different heat consumers the model consists of two parts – building model and domestic hot water preparation model. To obtain proper model the identification data must be collected during normal use of the building. Data collection system should not disturb inhabitants' conditions of living. In the same time it should register as many abnormal situations as possible. To satisfy these requirements specially designed data collection system has been developed. It consists of two types of units: Central Unit (CU) and Radio Modules (RM) – see Fig. 3. General assumptions of the system are: wireless communication temperature measurements, digital and analog inputs and outputs, communication with the PC for data storage, energy-saving work mode, small dimensions of devices.

The data collected during three years observation of representative buildings (Vaisala's environment has been involved – see Fig. 35) allowed to design the structure and identify the hybrid model (Fig. 39). The model describing heat transfer in the building consists of one non-linear Hammerstein model (NL Model) and artificial neural network model (ANN1) with outputs combined with the static model (SM). Another artificial neural network model (ANN2) is used to describe humidity changes in the building. The last part is another non-linear model (HWM) describing the process of domestic water preparation. Detailed description of the models identification can be found in [II.153].

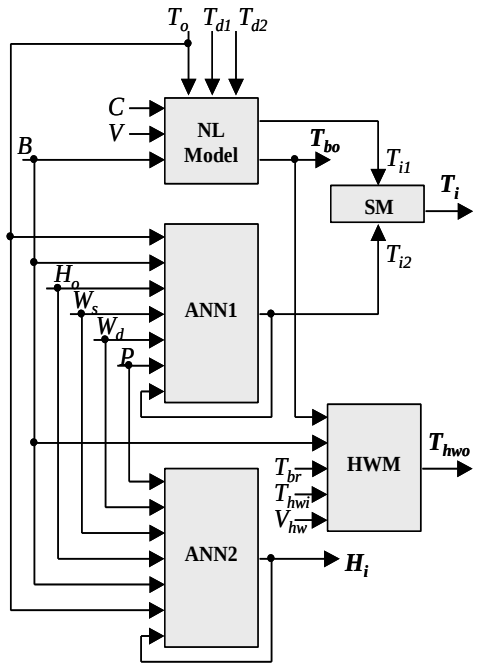


Fig. 39. The structure of the hybrid model.

Using the model describing changes of the temperature in the building new method of heating curve design was developed. The heating curve constitutes the relation between outdoor temperature and the temperature of the heating medium. In commercial devices it has to be chosen from the family of heating curves, which are proposed by the device producer and are built in the controller. Here, the adaptive case version of heating curve is proposed. Based on NL model structure the non-linear equation describing heating curve was designed. Parameters of the equation (the shape of the heating curve) depends on the on-line identified parameters of the NL model. This allows for the automatic tuning of the control system without necessity of experimenting with different (producer designed) heating curves.

The proposed control system is implemented in the CU which can operate as part of the laboratory set-up (Fig. 40). The model of the plant is simulated in MATLAB environment on the PC equipped with analog and digital I/O card from Advantech. The card is accessible from the GeniDAQ and the communication with the model bases on the OPC standard. The set-up allows for testing new algorithms implemented on the CU and compare their performance with different controllers available on the market.

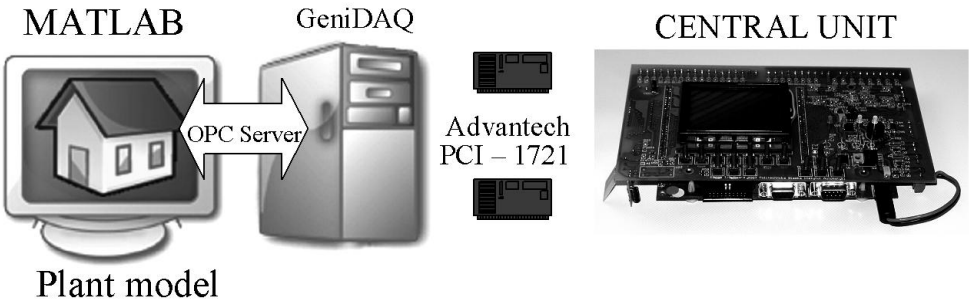


Fig. 40. Structure of the laboratory setup.

Heat control in a detached house

J. Wiora

The problem of economic supply of heat is fundamental for almost every household. The choice of energy source depends on regional prices of fuel, as well as the possibility of heater installation in the existing house.

The elaborated system (Fig. 41) uses ecological coal-fired central heating boiler with retort furnace as a primary heat source. The heat is distributed to radiators which are equipped with thermostats and located in rooms. Hot tap water system possesses recirculation and is supplied by storage cylinder. The water is warmed up by solar collectors, coal-fired boiler and the electric heater.

The control system consists of:

- regulation of boiler (feeding screw motor, air blower, pumps),
- return water temperature regulation,
- regulation of water temperature in radiator system,
- temperature regulation of water in storage cylinder supplied by boiler,
- different temperature control of solar circulation pump,
- control of electric heater,
- control of tap water recirculation pump,
- radiator thermostats.

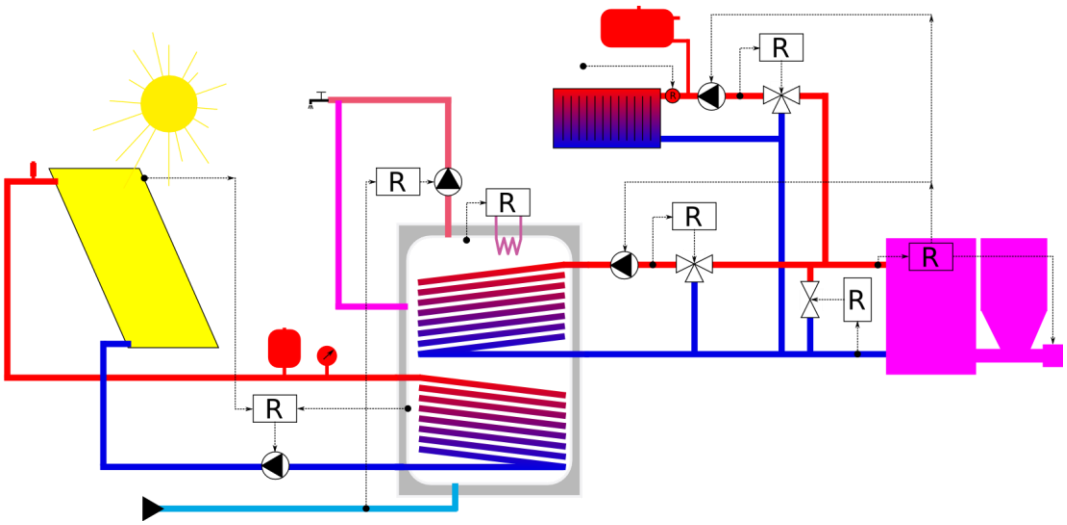


Fig. 41. House-heating system.

Active compensation of harmonics currents and reactive power

T. Szczygieł

The active compensation of harmonics currents and reactive power includes a set of problems connected with the occurrence, influence and elimination of harmonic filtration methods in the AC supplying networks. Main part of the problem is identification of the basic sources of higher harmonics and their features, including the traditional semiconductor converters. A lot of attention is paid to the problems of applying traditional LC filters in the networks. The research includes types of such filters, their features, and selected problems concerning modelling and analysing networks with filters. The analysis of the resonance phenomena in the branched networks is also discussed here. The next part of research deals with the perspective methods and the system energy active filtration and hybrid filtration. It presents their basic types, construction, models, principle of operation, energy-filtration properties and the areas of their application. The research concentrated on the modern methods, algorithms, and the control systems, including the control based on the theory of instantaneous power. Fig. 42 presents an example of the simulated control system response.

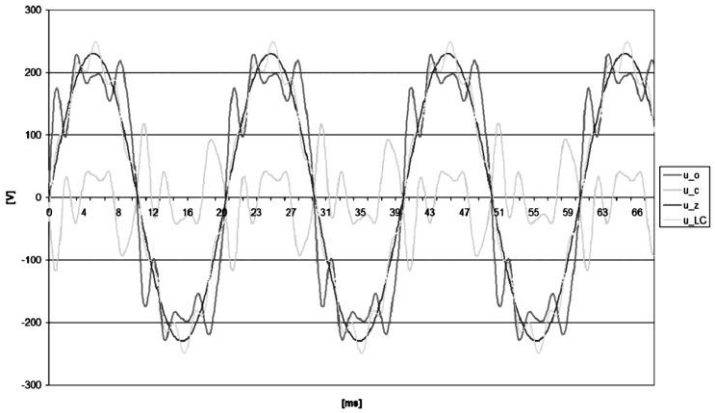


Fig. 42. The diagrams obtained during the simulation and experimental tests.

CONTROL THEORY

Combined feedback and feedforward minimum-variance control

M. Pawełczyk

The aim of the research was to analyse whether and how additional information on the output disturbance supplied in the form of a reference signal correlated with that disturbance can support the feedback control system (see Fig. 43). A combined control system has been thus designed using three approaches, where both the feedback and feedforward parts have been optimised to reduce variance of the system output [II.20, II.49, II.154, II.50, II.51, II.156].

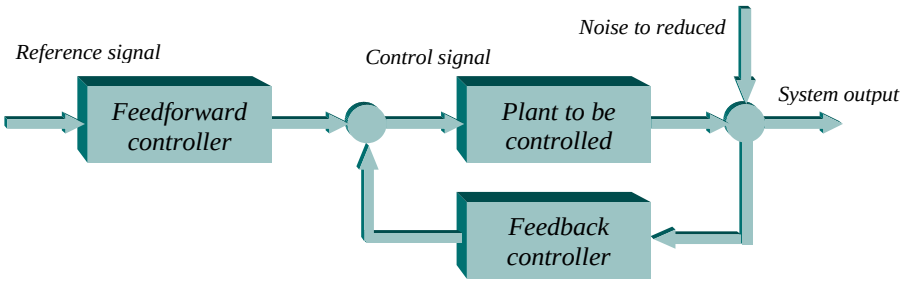


Fig. 43. Combined control system.

The polynomial based approach with two Diophantine equations has been used. Non-minimum phase property of the plant has been considered and therefore weighting of the control signal variance was included in the cost functions. Stability analysis has been performed and expressions for the optimal output and its variance have been derived. The design has been performed for the cases were the time delay of the reference (feedforward) path is smaller and larger than the time delay of the main control path. Effectiveness of the combined control system has been compared to effectiveness of feedback and feedforward systems operating alone. The problem of plant parameters changes has also been considered. Theoretical analysis has been accompanied by a number of experiments based on the real data obtained from an acousto-electric application. Superiority of the combined system has been proven both in terms of quantity and quality analysis. Even if the feedforward part has the information on the disturbance provided in advance, the feedback part is supportive, particularly if the plant is non-minimum phase or there are modelling errors.

Controllability of dynamical systems

J. Klamka, J. Wyrwał

Controllability is one of the fundamental concepts in mathematical control theory. This is a qualitative property of dynamical control systems and is of particular importance in control theory. Roughly speaking, controllability generally means, that it is possible to steer dynamical control system from an arbitrary initial state to an arbitrary final state using the set of admissible controls. Controllability is also strongly related to many important problems of control theory such as the theory of minimal realization, optimal control, stabilizability and pole-assignment. Almost every workable control system is designed to be stable since unstable systems are usually of no use in practice. If control system is not stable it must be stabilized. It is impossible when the control does not affect the complete state of the dynamical system but only a part of it. Therefore it is very important in practice to determine whether or not control of the complete state of the dynamical system is possible. In other words, controllability of the dynamic system has to be verified. Systematic study of controllability was started at the beginning of sixties in the last century, when the theory of controllability based on the description in the form of state space for both time-invariant and time-varying linear control systems was worked out. It should be mentioned, that in the literature there are many different definitions of controllability, which strongly depend on class of dynamical control systems.

In the papers, [II.33, II.34, II.104, II.36, II.38, II.40] constrained local controllability problems for finite-dimensional non-linear stochastic dynamical control systems, described by ordinary differential state equations is considered. Sufficient conditions for

constrained stochastic local controllability in a prescribed time interval for nonlinear both nonstationary and stationary stochastic dynamical systems which nonlinear terms are continuously differentiable near the origin are formulated and proved. It is generally assumed that the values of admissible controls are in a given convex and closed cone with vertex at zero, or in a cone with nonempty interior. Proof of the main result is based on a so-called generalized open mapping theorem presented in the paper. Some remarks and comments on the existing results for controllability of nonlinear stochastic dynamical control systems are also presented. Illustrative examples are also given.

Semilinear dynamical control systems contain both linear and pure nonlinear parts in the differential state equations. In the papers [II.125, II.37, II.121, II.122, II.40] sufficient conditions for constrained local controllability in a prescribed time interval for semilinear second-order stationary dynamical systems which nonlinear term is continuously differentiable near the origin are formulated and proved. Both semilinear systems without delays and with delays are considered. It is generally assumed that the values of admissible controls are in a given convex and closed cone with vertex at zero, or in a cone with nonempty interior. Proof of the main result is based on the generalized open mapping theorem. Roughly speaking, it is proved that under suitable assumptions constrained global controllability of a linear first-order associated approximated dynamical system implies constrained local controllability near the origin of the original semilinear second-order dynamical system. This is a direct generalization to constrained controllability case some well-known previous results concerning controllability of linear dynamical control systems with unconstrained controls.

During last few years many results concerning theory of fractional control systems have been published in the literature. However, controllability problems studied in the literature concern fractional discrete-time control systems without delays. In the papers [II.73, II.119, II.120, II.171, II.118] unconstrained controllability problem both of finite and infinite-dimensional fractional-discrete time linear systems with delays in control is addressed. Using formula of solution necessary and sufficient conditions for approximate and exact controllability in a given number of steps are formulated and proved.

In the papers [II.123, II.163, II.35, II.39] unconstrained approximate controllability problem for linear infinite-dimensional second-order continuous-time linear system described by abstract differential equation is addressed. Using theory of infinite dimensional linear selfadjoint operators, theorems on semigroups of linear bounded operators taken directly from functional analysis and formula of solution for abstract linear differential equations necessary and sufficient conditions for approximate controllability in a given time interval are formulated and proved. As an illustrative example approximate controllability of certain infinite-dimensional control system described by linear second-order partial differential equation is discussed.

Predictive control

Z. Ogonowski

One of the few only advanced control methodology that had a significant impact on industrial control engineering is predictive control. It poses a control problem as a constrained optimisation task referring to the finite receding horizon. The nineties brought number of theoretical works which established stability problem of a generic predictive control: basing on the monotonicity of a suitable difference Riccati equation and specially designed cost-function with terminal constraints the stability has been

proven. However, on-line solution of the optimisation problem has to be known. It can be effectively solved only for relatively slow plants. To make on-line optimisation implementable, heuristic or sub-optimal approach is necessary. Seminal paper by Scokaert *et. all* (IEEE Trans. on AC, vol. 44, no 3) "Suboptimal model predictive control (Feasibility implies stability)" showed that the stable suboptimal scheme exists.

Mechanical systems serves as the example of difficult application of predictive control due to fast sampling. These problems are surveyed in [II.172]. A novel approach to vibration control in semi-active mechanical systems, which bases on numerical analysis of the mechanical model exited with harmonic disturbances is presented in [II.145]. So called qualifying function is introduced to describe different level of vibration damping deterioration imposed by succeeding higher harmonics. Using the quality function the criterion index of optimisation problem is defined and optimal relation between dominant frequency of the disturbances and control signal is determined. This relation creates static nonlinear part of the controller. Dynamic part in the form of FIR element estimates dominant frequency of the system response in an adaptive way.

The above solution gave rise to the suboptimal approach which is presented in [II.144]. To improve vibration damping quality two approach are proposed: indirect linear algebraic approach and direct nonlinear predictive control. The first uses linearization by feedback and models stochastically disturbances that consist of linearization residuals. The task is to place poles and zeros of disturbance channel linear model. The second approach bases on general idea of nonlinear model-based predictive control and uses the mechanical system to predict the disturbances and solve objective function minimization problem using a heuristic algorithm.

Well known heuristic approach in predictive control is successive linearization. The method, however, suffer from numerical complexity due to on-line linearization. In [II.150] a new fast linearization algorithm is proposed which uses identification procedure. It is assumed that non-linear noise-free model is given. Data for identification are created with the model impulse response. This allows for more flexible linearization where the vicinity of the operating point is discussed rather then point-sensitive linearization provided by the standard procedures. The method couples linearization of continuous system with its discretization. Because of the Toeplitz-type of the matrix being inverted in the identification Least-Mean-Square algorithm, a special inverting algorithm can be used. It is shown that the number of matrix elements is reduced usually 4-5 times. The efficiency of the resulting algorithm can be seen by comparison of the computation-time with standard linearization procedure, which bases on perturbation algorithm and discretizes obtained model using modified scaling and squaring method.

SENSORS AND ACTUATORS

Calibration of acceleration sensors

D. Buchczik, R. Wyżgolik

The fast progress in a silicon micromachining technology makes possible construction of sensors for static and low frequency acceleration measurements. Determination of metrological characteristics of the acceleration transducers is necessary by reason of application of additional circuits that modify characteristics of monolithic accelerometers.

Calibration of the transducers can be performed using two different calibration set-ups, depending on the frequency range.

Calibration of the transducers for frequencies higher than 20 Hz can be performed using a calibration set-up, whose schematic diagram is shown in the Fig. 44 [II.164]. The view of the calibration set-up is presented in the Fig. 45. The test stand is equipped with the B&K 8305S reference accelerometer coupled with the B&K 2525 measuring amplifier. An output voltage of the transducers is measured using the HP34401A multimeter as well as the NI-PCI 6221 data acquisition card, which is used for a noise waveform acquisition. The TDS 2004 digital oscilloscope is used for checking output waveform of both the reference and the under test transducers. The B&K 4809 vibration exciter is coupled with the B&K 2706 power amplifier and the HP 33120A digital waveform generator. The reference accelerometer is mounted on a test table of the vibration exciter. On a top mounting surface of the reference accelerometer there is fixed a triaxial mount that enables easy positioning of the tested transducer.

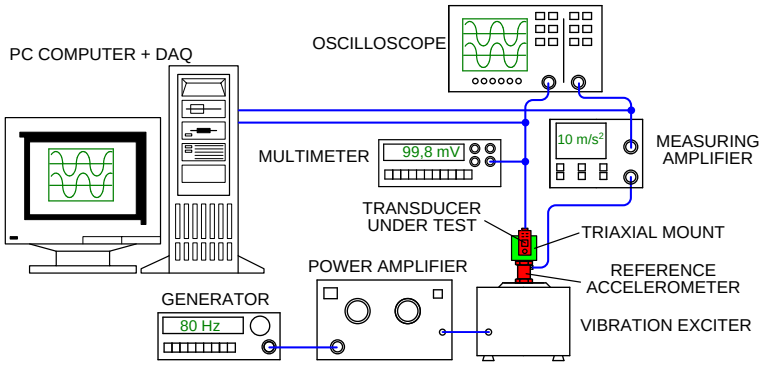


Fig. 44. Diagram of the calibration set-up for frequency range 20Hz – 20kHz.

Fig. 45. View of the calibration set-up for frequency range 20Hz – 20kHz.

For low frequencies, there can be used the calibrator based on a linear displacement unit [II.61, II.183]. The main component of the calibrator is the linear displacement unit (linear axis) of type DGE-25-2000 from FESTO, which is coupled with the AC servomotor. The belt transmission drives the test table of the unit. The resolver integrated with the AC servomotor measures the position of the test table.

The calibration stand is controlled by PXI measurement system with a use of LabVIEW environment. The PXI system is an industrial computer equipped with various modular instruments. The PXI system calculates a reference signal that controls the movement of the test table on the basis of the analogue position signal from the resolver. NI-PXI 6251 high speed multifunction data acquisition card is used to generate analogue reference signal and acquire the position signal.

B&K 8305S accelerometer coupled with the B&K 2525 measuring amplifier is used as reference transducer. Output voltage of the transducers under test is measured using the NI-PXI 6251 data acquisition card by reason of limited performance of multimeters at low frequency.

The diagram of the system is shown in the Fig. 46 and its view is presented in the Fig. 47.

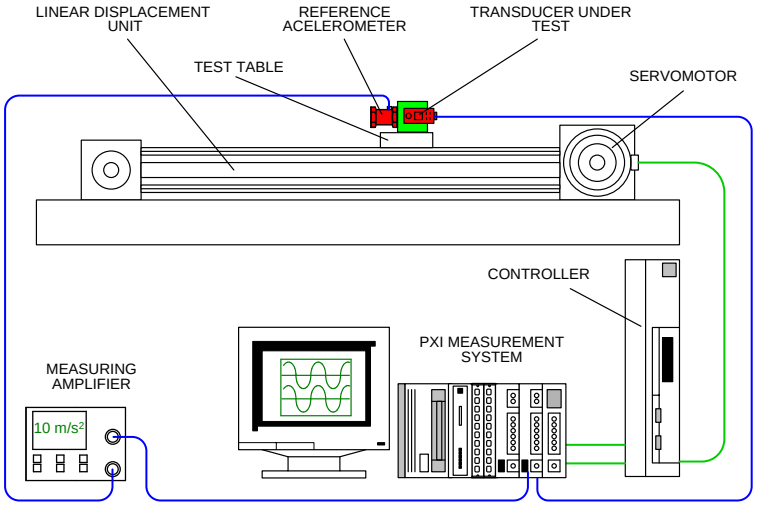


Fig. 46. Diagram of the calibration set-up for frequency range 1Hz – 10Hz.

Fig. 47. Low frequency acceleration calibrator.

Calibration system for pressure sensors and transmitters

J. Żelezik

The measurement system for testing pressure sensors and transmitters (Fig. 48) is based on the set of computer controlled measurement instruments linked with personal computer, which takes complete control of the calibration (acquisition, analysis, documentation and presentation). It enables automatic calibration and measurement metrological characteristics of gauge and absolute pressure instruments – sensors and transmitters with standard signal output. An accuracy of the gauge pressure calibrator is 0.04 % in two ranges: 20 kPa and 200 kPa. The standard for measuring absolute pressure range 1100 hPa has accuracy 0,01 %.

The laboratory is equipped with a climate chamber Feutron, which allows temperature characteristics of the pressure instruments test end temperature errors compensation. The system for a temperature compensation and normalization silicon piezoresistive pressure sensors has been developed in our institute and has been used in industry and education. We can distinguish three stages of operation of the system [II.26]:

- automatic measurement of metrological characteristics of all produced sensors,
- selection of compensating and correction elements,
- metrological properties checking of ready sensors, testing and preparing of documentation.

Other industrial use was to develop an automated system for final testing and calibration pressure transmitters with standard signals 4-20 mA and 0-20 mA.

Fig. 48. Calibration system for pressure sensors and transmitters.

Methods of primary calibration and temperature compensation in smart transmitters

J. Żelezik

In conventional transducer design, calibration and compensation are performed in the analogue domain. An additional elements (resistors, thermistors) are used for the compensation of temperature errors in conventional transmitters and performance is limited because of nonlinearity errors and elements accuracy. In smart transmitters design, digital trimming of sensors is performed with individual correction coefficients, which are stored in non-volatile digital memory after calibration and compensation. It lowers measurement errors and simplifies transmitters manufacturing.

There are two essential conceptions of measurement blocks construction of smart transmitters, referring to the way of the signal processing from sensors:

a) Analogue sensor signal processors (ASSP) digitally adjust the offset and gain of amplifiers, as well as sensor excitation, to achieve sensor calibration and temperature compensation in an analogue domain, without signal quantization.

b) Digital sensor signal processors (DSSP) convert the sensor signal into a digital domain using an A/D converter (ADC); perform calibration and compensation in a digital domain using microcontroller or custom logic; and, if needed, convert the compensated signal into an analogue domain using a D/A converter (DAC).

Ad a) A research on using the exemplary analog processor MAX1452 to the signal conditioning and the temperature compensation for the piezoresistive pressure sensors was carried out [II.95]. In this processor four digitally controlled analogue to digital converters DAC correct sensitivity and offset the transmitter as the function of the temperature by changing the offset and gain of the programmable gain amplifier and sensor supply current (Fig. 49). In the situation, when temperature errors are at first big and non-linear therefore applying the two-stage experimental procedure is giving the best results of compensation [II.94]: in the first stage compensation for linear components of errors, but the more further improvement behind the help of the multislope compensation. On account of measuring noises it is intentional so that identification experiment of the models needed for the compensation contains certain excess of measurements in relation to the number calculated coefficients.

Ad b) For smart transmitters with DSSP processors the primary calibration consists in calculation coefficients of reconstructing the digital model of the measurand on the base signals from sensors. A research on design of experiments for smart transmitters calibration was conducted [II.96]. The goal of the transmitter calibration is determination of the model, which minimizes the worst-case measurand reconstruction error over the measuring range. For the regressive polynomial model a criterion of G-optimal design is appropriate. When regressive assumption about errors aren't fulfilled, a more general criterion of the minimization of weights of calibration errors was proposed. It causes similar solutions. The designs with points evenly distributed over the range are correct only for low-order models.

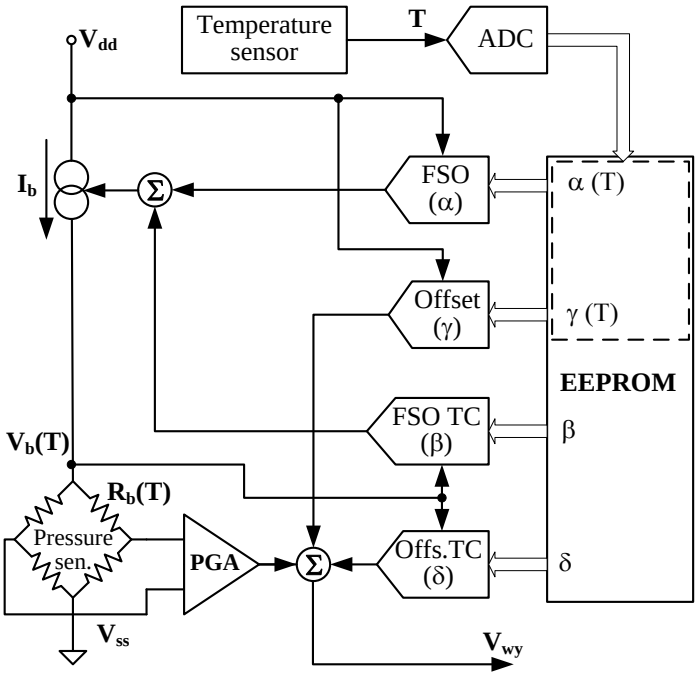


Fig. 49. Functional diagram of the MAX1452 processor for temperature compensation of piezoresistive pressure sensors.

Metrological properties of ion-selective electrodes

J. Frączek, A. Kozyra, A. Wiora, J. Wiora

Ion-selective electrodes (ISEs) are sensors utilized in measurements of chemical composition. When applied they cause measurements to be less expensive in comparison with other analytical methods. Unfortunately, their metrological properties are simultaneously worse; however they have been applied in many fields, e.g., environmental monitoring of pollution, food industry or medicine.

Researches in the field of potentiometric measurements conducted in the Institute are focused on the following subjects:

- multicomponent calibration and measurements of ISEs;
- dynamic properties of ISEs;
- investigations of physicochemical phenomena taking place during potentiometric measurements;
- assessment and minimization of concentration uncertainty obtained by potentiometric measurement.

In the recent years three Ph.D. theses have been set. Based on them, the monograph "Uncertainty evaluation for potentiometric measurements" (in Polish) was published (Fig. 50) [II.10, II.77].

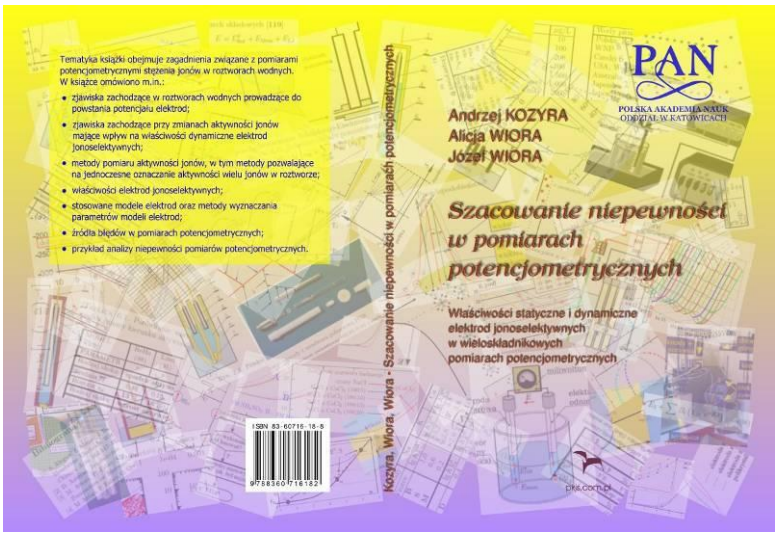


Fig. 50. Binding of published monograph.

A typical measurement performed by using ISE has to be preceded by sample pre-treatment eliminating other ions which interfere with result. Nowadays more selective electrodes can be used to determine ion activities in mixture. In multi-component measurements (MCM) an array of electrodes is applied. Each electrode potential is dependent on concentration of many ions species. The potential can be described by the semi-empirical Nikolsky-Eisenmann equation. When parameters of the equations describing the electrodes are known then the concentrations of ions can be calculated. However, before the measurement the electrode array should be calibrated because its parameters could have been changed.

Fig. 51. The measuring set-up for multi-component ion-selective measurements.

The multicomponent investigations are conducted in the institute laboratory (Fig. 51). The measuring set-up consists of ISEs, Pt100 temperature sensor, a six channel signal conditioner, 16-bit ADC with microprocessor based on communication module. All data is acquired by PC computer. The elaborated calibration procedures and multicomponent measurements of ion activity are implemented. A typical electrode response is shown in the Fig. 52. Each electrode is characterized by different parameters like: slope, standard potential, limit of detection and selectivity coefficients. It is very important to determine those parameters with proper accuracy. There are many

influences which disturb electrode potential such as temperature, electrode potential drift and contamination of the electrode membrane. It is very important to make recalibration with proper frequency. To perform it a set of standards having activities of individual ions enough varied to cover whole measuring range has to be prepared.

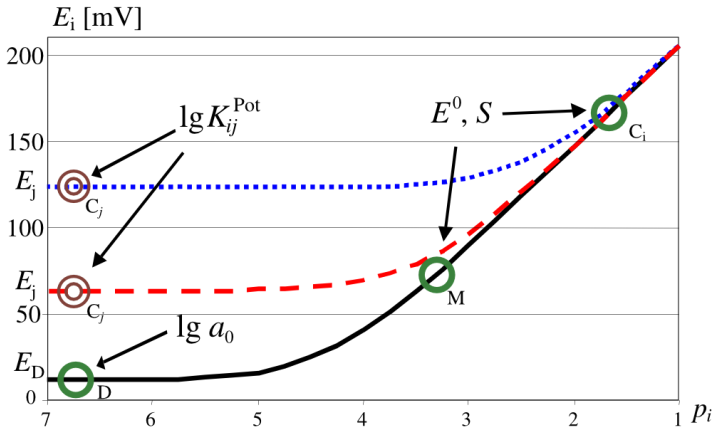


Fig. 52. Response of Na^+ electrode potential in pure NaCl solution (black solid line) and in presence of interfering ion: $p(NH_4^+) = 0.7$ dashed red line and $p(K^+) = 2$ dotted blue line. Circles represent exemplary calibration points.

In the investigations, the new calibration procedures which are simpler and more suitable for MCMs, are developed and tested [II.75]. In the procedures, several electrodes selective for different ions are calibrated simultaneously in the same standard. Obtained calibration parameters are used for determination of ion activities in many aqueous solutions.

Research on a dynamic of ion-selective electrodes (ISE) permits a description of their behaviour during measurements. One of parameters of the ion-selective electrodes is their response time t_{90}, which is defined as a time within which the electrode achieves 90% of the response signal. Another one is the delay time t_0. The overall response time is affected by a series of factors dependent either on the electrode (a type of membrane and electrode structure) or external factors (temperature and flow of the sample, time constant of the measuring instruments) [II.82].

Because of the complexity of the phenomena which occur in the measuring systems and many factors which influence the dynamic response of the electrode, the following conditions should be fulfilled:

- the influences of distractions should be eliminated or minimized,
- the flow of sample should be constant,
- the step change of sample activity on the membrane should be ensured.

Investigations are performed by using one of the recently elaborated measuring cells (Fig. 53). They allow the step change of two mixtures having different activity. The results of measurements are acquired by using JPomiar software which has been written especially for this purpose. Received real response time of ISEs is approximated using different dynamic models and is compared with t_{90}. The dispersion of issues is less then 7% for t_{90} for measurements made at the same conditions [II.83, II.84, II.85, II.178].

Nowadays, electronic devices (such as measurement amplifiers, analogue to digital converters, microprocessor systems) are constantly being developed. On the other hand, the progress in physical-chemical sciences allows the application of improved mathematical models. As a consequence it leads to an enhancement of the measurement quality [II.87].

a) b)

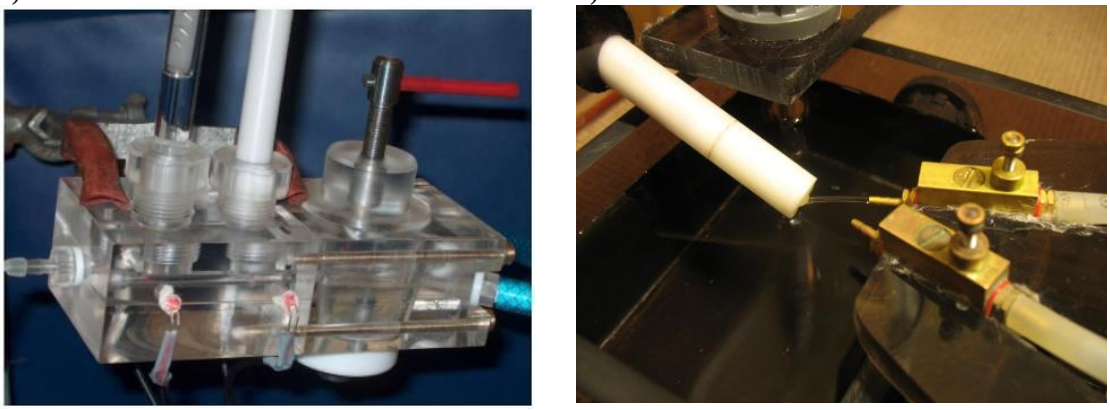


Fig. 53. The measuring cells for research on a dynamic of ISE: a) with mechanically changed solution streams b) with electric valves changing the streams.

It is very important to order the already known static models of the phenomena which take place during the potentiometric measurements. Many things influence on the final result of measurement. However, if the maximum uncertainty of result is assumed, it is not necessary to take into consideration all of these influents. Otherwise the obtained mathematical model would become needlessly complex [II.87].

Calculations and simulations of the measured quantity value as a function of the changes in influents are performed. In this way the final uncertainty is estimated. In the next step the application criterion of models is formed. The nature of the studied phenomena is strong nonlinear, hence there are many difficulties. One of them can be the determination of the calibration coefficients, which can be obtained either by the iterated numerical solving or by the application of the artificial neural network [II.88, II.179, II.180].

Sensors and techniques for concentration measurements of chemical substances

J. Wiora, A. Wiora, A. Kozyra, T. Grychowski, W. Ilewicz

The measurements of chemical substances are very important in the industry because of controlling the product quality [II.10]. The Institute's laboratory is equipped with high class measuring devices used for scientific and didactic purposes (Fig. 54):

- Investigations of water purity are conducted with the industrial ABB 4620 Conductivity Transmitter with industrial and laboratory measuring cell.
- pH and ion activity measurements are performed using one of pH/ion-meters: industrial ABB 4630 pH/Redox Transmitter, bench-top Orion 930 Ionalyzer or custom-constructed multichannel data acquisition system. Additionally, standard-sized ion-selective electrodes sensitive to H_3O^+, Na^+, Li^+, K^+, Ca^{2+}, Cl^-, NH_4^-, SO_4^{2-} ions are applied. Investigations on miniature solid-contact ion-selective electrodes are also conducted.
- A custom-constructed potentiostat is used for voltammetric investigation of bio-chemical substance dissolved in water.
- Concentrations of substances in air are measured using EMAG Center in Katowice measuring devices: MCO, MCO2, MO2, MCH, as well as multi-sensor Draeger Xam2000 and combustible gas interferometer [II.70].

- Analysis of carbohydrates mixture is performed using Varian CP3800 gas chromatograph with flame ionisation detector (FID) and using Chrom5 gas chromatograph.

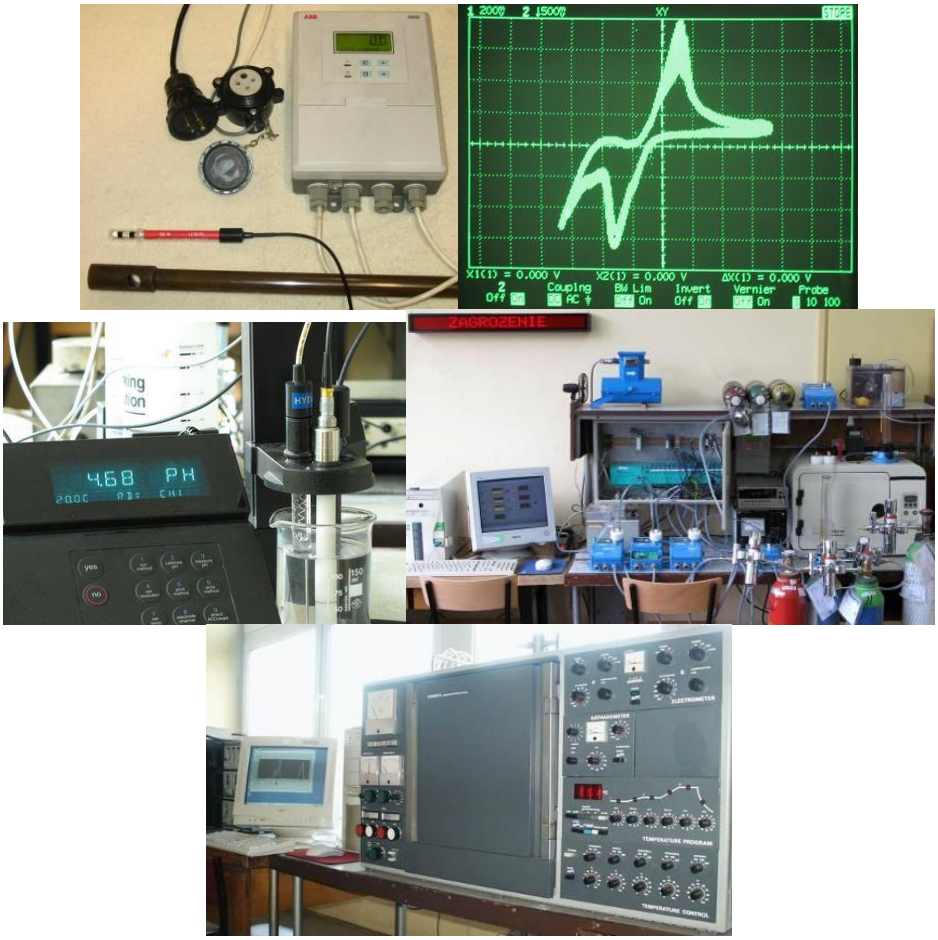


Fig. 54. From top left: ABB 4620 Conductivity Transmitter with measuring cells, Orion 930 Ionalyzer with ion-selective electrode, typical cycling voltammogram obtained by elaborated potentiostat, measuring installation with EMAG's coal mine devices controlled via ProfiBus, Chrom5 gas chromatograph.

Sensors for biomedical applications

D. Buchczik, A. Kozyra, R. Wyżgolik

In the topic the research activities for the low-frequency acceleration transducers for various biomedical applications and a dynamometer for investigation of the rehabilitation process are described.

Low-frequency acceleration transducers [II.164]. The general objective of this research activity is to carry out a comparative study of the acceleration transducers which have been constructed by Institute of Electronics, Silesian University of Technology, Gliwice, Poland. The transducers are intended for biomedical measurements such as an investigation of stability of a human body, an examination of a tremor of limbs, etc. Their performance has been optimized for both low acceleration and low frequency measurements.

The transducers are based on monolithic accelerometers of different manufacturers which have been soldered to printed circuit boards of similar size (approx. from 15x25 mm up to 18x35 mm, depending on the monolithic accelerometer). A specification of the applied monolithic accelerometers is presented in Table 1. Circuit diagrams of the transducers are shown in the Fig. 55 and the view of the transducers is presented in the Fig. 56.

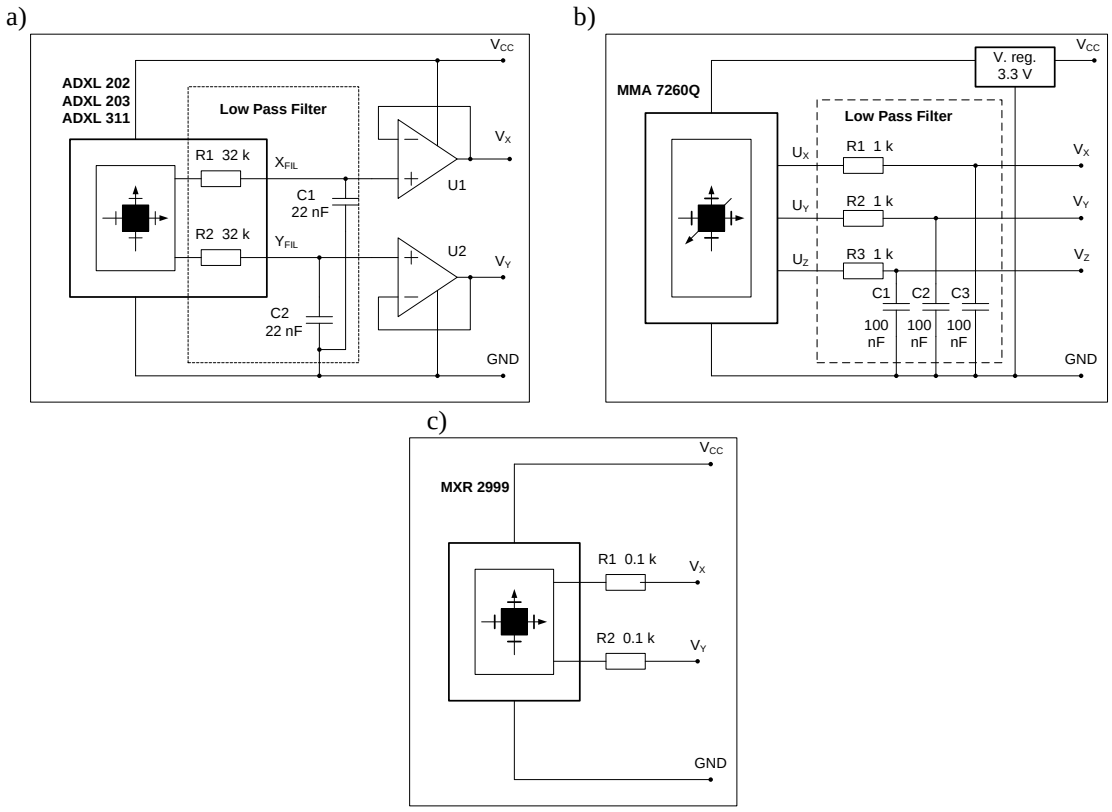


Fig. 55. Board schematic for acceleration transducers: a) based on ADXL 202/203/311, b) based on MMA 7260Q, c) based on MXA 2990.

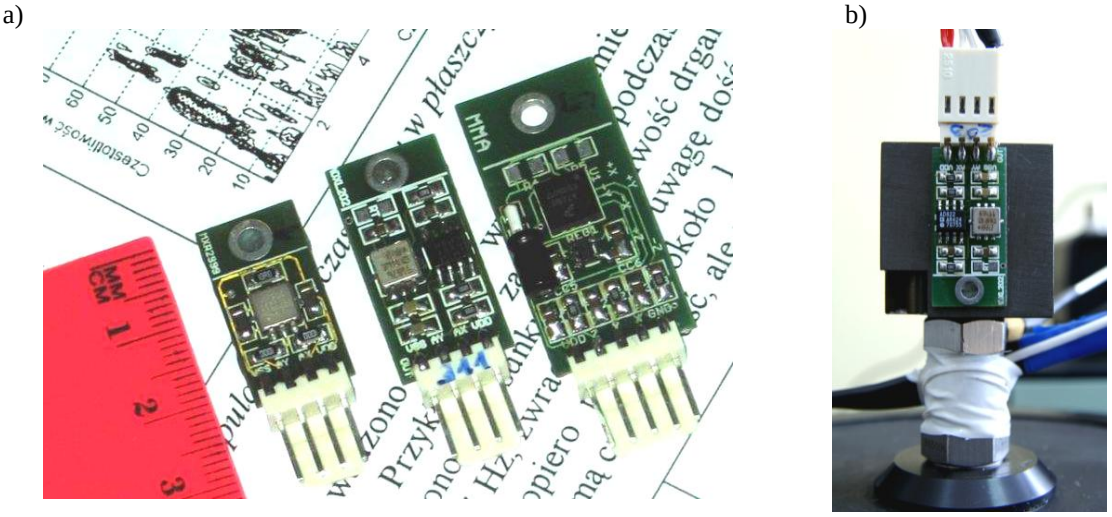


Fig. 56. Accleration transducers: a) from left, based on: MMA 7260Q, ADXL 202, MXA 2990, b) view of the ADXL 203 based transducer on the calibration set-up.

All of the transducers (except based on MXR2999) have a frequency range narrowed to 200 Hz using a low-pass filter. A bonding of the monolithic accelerometers (and additional elements such as constant-voltage regulators, low-pass filters, sockets, etc.) with the circuit board as well as circuits that modify characteristics of the monolithic accelerometer are main reasons to determine metrological characteristics and to carry out the comparative study of the transducers.

Calibration of the transducers was performed using a calibration set-up that was equipped with the B&K 8305S reference accelerometer coupled with the B&K 2525 measuring amplifier. An output voltage of the transducers was measured using the HP34401A multimeter as well as the NI-PCI 6221 data acquisition card, which was used for a noise waveform acquisition. The TDS 2004 digital oscilloscope was used for checking output waveform of both the reference and the under test transducers. The B&K 4809 vibration exciter coupled with the B&K 2706 power amplifier and the HP 33120A digital waveform generator. The reference accelerometer was mounted on a test table of the vibration exciter. On a top mounting surface of the reference accelerometer there was fixed a triaxial mount that enables easy positioning of the tested transducer. The PCB petro wax was used to fix the tested transducer on the triaxial mount.

Table 1 Short specification of the applied monolithic accelerometers. (a_{max} – acceleration range, S – nominal sensitivity at 0 Hz, for power supply voltage 5 V and 3,3 V for MMA7260Q, f_{max} – frequency bandwidth without external low pass filters).

Type of the monolithic accelerometer	a_{max} [m/s^2]	S [mV·s^2/m]	f_{max} [Hz]
ADXL202 (Analog Devices)	20	31,4	6000
ADXL203 (Analog Devices)	17	31.4	2500
ADXL311 (Analog Devices)	17	100	3000
MMA7260Q (Freescale)	15	80	350(XY)/150(XY)
MXR2999 (Memsic)	10	100	17

Dynamometer for investigation of the rehabilitation process. The advance in improvement of the rehabilitation methods demanded equipment for certain evaluation effects of rehabilitation. The general objective of this research activity is to develop measuring equipment for investigations performed in Chair of Ergonomic, Prostheses and Orthoses in Academy of Physical Education in Katowice [II.76].

The push-pull dynamometer had been developed to investigate patient's muscle strength. The dynamometer circuit is based on the ADμC845 microconverter (Fig. 57a). Microconverter consist of two precision 24-bits analog to digital converters and most element necessary to build measurement devices. As the strength sensor the Magnetron KMM20-2kN strain gage load cell had been applied. With that load cell dynamometer has ±2 kN measurement range with uncertainty better then 0,2% of the range.

Reading of the values of force and maximum force can be done on the LCD display (Fig. 57b). It can be difficult to read measurements on the display during exercises. The application of the wireless data transmission between the dynamometer and computer allows users to record and make analysis of rehabilitation process on computer. Application in LabVIEW was created for analysis of data from a dynamometer (Fig. 58).

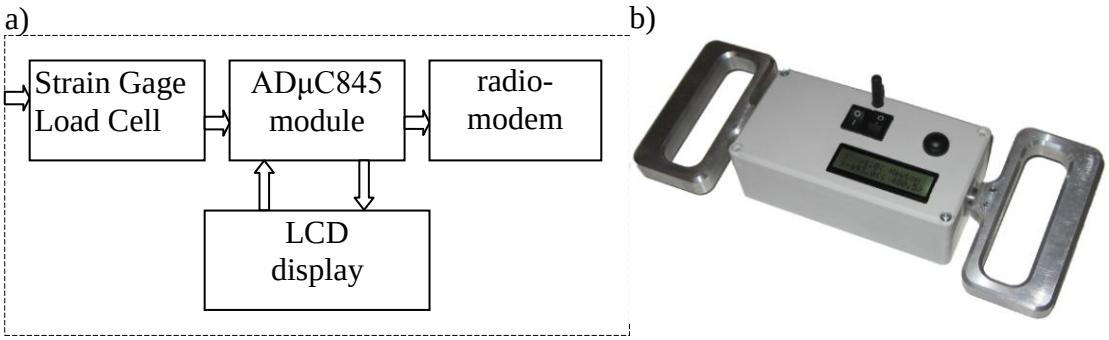


Fig. 57. The Push-pull dynamometrer: a) The block diagram; b) View of the dynamometer.

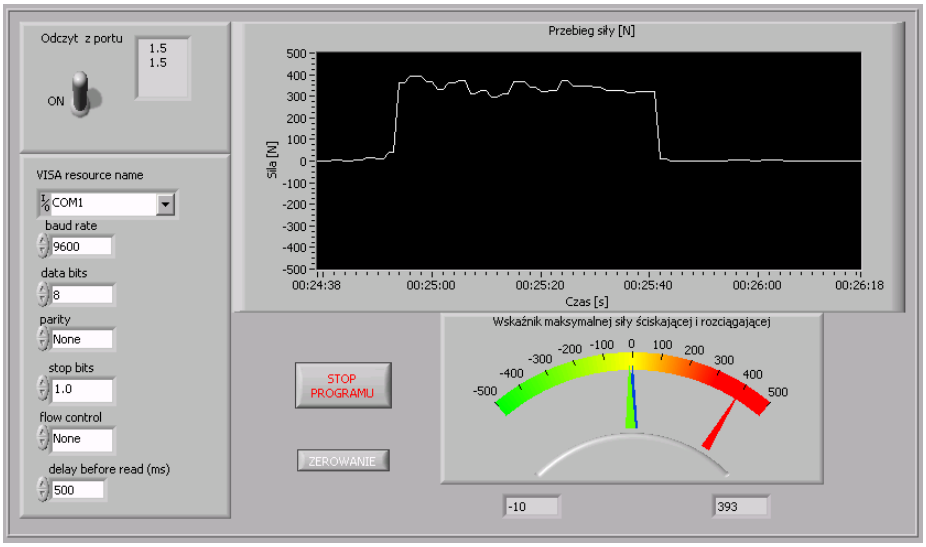


Fig. 58. The application allowing the measurement data acquisition from the dynamometer.

System for determination of range of motion of human joints is planned to develop. In that system human limb will be moved and the resistance of tissues will be measured.

Smart transducers and interfaces

R. Wyżgolik

Today, many different, directly incompatible industrial buses have been promoted and implemented. Different busses require a special gateway technology for interoperability. The IEEE 1451 Standards for Smart Transducer Interface for Sensors and Actuators is the proposition to overcome the problem. The standards define a set of interfaces for connecting the transducers1 to different systems: microprocessor-based, instruments, field networks, etc. The idea of the standard is presented in the Fig. 59. It is possible to disconnect the transducer form one network and connect it to another one, where it is self configured, so the transducer interface is manufacture independent. The concept of NCAP – Network Capable Application Processor, which acts as a bridge between the network and the TIM – Transducer Interface Module has not been accepted by the market. The self identification of the transducer is based on TEDS – Transducer Electronic Data Sheet concept introduced by the standard. There is an old version of the

TEDS, described by the IEEE 1451.2 (1997) standard and more flexible, described in the IEEE 1451.4 (2004).

The main objective of the IEEE 1451 Standards for Smart Transducer Interface for Sensors and Actuators is to simplify transducer connectivity to existing networks [II.92]. At present, the family of IEEE 1451 standard is divided into seven parts, where four are approved as the standards and three are in proposal state. The approved standards are: IEEE 1451.1, IEEE 1451.2, IEEE 1451.3 and IEEE 1451.4, while the proposed are: IEEE P1451.0, IEEE P1451.5 and IEEE P1451.6 (P denotes the proposal). The general concept of the IEEE 1451 family of standard is presented in the Fig. 60.

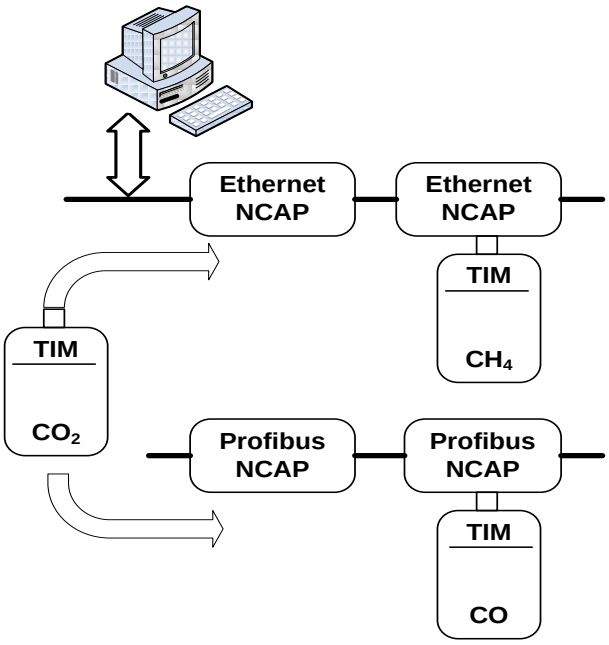


Fig. 59. The concept of the plug-and-play sensors.

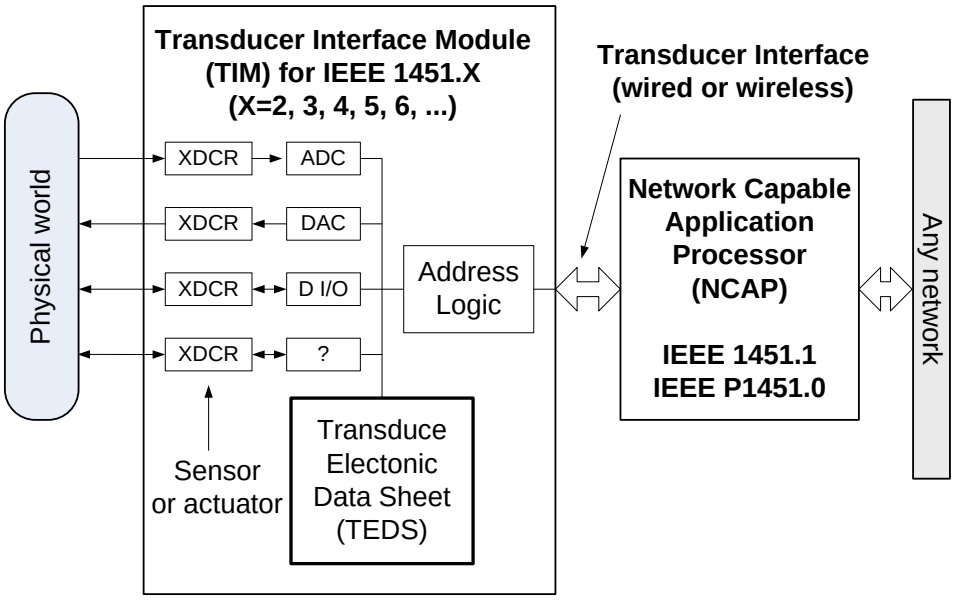


Fig. 60. IEEE 1451 concept diagram. In the case of IEEE 1451.4 the NCAP may be replaced by a measuring instrument.

The example of the IEEE 1451.4 measuring system used in our laboratories (presented in the Fig. 61), consist of PC based computer equipped with the DAQ board and IEEE 1451.4 dedicated input panel with signal conditioning modules for strain gauges, temperature sensors as well as universal feed through modules [II.91].

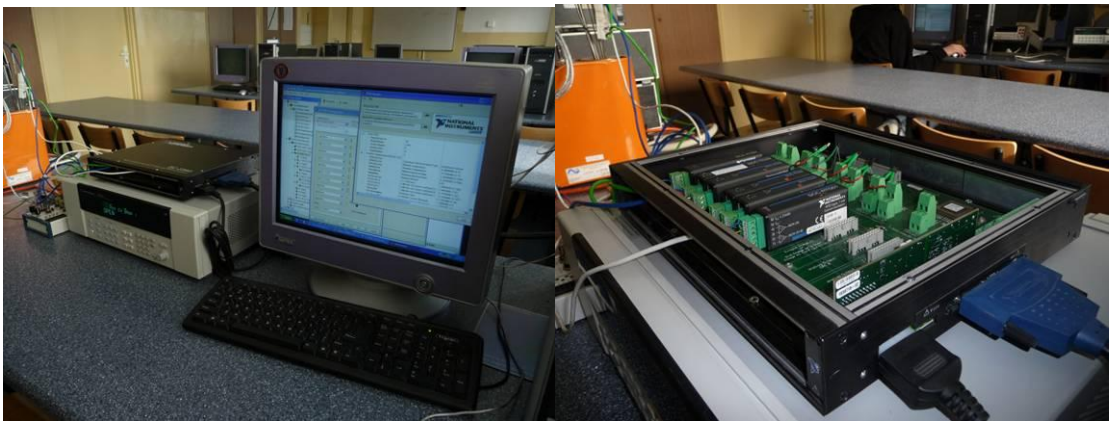


Fig. 61. IEEE1451.4 system with signal conditioning modules.

METROLOGY AND MEASUREMENT SYSTEMS

Analysis of the complex chromatographic data

W. Ilewicz

The research covers problems of analysis of complex chromatographic data. Complexity of the data is caused by a poor separation during the chromatographic analysis of mixtures with many components (like for example in environmental analysis or DNA), baseline drift, random noise. As a result peaks in the signal are overlapped so that direct accurate quantitative analysis is impossible. Research is focused on invent and testing algorithms of processing of chromatographic data and development of software for full automatic analysis of such a data. Algorithms like: signal smoothing [II.71], recognition, modelling and correction of base line, peak detection, segmentation of chromatogram into separate parts, peak modelling and peak parameters estimation by means of LSQ methods and similar, identification of mixture components, are taken into consideration.

The research is supported by two chromatographic stands which are sources of real chromatographic data used for purpose of the algorithms testing. First stand consists of Varian 3800 Gas Chromatograph equipped with Flame Ionisation Detector and a capillary column of type WCOT Fused Silica CP-Sil 5 CB. The chromatograph go along with a computer system and a specialized software for the chromatographic data analysis. The second stand consists of CHROM5 gas chromatograph with FID and a packed column.

As a result of research there are developed two computer programs, first in Matlab environment and the second one in WWW environment (using PHP) able to do fully automatic analysis of chromatograms.

The research is continued with respect to speed up computation (for example by parallel programming) and adapting of AI to improve capabilities of software.

Fig. 62. Chromatographic stand with Varian 3800 Gas Chromatograph.

Development of the system for seismic event detection in Polish coal mines[1]

R. Wyżgolik

Coal-mining leads to arising the varied of dangers. One of the most important is seismic events due to stress. This events – mainly rock mass vibration and tremors – can produce rock bursts. The prediction of occurrence of mining rock bursts is indisputable the most important for the safety of mining and protection of human lives. Therefore the important is to record these events and localize them. Various apparatus works at mining tremor stations to register this events.

The seismic signals, which contain information about seismic event, consist of several different phases (waves). For location methods the most important are P and S phases (see Fig. 63). In Polish coal mines, where only the one-component seismograms are registered, the most commonly used is P phase time arrival method, where at least 5 time arrivals are needed. Therefore signals are registered in 8 up to 16 channels.

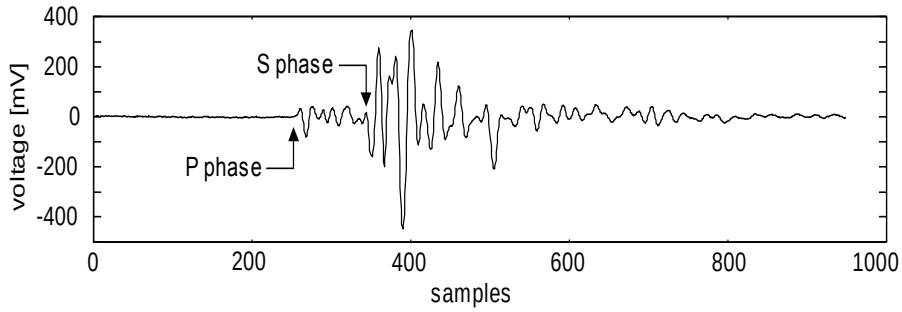


Fig. 63. Example of one-component seismogram registered in a coal mine.
The P and S phases times arrivals is depicted.

[1] Research preformed in cooperation with J. Koza from Coal Mine "Wujek", ul. Wincentego Pola 65, 44-596 Katowice, Poland and A. Augustyniak from Sterlab, ul. Kępowa 29, 44-583 Katowice, Poland

There are various systems currently being used in Polish coal mines to collect the data form the seismic events. Most of them use analog transmission from remote seismic station to data logging system. We describe here the system with digital transmission [II.93], which block diagram is presented in the Fig. 63.

The remote seismic stations work underground in hazardous area (gas explosive) and are equipped with a sensor (seismometer or geophone), data acquisition unit and digital communication unit. The data are acquired in real time, with sampling frequency up to 1 kHz, and continuously transmitted to the master station (MS). The transmission line length is up to 10 km. There are 8 up to 16 remote stations. Each is synchronized, together with master station (MS) using the GPS clock.

The system meets the requirements for typical dynamic range of energy of seismic events in Polish coal mines. The energy of the lowest is about 10 J while the strongest events has energy about 1010 J. Therefore the dynamic rang is about 90 dB, which gives us the required resolution of the A/D conversion at least 15 bits.

The master station (MS) work together with the event detection module (EDM) which is also responsible for data transmission to the PC. One of the problems is large number of seismic events occurring in the mines. The acquired digital data carry redundant information. The difference between consecutive sampled seismic signals is mostly lower then 8 bits. The speed of signal growth is limited by an antialiasing filter at each remote station. To obtain the optimum transmission speed, digital data should be already compressed at the remote seismic station. If the transmission error occurs or the difference between the samples is higher than 8 bits, the transmission must be repeated. In this case the data are carried with delay in a „quasi real" time mode. If the difference between the consecutive samples is in excess of 8 bits, the measurement absolute value ought to be transmitted.

The weakness of this seismic system is low transmission speed between the master station (MS) and the EDM module as well as between the EDM module and the PC. The reason is the RS232 interface used for data transmission.. Also the EDM module misses some seismic events, especially low-amplitude. Another problem is the detection of some false events as the seismic events (eg. mechanical coal miner), which sometimes occurs. Therefore the aim was replace the master unit (MU) and the EDM modules (see Fig. 64) with CAN bus, implemented in the digital receivers modules (RC). Such a solution should enable direct transmission of the signals from the remote seismic stations to the PC. In this case, the PC should take over the event detection task.

Up till now we have built the new RC module, equipped with 8 bit microcontroller with built in CAN 2.0B controller. It seems that the throughput of the CAN is sufficient to implement the event detection and seismic events identification algorithms in the PC. The next advantage will be the 24 bit nominal resolution A/D converter in the new version of the remote seismic station. The real dynamic range will be then about 120 dB.

In addition an analogue data logger has been developed for the system. The data logger is thought as the complement for the seismic transmission systems currently working in coal mines as well as the complement for currently developed new version of the DTSS system from EMAG. The complete system is presented in the Fig. 65.

The data logger consist of the PC equipped with the Data Acquisition board (DAQ) – NI PCI-6220 from National Instruments, the dedicated software and the HP Designjet 130nr printer. The future version will be also equipped, depending on the requirements, with CAN 2.0B communication interface. Some of the main features of the data logger are as follow:

- up to 16 analog input channels with voltage range +10V or –10V,
- 16 bit resolution, very flexible sampling rate,
- hardware or software triggering,
- data logging on hard drive and on-line printing of seismic events.

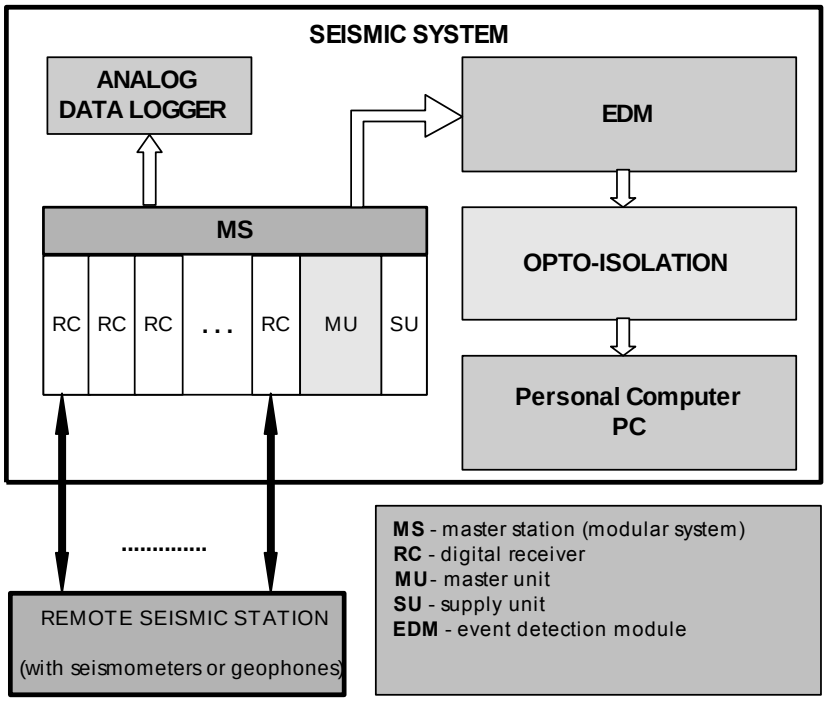


Fig. 64. System for seismic event detection in coal mines.

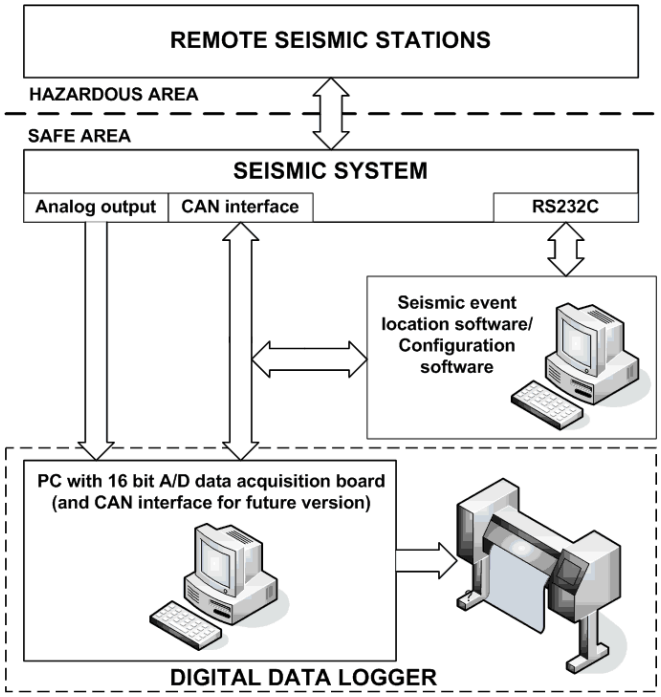


Fig. 65. Seismic system with new digital data logger. The CAN interface is for future version of the seismic system.

Dispatcher's support software for gas hazard detecting

T. Grychowski

There were proposed new solutions based on quality analyses of measured data**.** Basing on the knowledge of the operator there has been built a fuzzy approximate reasoning system, which is used to improve reliability in a decision making process and a hazard identification. Metrological properties of measurement devices on which the operator's decisions are made have been tested. The following problems have been analyzed: the existing system of controlling of mine atmosphere, specific conditions of operator's work and his subjective interpretation of measurements, measuring ways and techniques of a mine atmosphere and its qualities. Implemented algorithms will monitor the endogenic and egzogenic fire hazard by estimating the difference of carbon oxide, concentration of carbon dioxide, oxygen and quantity of carbon oxide. These algorithms will allow detecting explosive mixtures by monitoring methane and oxygen concentrations as well. Used sensors are especially built for air hazard control. For example the carbon oxide sensor detect fire in precisely part per million scale. Example of dispatcher's support software is illustrated in the Fig. 66.

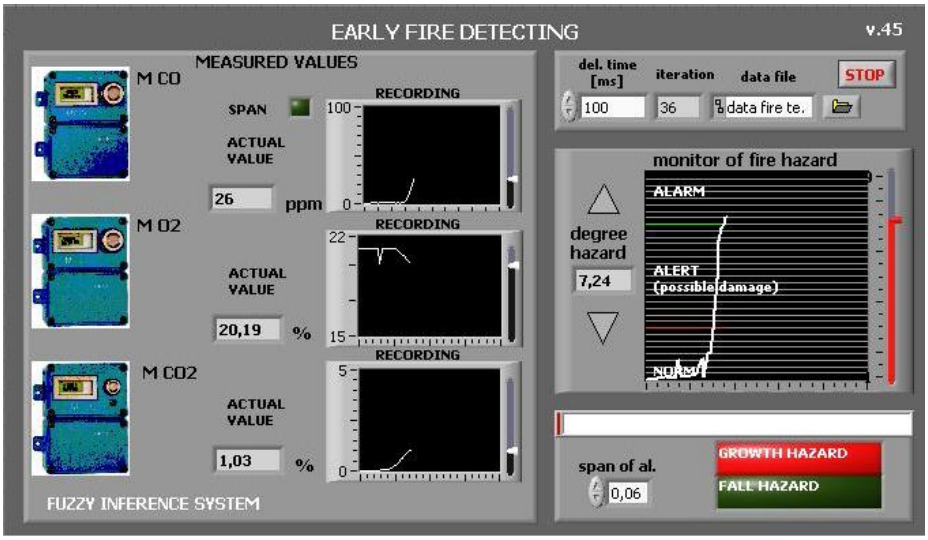


Fig. 66. Dispatcher's support software in LabVIEW environment.

The graph "monitor of fire hazard" shows the egzogenic hazard trend (result obtain from fuzzy algorithm) allows aggregation of the data from three measuring devices and to follow the hazard level fluently [II.32]. Fig. 67 presents an example of the tuning panel of endogenic fire support system created on the basis of the information from mine regulations. The panel examines the influence of fuzzy processing mechanisms on the result of inference and it presents the construction of knowledge base as well as membership function [II.70].

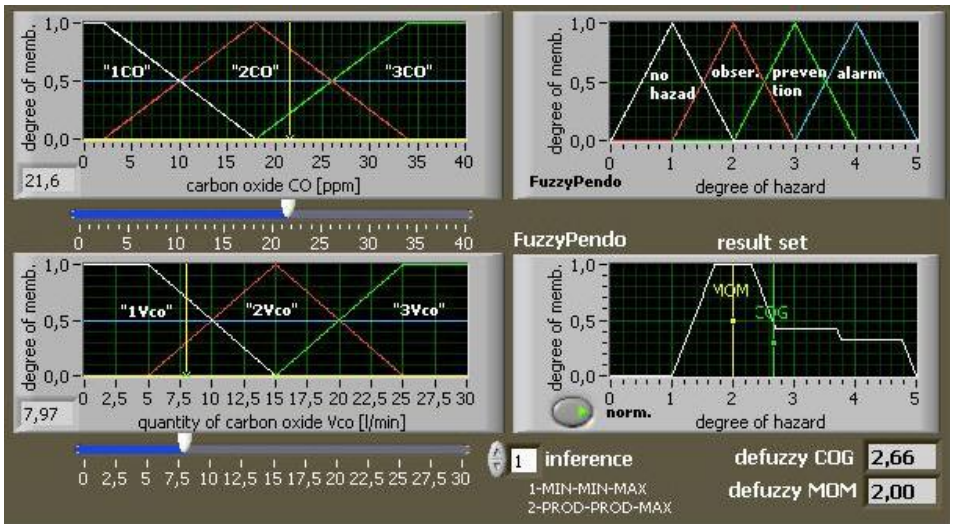


Fig. 67. Tuning panel of endogenic fire hazard support system**.**

Experimental system including measuring equipment for control of parameters of the mine atmosphere

J. Frączek, T. Grychowski

The laboratory system was build to control the physical parameters of the air. In the Fig. 68 a block diagram of the system is presented. The measuring experimental installation includes the Pepperl+Fuchs "Remote Process Interface" intrinsically safe system and mine sensors from EMAG Center to control toxic and combustible gases which appear in mine atmosphere [II.70]. RPI system was equipped in Profibus DP interface. This system enables simulation of gas hazards, testing software supporting the operator based on fuzzy logic in real time, as well as checking and calibration gas sensors. The measuring installation is used for research work, classes with undergraduate students. The graphics LabVIEW environment of the National Instruments was used to build the software system.

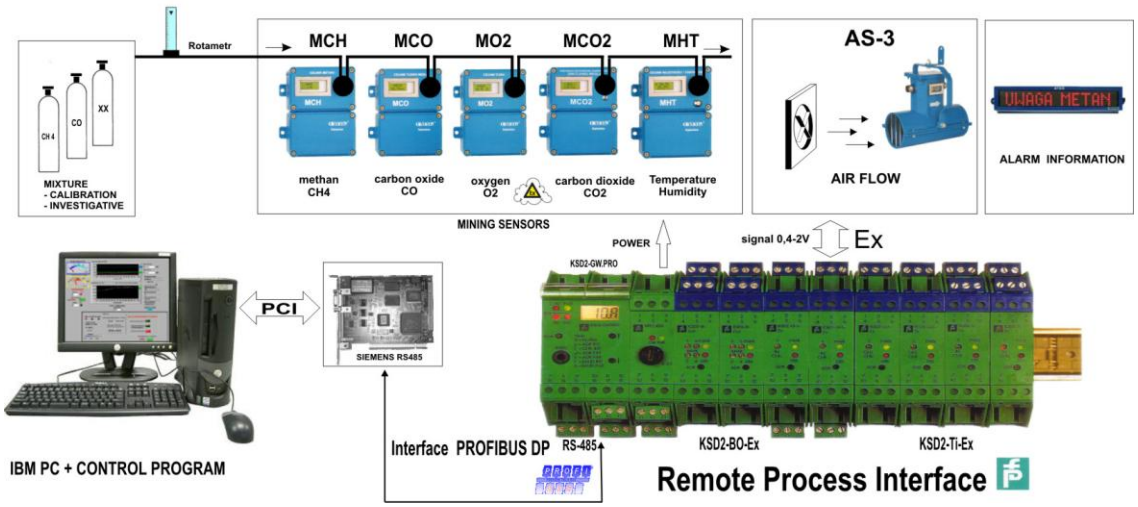


Fig. 68. The laboratory system with mining sensors and intrinsically safe system.

Flow measurement and mathematical modelling of flowmeter sensors

W. Błotnicki, S. Waluś

The flow measurement laboratory consist of three stands for research of metrological properties of: 1) water flowmeters in closed conduits, 2) air flowmeters, 3) water flowmeter in open channel.

1) The installation consists of two tanks, the pipeline with primary devices of flowmeters and the stand with secondary devices of flowmeters and computer system. The main part of this stand is shown in the Fig. 69.

This installation enables the calibration of flowmeters for volume flow-rate to 10 [m^3/h] and an uncertainty of ± 0,2% may be achieved. The measuring data can be read by observer and are transmitted to the computer for further calculations. In the measuring conduit are installed following flometers: Promag 30F (ENDRESS + HAUSER), insertion turbine flowmeter BEP 5 MK II (BESTOBEL), electromagnetic flowmeter MPP-02 (ENKO), ultrasonic flowmeter UF-311 (ULTRAFLUX), ultrasonic flowmeter SONIX 3D (SONIX). The level of the water is controlled by the ultrasonic level meter 192L1270 (DANFOSS). With help of this stand the Coriolis flowmeter was investigated and were made some researches of tracer method, which is used for flow-rate measurement in an open channel. Open channel is connected with this installation [II.78]. The measuring results give some data for velocity profile estimation [II.177]. The experiences with this installation helped to write some guidelines for flowmeter evaluation [II.21, II.72, II.80].

2) The installation consists of the pipeline with primary device of orifice flowmeter and enables to research thermoanemometer with surface sensor and impact tubes. It allows to investigate the velocity profile, what give possibility for further theoretical researches [II.79, II.81, II.176]. The installation is shown in the Fig. 70.

3) The installation consist of the model of open channel with weir, rotameter as the reference flowmeter and ultrasonic level meter. The stand enables to use various weirs and estimate their characteristic. Level meter enables the flow-rate measurement on the base the weir characteristic [II.165]. The overview of the installation and the scheme of the weir is shown in the Fig. 71.

Fig. 69. Overview of the installation for researching of water flowmeters properties.

Fig. 70. Overview of the installation for researching of air flowmeters properties.

Fig. 71. Installation for the flow-rate measurement in the open channel.

Intrinsically safe industrial measurement systems equipped with PROFIBUS DP

J. Frączek, T. Dzieżok, T. Grychowski

Integration of intrinsically safe field instrumentation into industrial communications networks requires including into consideration the safety integrity level (SIL) [II.69, II.168] which combines: safety at work in peculiar hazardous atmospheres [II.139], fieldbus intrinsically safe concept (FISCO), reliability [II.166], functional safety [II.167], Critical Human Error Rate [II.68] and transmission systems using optical radiation [II.66, II.67, II.170].

Research is first focused on safety and maintenance problems in coal mining and energetic industries. At both fields use of advanced functions of modern remote input-output stations and smart control algorithms for plant maintenance optimization may be efficient and economical. Remote input-output systems generally perform analog to digital and digital to analog converting function. It is the gate between control system and transmitters installed on controlled plant. Modern solutions of this systems are equipped with intrinsic safety barriers, required at hazardous atmospheres and HART multiplexer for on-line digital communication to current transmitters. Systems called "Remote process interface" are designed for the control room Zone 1 and Zone 2. Activating this feature engage possibility of logging not only measurement data, but other information, like transmitter diagnostic byte or enclosure temperature etc. Complete control system has been built, using measurement transmitters and two remote in-out stations coupled by Profibus DP. As a DP-Master unit, PC computer with expansion card is used [II.70].

Wide range of measurement devices have been tested in this systems, including specialized transducers designed for mines and HART pressure transmitters. For example, one of the system was build to control the physical parameters of the air. The research works with use of the system have been focused on test of metrological properties of intrinsically safe gas sensors to control toxic and combustible gases which appear in mine atmosphere as well as on application of artificial intelligence for improve reliability [II.32]. Supplementary data from SMART transmitters (sensors and actuators) would be used in estimation of current availability factor of hole system and particular transmitter. There is a conception of algorithm based on Weibull's distribution of a time to failure and using HART data for computing economy optimal maintenance schedule for subsystems of plant.

Least median of squares method in calibration of measuring instruments

D. Buchczik

Regression analysis is a fundamental statistical tool commonly applied in a calibration of measuring instruments and systems. The last squares (LS) method is generally used because of tradition and computational simplicity. However there exists danger of occurrence of outliers, which may totally spoil LS analysis. To avoid this problem statistical techniques called robust regression have been developed. One of the most advanced and promising robust procedure is the least median of squares (LMS) method. The LMS is based on the minimization of the median of the squared residuals, in contrast to the LS method, where the sum of the squared residuals is minimized. Due to the computational complexity of the LMS some statistical properties of the method have not been determined yet.

Evaluation of calibration lines of measuring instruments determined with a use of the LMS method is essential [II.59]. Standard error of mean response might be used to estimate the quality of the calibration lines [II.58]. An idea of estimation of the standard error of mean response in case of the LMS method has been examined. A priori procedure enables to perform the estimation before the measurements. A posteriori procedure is used after the measurements, when there are available its results. The procedures a priori and a posteriori have been verified in simulation research. The estimated and calculated on simulation values of LMS standard errors of mean response have been compared to proof correctness of the estimation method. Relatively small errors of estimation confirm that the procedure is correct.

Level measurement

W. Błotnicki, A. Kozyra, S. Waluś

The level measurement is one of most common industrial measurement. The level measurement laboratory stand is divided in two parts: first one is for calibration of level transducers (Fig. 72) and second one is for research on the ultrasonic level transducer. Properties of various level meters are introduced in [II.22].

Fig. 72. Laboratory stand for investigation of properties of level transducers.

On the first stand different types of transducers can be used. Stand allows comparing the differences in measuring properties for different measuring methods. On the laboratory stand there are two Endress & Hauser smart level transducers: differential pressure Deltabar S FMD78 and guided radar Levelflex M FMP40. Signals from transducers are transmitted to computer application. The special calibration procedure can be performed on the stand and then values of total error and it compounds like: repeatability, linearity and hysteresis are automatically determined.

The second part of the laboratory stand is a piece of greater installation, prepared for investigation of open channel flow measurement. On this stand there is a fixed ultrasonic level smart transducer EchoTREK STP-380-3. Laboratory stand allows checking the following parameters:

- check accuracy of level measurement,
- check how wrong angle mounting influence on the measure accuracy,
- check how obstruction on ultrasonic wave influence the measure accuracy,
- check how froth up water surface influence the measure accuracy.

Additionally on the stand there is an oscilloscope. It is connected to ultrasonic level transducer. On the oscilloscope one can observe send/read signal and measuring gate signal. More information about research on this stand is in literature [II.56, II.57, II.181].

Microphone array for measurements of sound pressure levels

K. Czyż

MMatrix is data acquisition system employing large microphone array for measurements of sound pressure level over an enclosure. System was designed at the Institute of Automatic Control, Silesian University of Technology, Gliwice, Poland. Multi-channel acquisition and signal processing system was developed on the basis of multiprocessor computer with NI PCI-6289 data acquisition card. Maximum number of processed analogue channels is limited by the acquisition card speed. The system is capable to pre-process and record up to 16 continuous analogue signals at 32 kHz sampling rate, all the 128 channels can be processed at 4 kHz sampling rate. System software enables on-line presentation of measured pressure levels over an enclosure, spectral analysis and estimation of dimensions of zones of quiet created by ANC systems. An exemplary noise attenuation map obtained by the MMatrix system during the multichannel ANC system operation is presented in the Fig. 73 [II.104].

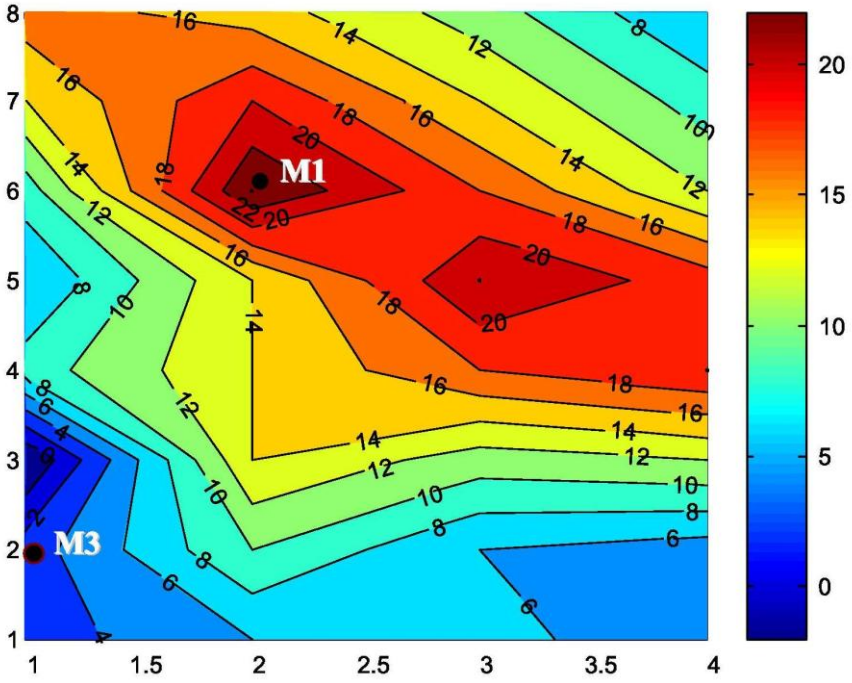


Fig. 73. An exemplary noise attenuation map obtained by the MMatrix system during the multichannel ANC system operation.

Measurement and control of the creep machine

J. Loska

The creep test is a test for checking new steel or other materials for creeping. This test takes a lot of time. The temperature are stabilized on the sample using thermocouples type S. The sample is strained using the lever arm, to the high level of stress. Data from creep tests are collected using an automatic system for supervision, control and visualization. This data are used for processing test results, creation of the data base and checking of the new materials for many parts of the industry.

This machine (Fig. 74) was designed for a very long term creep and stress rupture testing of metallic materials in accordance with PN-EN 1029. These special tests can run from a few hours up to and exceeding 100 000 hours. The special construction of this machine makes tests highly reliable.

Fig. 74. Creep and stress rupture test machine.

The system is equipped with:

- special tubular stoves with temperature ranges from 450 to 1050 °C with stabilization accuracy ±0.2 °C,
- extensometers for the test sample,
- lever arm loading system with a special assembly which automatically compensates elongation and keeps arm lever in the same position 0.1 mm accuracy,
- Thermocouples type S class 1, calibrated before measurement with 0.1°C accuracy,

- Linear inductive displacement sensors normally with 0.3% full scale accuracy, calibrated before test,
- PLC controller using 16bit analog cards for controlling and stabilizing the temperature to 1050°C, measuring displacement, compensates elongation.
- SCADA system for data acquisition, control and visualization using a pair of redundant servers
- Air-conditioning which stabilized the room temperature at level 23±3 °C

In 45-year of creep and stress-rupture testing history, machines are constantly rebuilding for new functionality in accordance with PN-EN 1029. Now is possible to control the test and access the data from the net using the secure channel.

System for monitoring climatic parameters in measuring laboratories

J. Żelezik

A purpose of the system is monitoring climatic parameters: the temperature, humidity and the barometric pressure in measuring laboratories. Monitoring is necessary at every examinations of the measuring apparatus, calibration of measuring instruments. It is required in particular in accredited measuring laboratories. The whole system was designed and realized from grounds in the Measurements and Control Systems Division. He is based on smart measuring transmitters – termohigrobarometers THB and termohigrometers TH with the serial interface and the MODBUS protocol. The multiparameter transmitters are realizing functions:

- Measurements of the temperature, humidity and the absolute pressure,
- Filtration; averaging measurements,
- measurand reproducing (also the temperature errors compensation and the correction of the nonlinearity error),
- communication through the serial interface according to the MODBUS protocol,
- the remote configuration;
- displaying results of the measurement on the local LCD display.

The most important metrological characteristics are given in the table 1.

Table 1.

Parametr	Barometer pressure	Temperature	Humidity
Range	750 - 1150 hPa	(-40) -10 - 70 °C	0 - 100 %
Accuracy	±0.3 hPa	±0.3 °C	±(2 – 4) %
Resolution	0.1 hPa	0.1 °C	0.1 %

A standard of the RS-485 interface was chosen as the physical layer of the network what is a most simple and at the same time fulfilling the requirements solution regarding the range, speed of the broadcast etc. The microcomputer fitted with the converter is a system controller. Software was realized with LabVIEW. The realized measuring network includes 6 laboratories located on two floors in the A building of the AEiI department and one measuring point outside the building as it was shown in the Fig. 75.

The system is working in the continuous way. Results of measurements are presented in the numeric and graphical form on the monitor of the system controller, as well as on the website: http://www.zpss.aei.polsl.pl/sp/. The user is able to look timing

diagrams of measurements through in the arbitrary, chosen horizon of the observation as it was shown for instance in the Fig. 76.

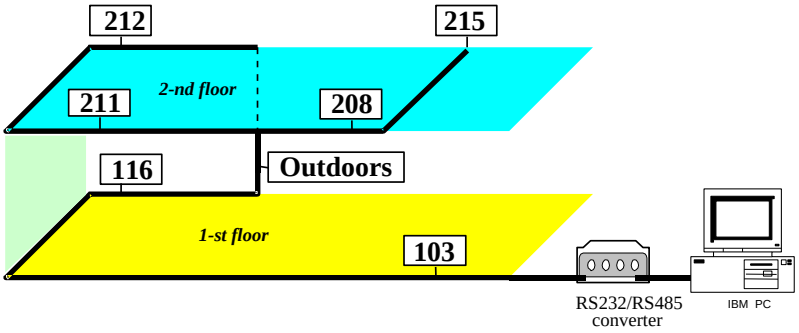


Fig. 75. Arranging elements of the system of monitoring in the building AEiI.

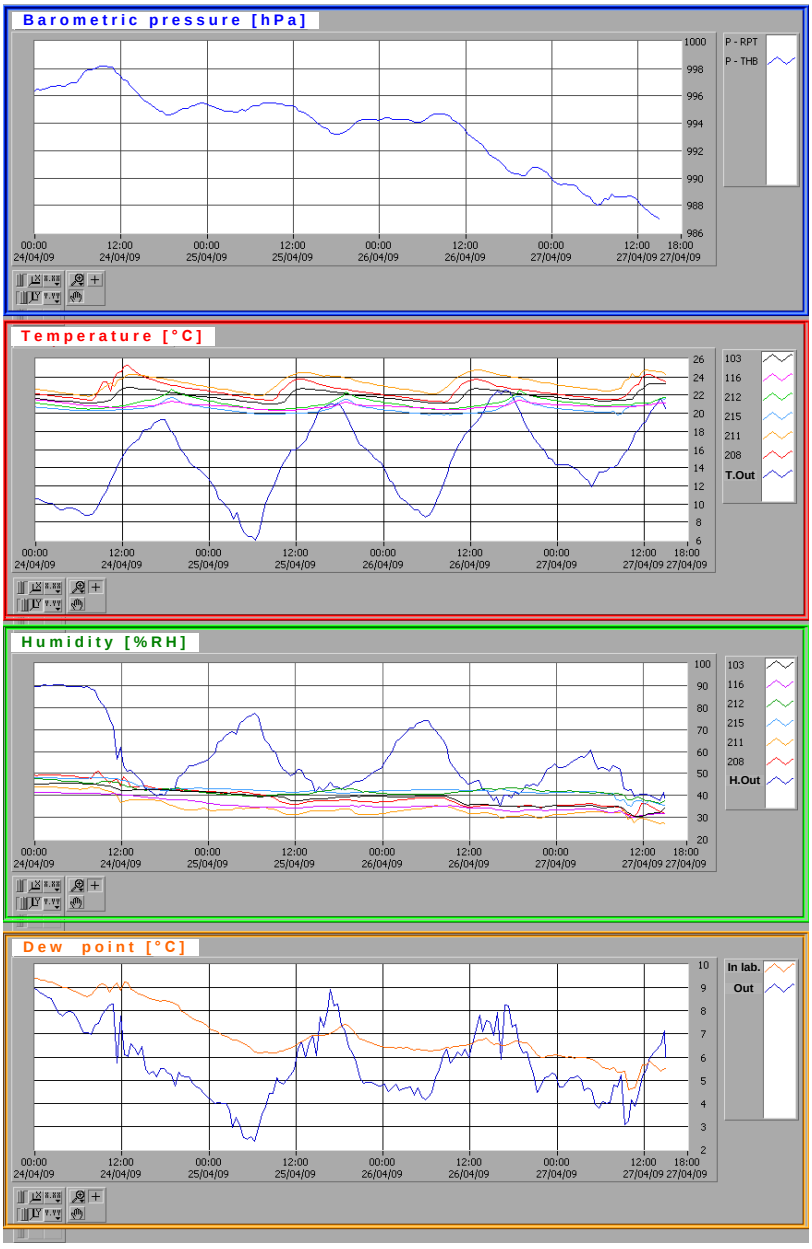


Fig. 76. Graphical presentation of results of measurements.

OTHER ACTIVITIES

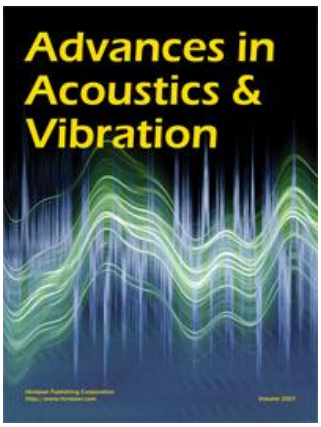
Periodicals

"Archives of Control Sciences"
Antoni Niederliński - Editor in Chief
Zbigniew Ogonowski - Assistant Editor

Prof. A. Niederliński is the Editor in Chief of Archives of Control Sciences (a quarterly of the Polish Academy of Science – committee of Automatic Control and Robotics). Dr Z. Ogonowski is the Assistant Editor of the quarterly. Every year 4 issues of ACS is published. In 2007-2009 there were total 84 papers published including 45 from the abroad (first issue of 2010 is also included). No. 2/2008 was a special issue devoted to "Constraint Satisfaction for Planning and Scheduling". Every paper is reviewed with two independent reviewers. All abstracts are available trough the Internet. See the ACS homepage http://ia.polsl.pl/acs.

"International Journal of Acoustics and Vibration"
Marek Pawełczyk – Managing Editor
Dariusz Bismor – Associate Editor
Krzysztof Czyż, Michał Wilk – Assitant Editors

The International Journal of Acoustics and Vibration is a refereed scientific quarterly publication issued by the International Institute of Acoustics and Vibration. The journal covers all subjects related to acoustics, noise and vibration. It is distributed to about 500 subscribers of 60 countries around the world. The Editorial Office has two divisions. One of them is held in Auburn, USA, and the other in the Measurements and Control Systems Group, Gliwice, Poland.



"Advances in Acoustics and Vibration"
Marek Pawełczyk – Associate Editor

Advances in Acoustics and Vibration is an Open Access refereed publication issued electronically by the Hindawi Publishing Corporation. The aim of the journal is to act as a platform for dissemination of innovative and original research and development work in the area of acoustics and vibration.

Conferences

"16th International Congress on Sound and Vibration – ICSV16"

Marek Pawełczyk – Congress Chair
Dariusz Bismor – Secretary of the Organising Committee
Małgorzata Michalczyk, Sebastian Budzan, Krzysztof Czyż – Members of the Organising Committee

ICSV16 was held in Kraków, Poland, 5 to 9 July 2009. It was a premier world event in the fields of acoustics, noise and vibration, with over 1000 participants from 53 countries and 20 exhibitions. It was within a series of ICSV congresses organised around the world, after Australia and South Korea. ICSV16 was organised under the auspices of the International Institute of Acoustics and Vibration (IIAV), Committee on Acoustics of the Polish Academy of Sciences, Polish Acoustical Society (PTA), AGH University of Science and Technology, Silesian University of Technology, in cooperation with: International Union of Theoretical and Applied Mechanics (IUTAM), American Society of Mechanical Engineers International (ASME International), Institution of Mechanical Engineers (IMechE) and European Acoustics Association (EAA).

The scientific programme included 56 Regular and 46 Structured scientific sessions, 7 keynote presentations as well as other events, like meetings of Editorial Boards of International Journal of Acoustics and Vibration, Journal of Sound and Vibration, Archives of Acoustics, meetings of the Executive Committee and the Board of Directors of the International Institute of Acoustics and Vibration, and meeting of the Main Board of the Polish Acoustical Society.

International Cooperation

1. Helmut-Schmidt-University of the Federal Armed Forces, Hamburg, Germany (Marek Pawełczyk, Jan Staniek)
2. Department of Mechanical Engineering, Aalborg University, Aalborg, Denmark (Marek Pawełczyk, Michał Wilk)
3. Union of Slovak Research and Scientific Associations, Slovakia (Zbigniew Ogonowski)
4. National Center for Research and Application of Renewable Energy Sources, Slovakia (Zbigniew Ogonowski)
5. Grant Agency of the Czech Republic (Zbigniew Ogonowski).

Cooperation with Industry

1. Elektrownia "Rybnik", Poland (Marek Pawełczyk, Krzysztof Czyż, Jan Staniek)
2. EMAG, Poland (Tomasz Grychowski)
3. „ENERGOPOMIAR" Sp. z o.o., Poland (Tomasz Dzieżok)
4. General Electric, USA (Ryszard Jakuszewski, Marek Pawełczyk)
5. IGLOO Sp. z o.o., Poland (Marek Pawełczyk, Jerzy Kasprzyk, Janusz Hajda)
6. Inova, Poland (Wojciech Legierski, Krzysztof Czyż, Marek Pawełczyk)
7. Kopalnia Wujek, Poland (Roman Wyżgolik)
8. Rockwell Automation, Poland (Marek Pawełczyk, Jerzy Kasprzyk)
9. „Sterlab", Poland (Roman Wyżgolik)
10. VIX Automation, Poland (Ryszard Jakuszewski, Marek Pawełczyk)
11. Instytut Metalurgii Żelaza, Poland (Jacek Loska, Zbigniew Ogonowski)
12. Ame Plus, Poland (Ryszard Jakuszewski, Wojciech Legierski, Jacek Loska, Krzysztof Czyż, J. Kasprzyk)
13. "ifm electronic" (Marek Pawełczyk, Dariusz Buchczik)
14. Danieli Automation (Marek Pawełczyk, Jerzy Kasprzyk)

Scientific Projects (Grants)

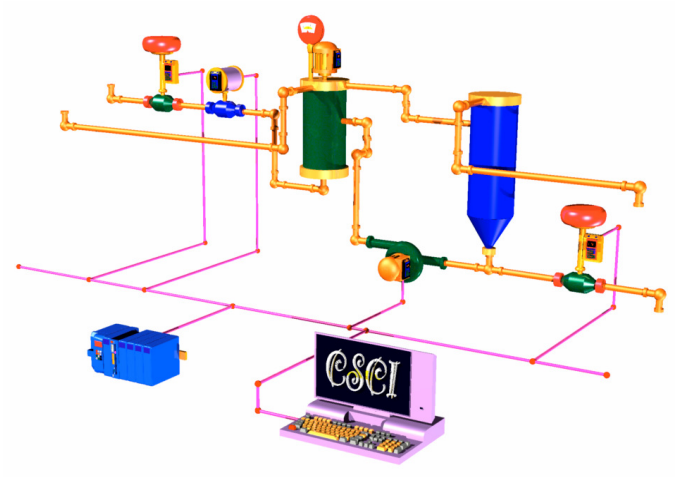
1. Research grant of the State Committee for Scientific Research, no. 3 T11A 012 29: „Control and identification algorithms for active noise control", 2005-2008
2. Research Grant of the Ministry of Higher Education and Science no. N N514 232037,
3. "Algorithms and control structures for active protection of humans moving in industrial halls, against acoustic noise", 2009-2012.
4. Research and Development Grant of the National Centre for Research and Development no N R14 0031 06, "A miniature personal hearing protector allowing for speech communication among works under high-level acoustic noise", 2009-2012.

Ph.D. Degrees

1. S. Budzan: Detection parametric surfaces using cloud of points from 3D scanner. Ph. D. thesis, Institute of Automatic Control, Gliwice 2008. (in Polish)
2. T. Grychowski: Support of the dispatcher during the monitoring of the coal mine atmosphere based on the fuzzy logic. Ph.D. thesis, Institute of Automatic Control, Gliwice 2007. (in Polish).
3. K. Plaza: Modelling and Control For Semi-Active Vibration Damping. Ph.D. thesis, Institute of Automatic Control, Gliwice 2008.
4. T. Główka: Higher-Order Spectra for Frequency Model Identification, Ph.D. thesis, Institute of Automatic Control, Gliwice 2009.

D.Sc. Degrees

1. Jerzy Kasprzyk: Computer aided process identification (in Polish), Faculty of Automatic Control, Electronics and Computer Science, Gliwice, 21.02.2007.
2. Ewa Bielińska: Bilinear time series in signal analysis (in Polish), Faculty of Automatic Control, Electronics and Computer Science, Gliwice, 22.04.2008.



CONTROL SYSTEMS AND CONTROL INSTRUMENTATION GROUP

GENERAL INFORMATIONS

The most important areas of research interests in the group are as follows:

- Phenomenological and mathematical modelling, simulation and control of continuous industrial processes: theory and practice of modelling and simulation, real-time simulation and training systems,
- Phenomenological and mathematical modelling, simulation and control of biotechnological processes in the environment protection with: a) aspects - activated sludge processes, sequencing batch reactors, biofilm processes, biofilters; b) problems: energy-saving, productivity improvement, safety,
- Phenomenological and mathematical modelling, simulation and control of biotechnological fermentation processes with a) aspects - anaerobic processes, yeast fermentation, enzymatic processes, biofuel processes; b) problems: energy-saving, productivity improvement, safety,
- Intelligent systems and instrumentation for automation: transmitters, actuators, regulators and controllers with problems - industrial networks, multi-agent-based control, holonic systems, self-organisation of MAS, cooperative, collaborative and competitive systems,
- Distributed Control Systems - programming of digital regulators, controllers, monitoring and SCADA systems, ppPDC transmission, TCP/IP-based virtual plants, controllers and control systems, OPC.
- Development and design of control systems in chemical, power and environmental protection industry,
- Microrobotics, microfluidics, microprocessing

The CSCI group consists of 14 researchers (including one titular professor and one associate professor). The members of the group teach about twenty courses to about four hundred fifty students in two faculties: the faculty of Automatic Control, Electronics and Computer Science, the faculty of Chemical Engineering and in the interdepartmental studies in Biotechnology. The courses cover both traditional topics of modelling, simulation, control and programming, and more recent topics in the real-time distributed systems and intelligent instrumentation for automation fields.

Members of the Control Systems and Control Instrumentation Group were involved in the project entitled "Hierarchical control system for biotechnological reactor based on hybrid models" supported by the Polish Ministry of Scientific Research and Information Technology under Grant No N514 006 31/1739 (2006-2008) as well as in the project entitled "Practical realization and experimental evaluation of DCS integration based-on MAS for pilot industrial processes" supported by the Polish Ministry of Scientific Research and Higher Education under Grant No N514 296335 (2008-2010).

REAL-WORLD EXPERIMENTAL PILOT PLANTS WITH DISTRIBUTED CONTROL SYSTEMS

Although the members of the CSCI group present some theoretical research results in the international publications (see bibliography), the most important area of teaching and research activities are concerning the real-world experimental investigations. The majority of support obtained by the CSCI group within the last years was used for design and development of semi-industrial-scale pilot plants treated as real-world control plants. All of these plants include real-world industrial measurement and control equipment. A new area of R&D activity deals with the application of the Internet both for development of virtual control systems and information-layer supervisory control systems based on our own ppPDC connection, standard TCP/IP and OPC connections; as well as for distribution of real-world control data from control plants by the Internet. The new research activity deals with agent-based and holonic technology applied for intelligent and mobile control and monitoring as well as microrobotics and microprocess technology. It should be also noticed that very interesting problems of the control-based forced modulation and stimulation of biological processes can be evaluated in our pilot plants. The plants are adapted each year to actual research purposes.

The following notes present our pilot plants and research results.

Industrial-scale heat distribution pilot plant

M. Metzger, P. Łaszczyk, K. Pasek

The industrial scale heat distribution pilot plant was developed and worked out at the laboratory of the CSCI group in the nineties. This pilot plant has a structure of a real heating system with flexible connections of the heat receivers. This structure itself was developed on the basis of the real industrial heat distribution plant and it consists of three heat exchangers of different type, the mixing tank, the electric water heater and the several water circuits. In the primary circuit the water is pumped from the electric heater to the spiral-tube heat exchanger HE1, which then transfers a part of the heat energy to

the secondary circuit consisting of the plate-type heat exchanger HE2 and of the double-pipe heat exchanger HE3. The outlet water from the heat exchangers of the secondary circuit finally flows into mixer.

Nowadays the optimal control of heat distribution plants is the important challenge in the field of the energy saving strategy. The flexible structure of our pilot plant allows us to operate the installation in the most important classical modes. Moreover, both the classical PID and the advanced low-level control algorithms, relevant to the chosen operating mode, can be applied to the plant and compared. There is also the possibility of the application of the high-level monitoring and SCADA systems, both classical and advanced based on the artificial intelligence.

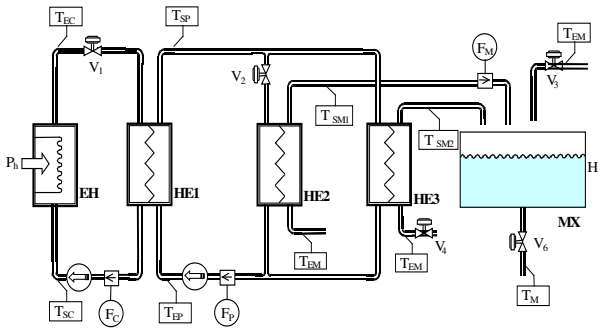


Fig. 1. Heat distribution pilot plant.

Figure 1 shows the location of the temperature sensors applied to collect the measurement data of the controlled variables. There are also two additional controlled quantities: the water flow rate F_C in the primary circuit and the water level H in the mixer. It is possible to use six valves as the control variables.

Pilot exothermic batch and continuous chemical reactor

M. Metzger

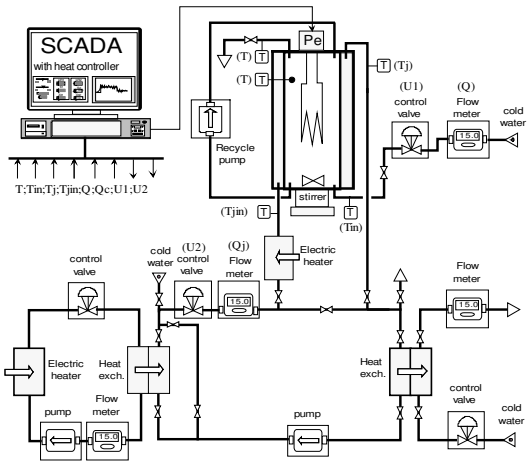
Both the continuous and the batch stirred tank reactors, considered as the control plants, are ones of the most frequently investigated processes. The classical irreversible $A \rightarrow B$ exothermic reaction, taking place in the reactor, is a great challenge faced by the automatic control engineers due to the nonlinear and non-stationary behaviour of this process. A very interesting control problem deals with the working-point regime of this process in which an open-loop operation is unstable. Therefore, for this kind of processes, there is a need to develop the sophisticated low-level control algorithms and then to compare their performance with the classical PID controller.

The idea of the structure of this pilot plant (see Fig. 1) is based on the following. In the real-world plants the equipment for measurement of the substrates and products concentrations are very expensive and in majority of cases it is impossible to obtain the continuous or discrete measurement data of these parameters. Therefore only the inlet and outlet temperature can be considered as the controlled variables since the temperature can be easily measured on-line.

When only temperature measurement data is accessible and the temperature inside the reactor is the controlled variable, the process of the cooling of the exothermic chemical reactor with the application of the cooling jacket can be considered as the heat exchange process. Therefore it is possible to carry out the process only with the water

inside the reactor tank. The heat, produced in the reactor due to the exothermic chemical reaction that should take place inside the reactor, can be simulated by means of the computer-controlled electric heater (see Fig. 1a). This approach allows us to ensure the low costs of the experiments and to avoid the problem of the security standards due to the operating of the chemical reaction.

a) Simplified scheme of the pilot plant



b) overview of the pilot plant

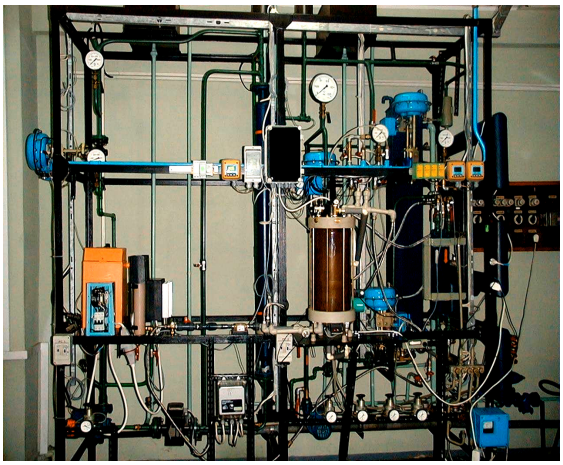


Fig. 1. Heating network with embedded exothermic reactor.

It is important to note that the temperature sensors, the flow meters and the control valves with actuators are the real industrial equipment – only the heat produced due to the reaction taking place is simulated. The pilot hybrid stirred tank reactor is designed in a special manner that it will be possible to incorporate this new stirred tank reactor to existing heat distribution installation. It was possible to connect the jacket of the chemical reactor into the heat distribution pilot plant to ensure the possibility of adjusting the inlet jacket temperature and the possibility of heating and cooling of the reactor jacket by means of two existing heat exchangers.

The reactor must be heated by the jacket for initialisation of the reaction, whereas it must be cooled when the exothermic reaction takes place (which will be simulated by controlled heater in the reactor). The simulated part of the pilot plant represents the value of the power P_e, which should be calculated in the real-time as control variable.

Neutralization pilot plant

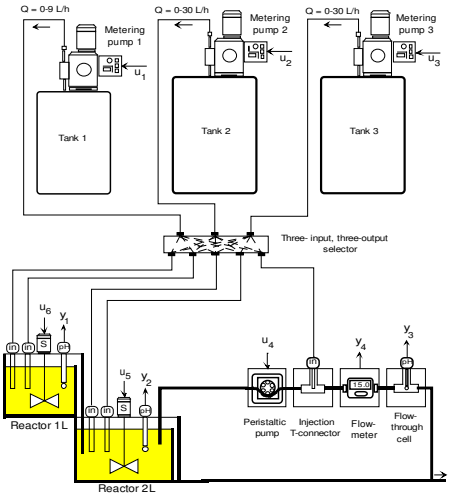
M. Metzger, D. Choiński

The modern neutralisation pilot plant has been designed and worked out at the laboratory of the CSCI group. The installation itself is a scale model of a real industrial neutralisation plant with two neutralisation reactors (stirred mixers) and with flexible connections of the injection pipes. There is also a possibility to carry out the in-line neutralisation process with the application of the in-line injection. The design features allow this installation to be considered as a first stage of the complete neutralisation and biological wastewater treatment plant that has been developed at our laboratory.

The simplified scheme of the neutralisation pilot plant is presented in Fig. 1. Three real-world industrial dosing systems with metering pumps from Milton Roy were chosen to dose the reactants (acid and base) into the reactors. The especially designed

system of two reactors was manufactured by Hydro-Eco-Invest. The three-input, three-output selector allows us to distribute the liquids into three separately chosen points of installation. The system of two stirred reactors is the main part of the plant. Each reactor has two injection points and is equipped with industrial pH-meter from Hydro-Eco-Invest. The remote pH measurement system consists of the pipeline, the peristaltic pump from Masterflex, the flow meter from Cole-Parmer and flow-through cell manufactured especially for this plant. Injection T-connector allows us to provide the in-line injection (in-line neutralisation process). The flexible pipeline system allows us to obtain different structures of the plant.

a) Simplified scheme of the pilot plant



b) overview of the pilot plant

Fig. 1. Neutralization pilot plant with flexible tubing connections.

The monitoring and control instrumentation consists of two systems a) the FieldPoint™ modular distributed system from the National Instruments with LabVIEW™ and LabWindows/CVI™ software; b) the Logix system from Rockwell-Allen-Bradley with RSLogix 5000 and RSView software.

Pilot switcheable SBR and SOCP processes for biological wastewater treatment

M. Metzger, D. Choiński, W. Nocoń

The classical continuous activated sludge process should contain at least two (aerobic and anoxic) reactors for both carbon and nitrogen removal. Although such classical processes are widely used, sequentially operated continuous processes (SOCP) and sequencing batch reactors (SBR) are an attractive alternative. In these processes, carbon and nitrogen removal can be accomplished in only one bioreactor in which the aerobic and anoxic phases are periodically sequenced.

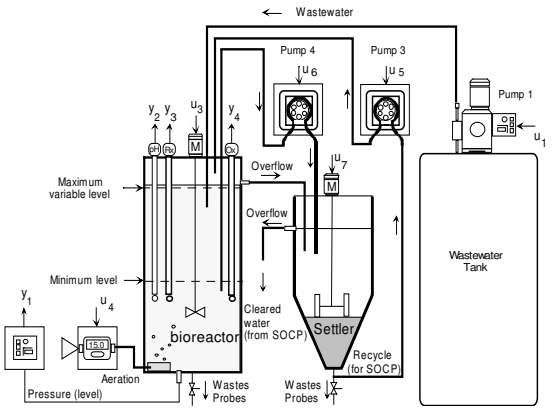
In comparison to classical continuous biological processes when the process can be carried out without any control system, the sequences of the periodically operated process must be controlled and thus the development of the SBR (or SOCP) as a real-world pilot plant can be very interesting for the real-world experiments.

Starting from the year 2000 a great effort has been done to design and develop the pilot plant. A special 30-liter SBR with appropriate fitting system as well as the pH, Redox and dissolved oxygen continuous measurements were carried out. The first

control experiments dealing with the hydraulic operations (fill, mixing, aeration and draw) started at the 2001. In the 2002, a new idea has been developed. It can be noticed that with very little financial costs the SBR reactor can be augmented with secondary clarifier and in that way we can obtain the SOCP process in witch the same reactor used as SBR can be applied as continuous aerator for sequentially operated continuous process.

The control and monitoring with visualisation of the process are based on the new distributed control systems from the National Instruments and from the Rockwell-Allen-Bradley. The spectrophotometer and COD reactor from the Hach allows us to analyse COD, nitrates and nitrites as well as ammonia nutrients according to the international standards for wastewater measurements.

a) Simplified scheme of the pilot plant



b) overview of the pilot plant

Fig. 1. Architecture of the enhanced pilot SOCP and SBR.

The first control experiments dealing with the hydraulic operations (fill, mixing, aeration and draw) and with switching between SBR and SOCP processes will start at the beginning of the 2003. After that, in the 2004 first growth of the appropriate microbiological cultures and the experiments of the carbon and nitrogen removal with synthetic municipal wastewater have been carried out.

In the 2004, a new extension of the pilot plant has been developed. Figure 1 shows the newest extension of the plant. The bioreactor is fed with synthetic wastewater from a wastewater tank using Pump 1. Although an overflow from the reactor to the settler is physically realized, when the volume of the reactor should be kept at a lower level, the peristaltic pump (Pump 4) is used to feed the settler. This pump, together with a pressure transducer that is used to measure the reactor level, are both used to maintain the appropriate level in the bioreactor. The bioreactor is aerated using air pump (u_4). The recycle of condensed sludge from the settler to the bioreactor is realized by another peristaltic pump (Pump 3). Two mixers are available: one (M1) used to maintain uniform sludge concentration throughout the bioreactor, and the other (M2) used to gently mix the bottom part of the settler. Appropriate manipulations with both flows between the reactor and the settler as well as with mixers speed allows us to, for example, temporary storage of the sludge majority in the reactor or in the settler. In the 2006/2007 two advanced measurement systems – the UV spectrophotometer and the FISH enhanced analytical possibilities.

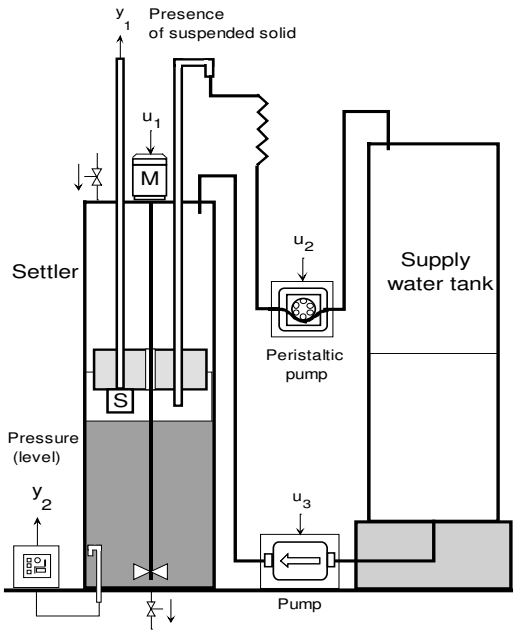
Batch sedimentation pilot-plant

M. Metzger, W. Nocoń

Sedimentation is one of the most widely used techniques of separation in the chemical, mineral and wastewater treatment processes. The process takes place in a settler, where solid particles suspended in a liquid are settling downward, leaving clear water at the top of the settler and concentrated slurry at the bottom. This downward movement of solids is caused by gravitational force. Two types of the sedimentation process can by distinguished: continuous sedimentation (solids are continuously fed into the settler) and batch sedimentation (the settler is filled with liquid containing suspended solids and settling occurs afterwards).

An experimental batch sedimentation pilot-plant has been designed and developed in the Control Systems and Control Instrumentation Group at the Institute of Automatic Control. This pilot-plant is schematically shown in Figure 1a, and its view is shown in Figure 1b. The sedimentation process takes place in the settler where the level of liquid is measured by a pressure transducer (y_2). The cleared water is removed from the settler by a Masterflex peristaltic pump (u_2: on/off or continuous flow control) and the suction nozzle is mounted on the float. A turbidity sensor (y_1) is mounted on the same float and is used to indicate the presence of solids in the water being removed form the settler. The sensor itself was developed in the CSCI group is designed to be a low cost indicator of sludge blanket presence. The cleared water is fed into the supply tank from which it can be returned to the settler by a second pump (u_3: on/off). A stirrer is provided (u_1: on/off) to stir the suspended solids inside the settler. The measurement signals and control variables are accessed in a PC computer using the FieldPoint Modular I/O System. In 2007 the new distributed control system from MetsoDNA enhanced control experiments. The pilot plant can be also connectod to the Simatic S7 control system.

a) Simplified scheme of the pilot plant



b) Overview of the pilot plant

Fig. 1. Batch sedimentation pilot plant.

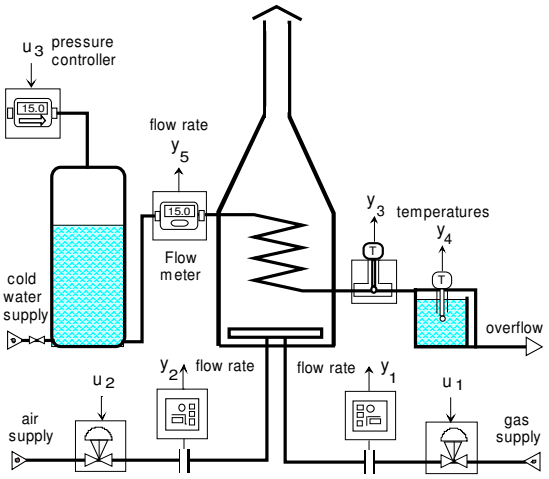
This pilot plant is used to design and test different methods and algorithms for control of the clearing processes in batch settlers (including identification of sedimentation process parameters from the simple measurements, calibration of simple sensors and optimisation of the clearing processes). Moreover, it serves as an excellent educational example of non-trivial real-world processes with highly non-linear dynamics.

Combustion pilot plant

K.Pasek, M.Metzger

Basing on the old famous "Senkała kiln" the new combustion laboratory stand has been carried out in 2006/2007. Except old kiln all the instrumentation is new and has been integrated and carried out in a new stand. The plant was developed in such way that different control systems can be connected by standard signals. The plant is presented in Figure 1.

a) Simplified scheme of the pilot plant



b) Overview of the pilot plant

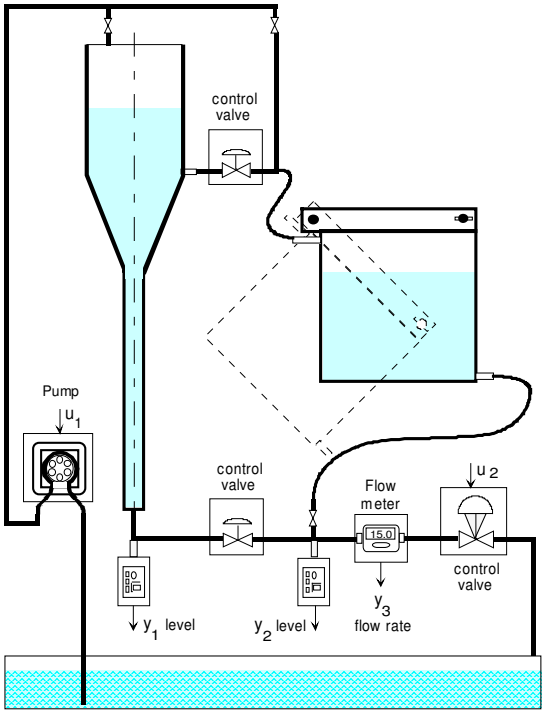
Fig. 1. Combustion process

Hydraulic pilot-plant with strong nonlinearities

M. Metzger

The problems of nonlinear control are still big challenge in the modern control theory. Although a big number of theoretical investigations are published each year, there are a very little communications dealing with real-world nonlinear processes. Immortal control objects such as exothermic continuous stirred tank reactor as weel as pH neutralization (although having strongly nonlinear mathematical models) in most cases can be controlled in a working point of the process even by simple PID controller. Hence, it will be very interesting to design a real-world process that is characterized by strong nonlinearity and should be controlled in whole limit of the nonlinearity. In 2006/2007 such a pilot plant has been designed, developed and carried out in the CSCI laboratory. The idea of the new hydraulic plant is presented in Fig. 1a, while Fig. 1b shows photo of realised plant.

a) Simplified scheme of the pilot plant



b) overview of the pilot plant

Fig. 1. Hydraulic pilot-plant with flexible two-tank architecture.

Broad range of changes of liquid's surface area in the left tank causes that time constant of the flow process changes even two hundred times. The right tank can be used classically with a constant liquid's surface area (solid line) or can be tilted to exhibit surface area changing about fifty times depending on liquid's level (dotted line). In both tanks the level should be controlled in the whole possible range.

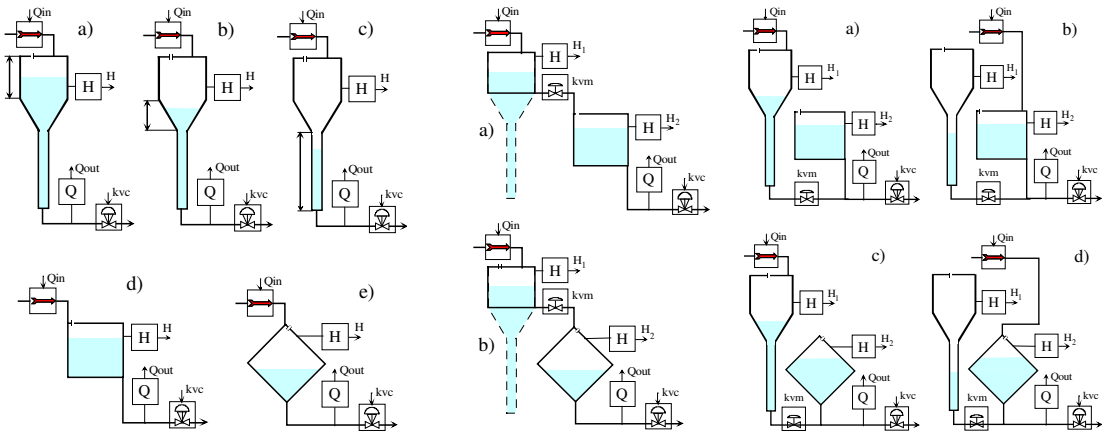


Fig. 2. Possibilities one/two tank and linear/nonlinear dynamic systems.

A vast number of various interesting cases of one/two tank systems can be configured by appropriate tube connections and switching valves (Fig. 2) including both interconnected (with hydraulic feedback) and "tank-in-serie" systems.

Architectures of network-based Distributed Control Systems for CSCI pilot plants

M. Metzger

Over the past two decades decentralised, distributed control systems appear as a well-agreed standard in the automatic control. The big world producers offer very expensive, different communication network systems for all layers of control. One of the most important steps in the development of real-world control system is this system testing. Control software and control instrumentation can be tested on the real-time simulators. However, the most important tests should be carried out on the real-world plants. Although testing control equipment on the semi-industrial scale pilot plants is more expensive than on the simulators, it is also more realistic.

A big effort was made over the last years in the CSCI group for design, development and building of semi-industrial scale pilot plants treated as real-world control plants. All of these plants include real-world professional industrial measurement and control instrumentation. The control instrumentation allows developing distributed control systems for operating, control and device levels of data transmission.

Several real-world distributed control systems have been designed, developed and carried out in the CSCI group. All of them are designed for control of our pilot plants.

The first system (see Fig.1) designed for all pilot plants is based on hardware and software from the National Instruments.

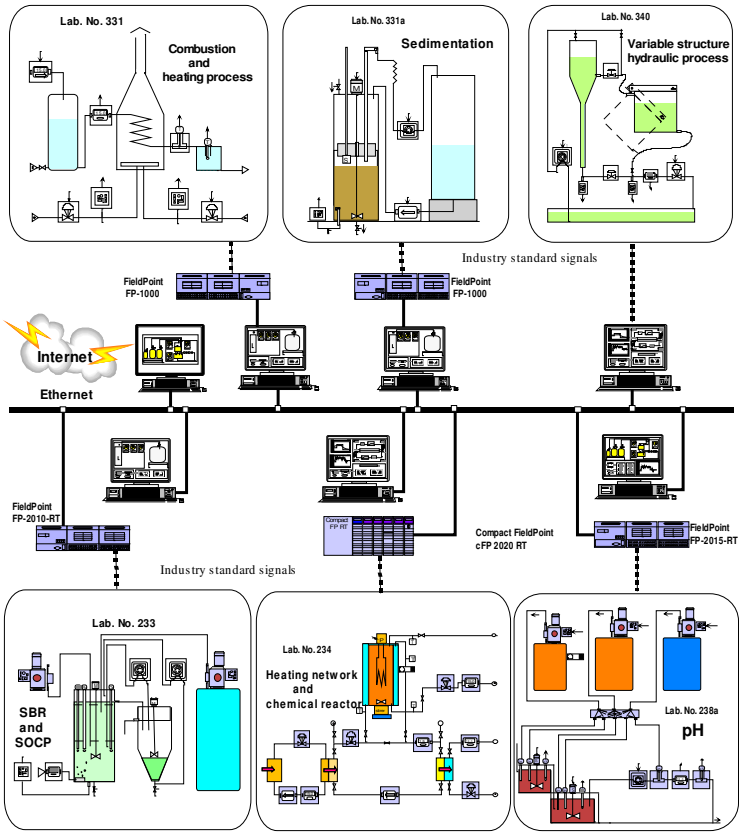


Fig. 1. Architecture of the DCS based on the FieldPoint instrumentation.

This system exerts only one standard of data transmission based on the Ethernet. The SS2 Switch 3300/100Mhz equipment allows communication with an application of TCP/IP and OPC protocols.

Five FieldPoint type controllers (majority of them are the newest FP-20XX-serie controllers with hard real-time operating system and the www capabilities) and appropriate data acquisition boards allow distributed control and monitoring. The system can be programmed with an application of the LabVIEW standard, and that is why it will be very user-friendly for research and teaching. The supervisory information system, presented in Fig. 1, will be an experimental plant for comparative investigations of transmission possibilities.

The second system is based on another idea. Namely, it is an industrial system from one of the world's most-advanced systems from a big producer.

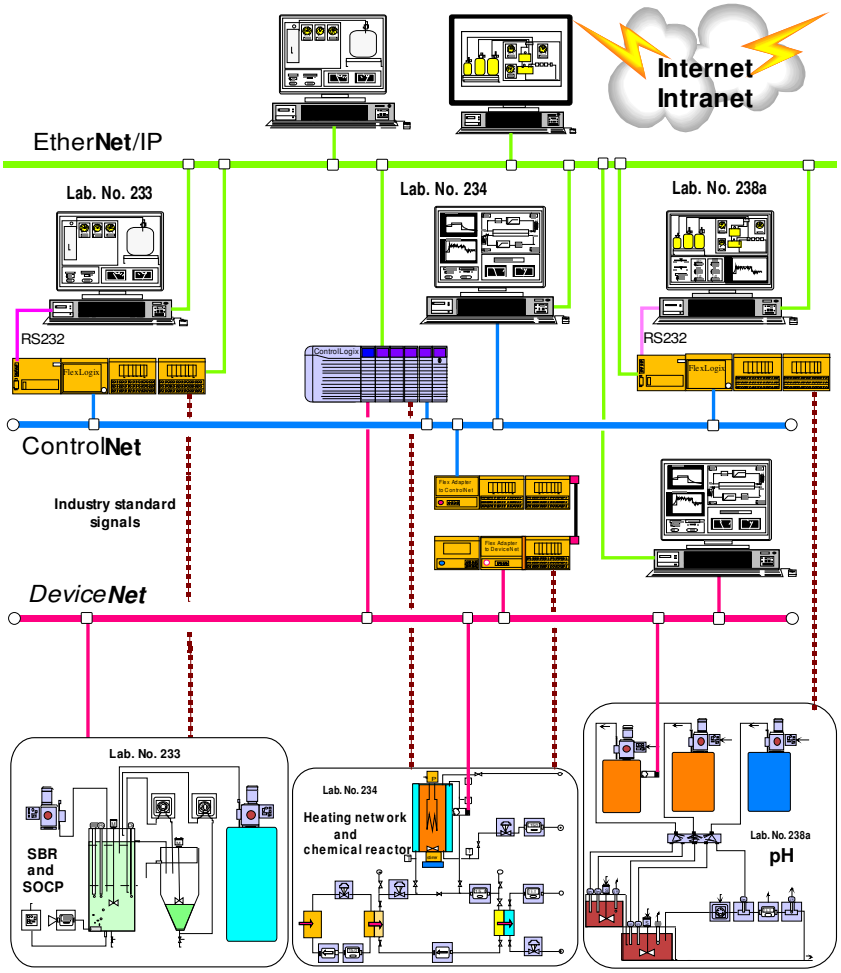


Fig. 2. Architecture of the distributed control system based on the Logix system.

The Logix system from Rockwell-Allen-Bradley includes five controllers: two ControlLogix and three FlexLogix as well as one Flex I/O for distributed data acquisition. Three of them are connected to the pilot plants (Fig.2).

The Rockwell system includes three-level open architecture of data transmission: namely, the information, control and device levels. The Ethernet, ControlNet and DeviceNet standards offer services for these levels respectively.

Although the hardware and the software of the Logix system demand more sophisticated knowledge but also show the problems in the area of designing real-world, multi-level-network distributed control systems.

Over the last years the appropriate control and information instrumentation has been completed. Both systems were designed and carried out in the form presented in Fig. 1 and Fig.2. The members of the CSCI group as well as our graduate students and doctorants have performed several aplications.

The PCS7 (Simatic S7) distributed control system from Siemens is very frequently used in the European industry. Hence, this system should be included in the educational and experimental schedule. Three Simatic S7-300 controllers are connected to the pilot plants at the laboratories 331, 331a, 340 (Fig. 3).

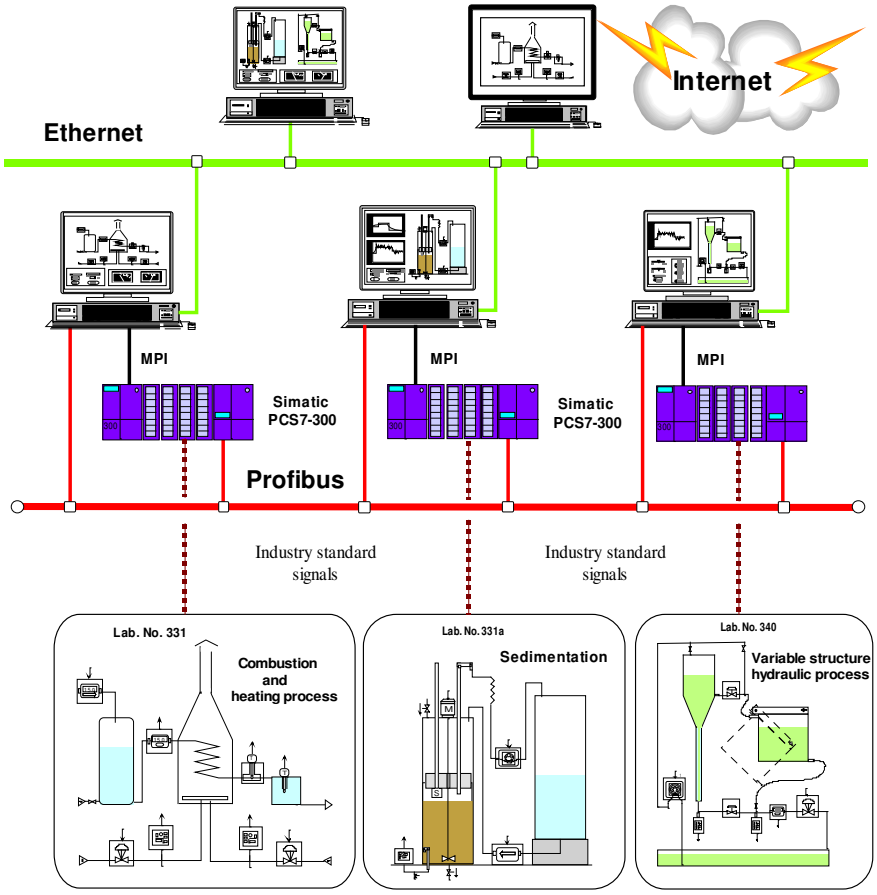


Fig. 3. Architecture of the distributed control system based on the Simatic system.

It will be very interesting to apply also the PCS7 Simatic system (although not connected to pilot plants in 233, 234 and 238 laboratories) as the third distributed control system for these plants. A concept of not too much complicated, Intranet-based communication can solve this problem. Using the FieldPoint system as distributed field I/O moduls (connected to the pilot plants) we can connect digitally by the Ethernet the PCS7 Simatic controllers to our pilot plants. The architecture of the distributed control system based on the transfer data between Simatic and FieldPoint systems is presented in Fig. 4.

Five remotely controlled web-cams augment the capabilities of the control and monitoring system based on DCS. Those capabilities can be very useful especially for educational purposes

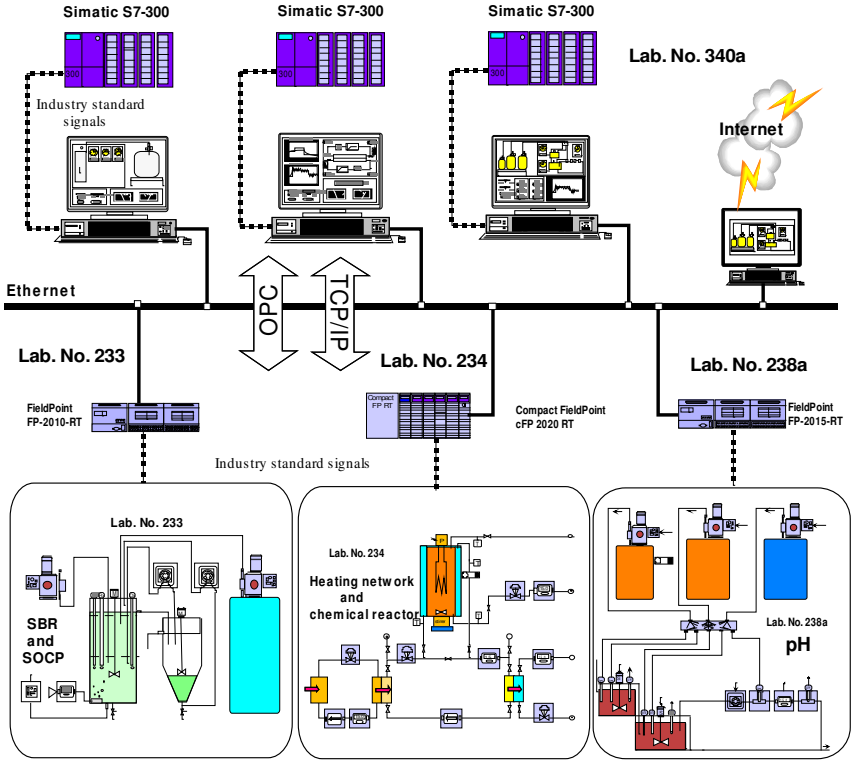


Fig. 4. Architecture of the nonstandard Simatic plus FieldPoint system.

The distributed control system offered by metsoDNA has some interesting features. The design and programming of control system in the metsoDNA system should be performed in the AutoCad environment. Such feature can be interesting for educational purposes.

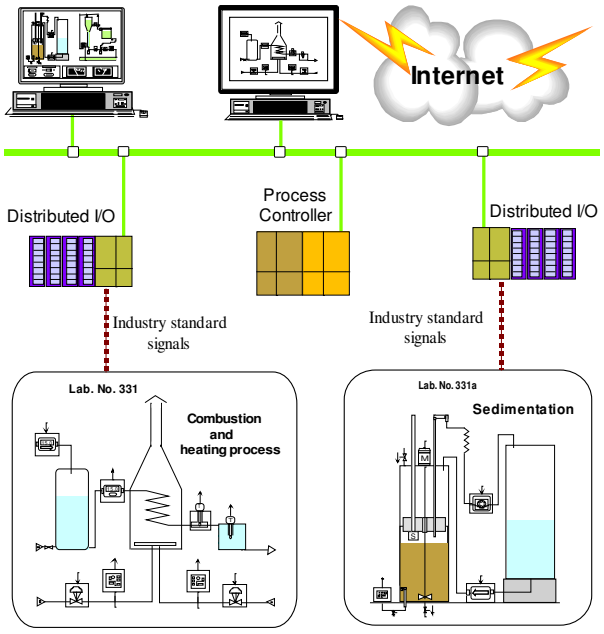


Fig. 5. Architecture of the distributed control system from metsoDNA

PROCESS CONTROL

B-BAC: the Balance-Based Adaptive Control Methodology for a Wide Class of Industrial Processes

Jacek Czeczot

The Balance-Based Adaptive Control (B-BAC) methodology combines simplicity and generality that are characteristic of the classical PID controller and very good control performance and robustness resulting partially from its adaptability and feedforward action and partially from the characteristic properties of the methodology itself. B-BAC is dedicated to control a wide class of technological processes and its generality follows from the fact that the control law is derived on the basis of the simplified part of a nonlinear physical model of a process, namely on the general balance-based dynamic equation describing a controlled variable, which always has the affine form. In this equation, the nonlinearity, resulting from a number of reactions and/or heat exchange phenomena taking place due to a process, is represented by the only one time varying term. Moreover, this term can additionally represent the modeling uncertainties and inaccuracy. Its value is not measurable and thus it must be estimated on-line. However, since there is only this one parameter to estimate, it can be easily managed by the scalar form of the recursive least-squares procedure basing on the same simplified model of a process. This approach allows us to avoid common difficulties either with large uncertainty on the reaction and/or heat exchange kinetics and nonlinearities as well as with the multiparameter identification. Moreover, there is no longer a need to know the complete form of the physical model of the process. Only its part, describing a controlled variable, must be given in the simplified form.

We can apply the B-BAC methodology if there is a possibility to define the control goal in the following way: one of the parameters characterizing a process, defined here as Y(t) and called the controlled variable, should be kept equal to its pre-defined set-point Y_{sp}. Y(t) can be chosen as one of state variables (a component concentration or the temperature) or as a combination of two or more state variables. In a process a number of isothermal or nonisothermal biochemical reactions and/or heat exchange phenomena with unknown kinetics can take place. A process itself takes place in a tank with time varying volume V(t) [m^3].

The generality of the B-BAC methodology ensures that it can be considered as an interesting alternative for the classical PID controller. The control performance of the B-BAC algorithm in the application to different technological processes was validated by computer simulation and can be found in [III.1]. Moreover, the properties of the estimation procedure are investigated both analytically (proof of convergence) and by simulation. The suggestions for the practical implementation of the B-BAC methodology either in the form of the virtual controller and on the stand-alone PLC can be found in [III.1] too.

Practical validation of the B-BAC methodology

Jacek Czeczot, Piotr Łaszczyk, Mieczysław Metzger

For the practical validation the B- BAController has been applied to regulate the temperature at the outlet of the electric flow heater [III.14, III.36]. The controller synthesis and its simulation verification can be found in [III.1, III.14, III.35]. The experiments were carried out on the part (see Fig.1) of the heat distribution pilot plant that works at the laboratory of Institute of Automatic Control. The final form of the B-BAController with the complete feedforward action resulting from the additional measurements of the disturbing signals has been compared to its minimum form, which requires only the measurement data of the controlled outlet temperature. Additionally, the control performance of both B-BAControllers has been compared with the control performance of the conventional PI controller that still can be considered as the benchmark for every new control strategy due to its very large popularity in the industrial practice. Every considered control strategy has been implemented on the standard PC equipped with the plug-in analog I/O cards and with the LabWindows programming environment from National Instruments. During the experiments the sampling time has been set as $T_R = 0.1$ [sec]. The conventional PI controllers have been tuned on the basis of the open-loop step response of the particular system with additional retuning by the trial and error method to ensure satisfying control performance for a wide range of the disturbances changes. The B-BAControllers have been tuned only by the trial and error method. Because of the presence of the measurement noise it was necessary to apply the preliminary filtration of all required measurement data. The filtration was carried out by the first-order digital linear filters and the best results were achieved for the filter constant $\lambda_F = 0.5$. These filters have been applied for both B-BAControllers and for the conventional PI controller.

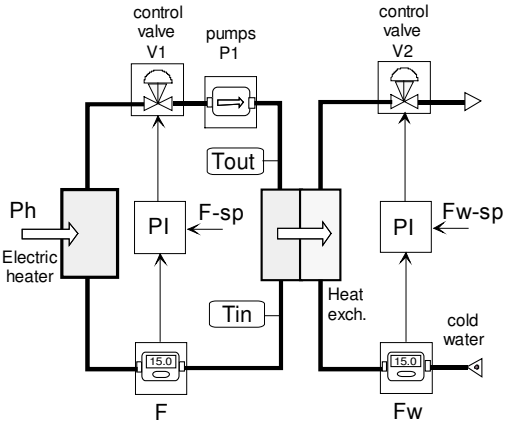


Fig. 1. Simplified diagram of the Heat distribution pilot plant.

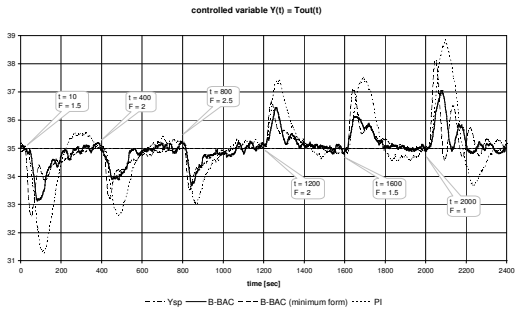


Fig. 1. Closed-loop responses for the electric flow heater in the presence of the step changes of the disturbing flow rate.

Figure 2 shows the chosen results of the performance of the considered controllers in the presence of the indicated step changes of the most significant disturbance – the flow rate of the water flowing through the chamber of the electric flow heater. Let us note that the B-BAController with the complete feedforward action significantly outperforms the other two controllers providing superior disturbance rejection characteristics, which results from the fact that the overshoots for this case are slightly smaller than for the

minimum form of the B-BAController and significantly smaller than for the conventional PI controller.

Although so far the practical experiments with the B-BAC methodology are limited only to the electric flow heater, the results are promising in our opinion and thus the future investigations will concentrate on the further practical experiments in the application to different systems and on the practical implementation on the industrial PLC devices.

Tuning of DMC controller

Tomasz Kłopot, Mieczysław Metzger

Model-based predictive controllers contain two challenging stages: difficult design and complicated tuning procedure. This reasons stands in the way of the practical implementation of advanced algorithms in wide range of industrial applications. These two reasons also implicate that traditional PID controller still playing main role in control applications. Presented work focused on an easy to use tuning strategy for Dynamic Matrix Control algorithm. This tuning procedure is designed for plants approximating by first order plus dead time (FOPDT) model, taking into consideration actual possibilities of industrial programmable controllers. It needs to be pointed out that dynamic matrix of algorithm is not filed in discrete step response of real plant, but elements of FOPDT model which approximating this real response.

Tuning sequence of the DMC controller

<table>
<tr><td>1. Select the sample time T as:
$T = 0.1T_1$</td><td rowspan="2">4. Compute the model horizon H_D:
$H_D = round\left(\frac{2T_1}{T}\right) + round\left(\frac{T_0}{T}\right)$</td></tr>
<tr><td>2. Compute the prediction horizon H_P:
$H_P = round\left(\frac{T_1}{T}\right) + round\left(\frac{T_0}{T}\right)$</td></tr>
<tr><td>3. Compute the control horizon H_C:
$H_C = 2$</td><td>5. Compute the move suppression coefficient λ:
$\lambda = H_P \cdot k^2 \cdot x$
where: x - fine tuning parameter initial value = 1</td></tr>
</table>

Thanks to presented tuning strategy, stage of controller tuning has been shorten that may have influence on economical benefits. Moreover using this strategy even the “blind” tuning is possible. Suggested tuning method covers wide class of industrial processes, which could be described by FOPDT model approximation and also untypical plants like processes with lead time. Very important fact is that for presented class of objects is possible to carry out automatic selection of DMC parameters even during normal work of plant. It should be emphasized that FOPDT parameter taken for control model gives only approximated dynamic behaviour of real plant. In spite of this the control quality is acceptable. Provided theoretical investigations and practical experiments proved correctness of proposed approach and designed control algorithm.

Dynamic Matrix Control for Heating Process

Tomasz Kłopot, Piotr Łaszczyk, Mieczysław Metzger

Model-based predictive controllers contain two challenging stages: difficult design and complicated tuning procedure. This reasons stands in the way of the practical implementation of advanced algorithms in wide range. This work presents an easy to use tuning strategy for Dynamic Matrix Control algorithm (presented above) applied for heating process. This tuning procedure is designed for plants approximating by first order plus dead time (FOPDT) model, taking into consideration actual possibilities of industrial programmable controllers. The work [III.38] presents results of practical implementation the DMC algorithm tuned in accordance with presented tuning procedure in bench-scale heating process.

Research studies and experiments of the discussed control were made using a fragment of our heating pilot installation (presented above). There is an electric heater and a heat exchanger connected as presented in Fig. 1. The fluid that is heated up in the electric heater is served to the heat exchanger. In heat exchanger the fluid is cooled down with the water of temperature T_{Win} supplied to the second circuit of the heat exchanger. The preheated water is served to another part of experimental plant, while cooled down fluid is served back to the electric heater. One of the control tasks is to stabilise the output temperature of the electric heater. The electric heater is a standard construction unit of 5.5 [kW] supplemented with an electronic device that performs PWM (Pulse Width Modulation). The period of modulated signal may be changed manually to adjust this parameter of PWM to one of the three possible for use heating units in discussed installation. Here in considered case was set to 5 [s]. One of the main problems with the dynamics of the given process is that none of the units in the installation could be separated from the whole system. Therefore none of them could be identified separately using any desired signal. It is possible to apply any change of electric power P for discussed electric heater or any change of flow F_1 in the closed fluid circuit but it is not possible to perform any kind of change of inlet temperature T_{IN}. This value strongly depends on heat exchange to the second circuit. Thus temperature T_{IN} is a function of temperature T_{Win}, flow F_2 and temperature T_{OUT}. The last value dependence makes the process more difficult for control because we face positive feedback with time delay. Nevertheless, the control results are satisfactorily [III.38].

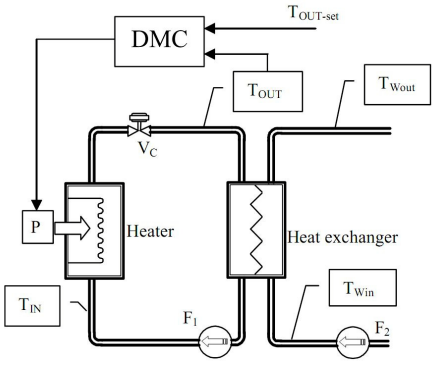


Fig. 1. The heating circuits from our pilot plant.

Predictive Functional Control For Neutralization Process

Piotr Łaszczyk, Krzysztof Stebel

One of the benchmark processes for testing nonlinear controllers is a pH neutralization process. Many controllers are designed using very complex phenomenological models. The paper [III.37] presents, how to obtain relatively simple model for such process and how to make use of it in control. There was applied the PFC (Predictive Functional Controller) in the presented approach. This control technique was tested using real-time simulator of the process, however application to the real plant is expected soon. Presented in [III.37] control results proved correctness of the proposed solution.

The full control structure should link both PFC and PPC (Parametric Predictive Controller) controller equations and suitable recalculation formulas as a result of neutralization curve. The structure of control system for neutralization process is presented in Fig. 3. In this structure given set point value p_{Hset} is recalculated into desired differential concentration xset. The same recalculation is done for measured process value of pHp, which gives actual differential concentration x_p. Comparison of these values gives the control error for the PFC controller. This controller calculates internal model and abstract manipulated value xeq basing on control error and measurements of other process variables. Value xeq is recalculated using the PPC controller into real manipulated variable that is flow of base F_2. It should be emphasized that a quality of control strongly depends on how efficient (without any other significant dynamic effects) and precise is the device which performs changes of the flow. One of the possible solutions is application of dosimeter pump. Another one is an application of another flow controller with pneumatic control valve because electric servo gives usually inadequate speed of performance.

It should be noted that PFC controller should be supplied with actual measurement data to secure bumpless switching from manual to automatic mode. Signals that are marked with dotted line in Fig. 3 are disturbances and should be measured during the control procedure. It is very important to serve constantly those signals to the PFC controller to secure satisfying adaptation and disturbance compensation in order to reach high control quality.

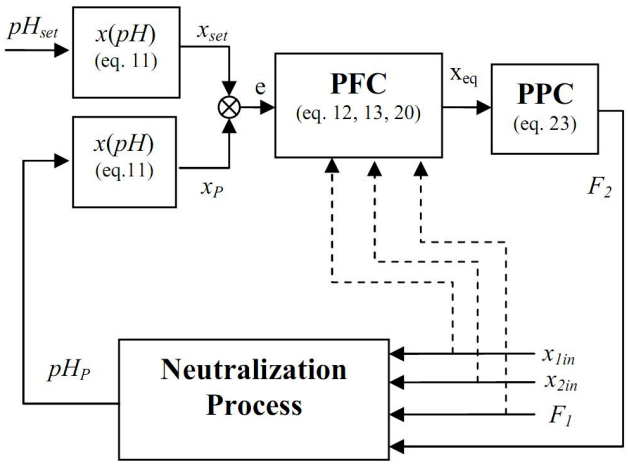


Fig. 1. PFC+PPC Control structure for pH Fig. 3. PFC+PPC Control structure for neutralization process neutralization process

Control and Monitoring of Batch Sedimentation based on Fractional Density Changes

Witold Nocoń

A methodology for control and monitoring of method of monitoring a batch sedimentation process and of controlling the removal of clarified liquid from the batch settler has been developed, modeled and practically evaluated [III.39]. It is based only on pressure measurement, hence no additional sensors (optic sensors for example) are required.

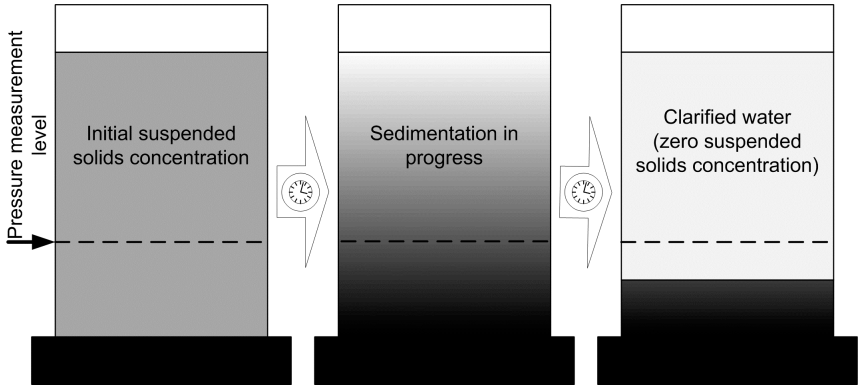


Fig. 1. Principle of fractional density changes due to batch sedimentation process.

Fig. 1 presents the general idea. In the initial phase of the process, right after mixing has been stopped in the reactor, the distribution of solid particles is uniform throughout the whole tank. As time progresses, solid particles move downward decreasing the overall density in the upper region of the reactor and increasing density in the lower part. Assuming that a hydrostatic pressure sensor may be located at a certain distance from the bottom of the tank and that the suspension is heavy enough to have a measurable effect on the hydrostatic pressure, the measured density changes in the upper fraction of the suspension may indeed be used to control and monitor the batch sedimentation process.

Fig. 2 presents an example of simulation and experimental results carried out using the experimental batch sedimentation pilot plant. Because level measurement in the settler is realized by a pressure transducer, the influence of fractional density changes is clearly visible as a variation in the measured level in the settler.

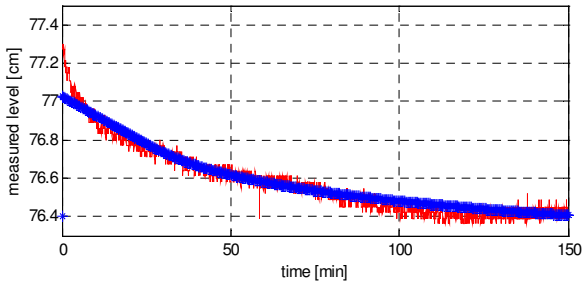


Fig. 2. Example of simulation and experimental evaluation of fractional density changes phenomenon.

The presented phenomenon may therefore be used to monitor to progress of batch sedimentation process, to signify any failures in the sedimentation process and may also be used in on-line identification of sedimentation process model parameters.

Appropriate Plant Diagram Synthesis for User-Suited HMI in Operating Control

Mieczysław Metzger, Grzegorz Polaków

In the paper [III.17] a study on appropriate plant diagram synthesis for user-suited HMI in operating control is presented. Discussion is based on the long-term personal experience and illustrated with excerpts of existing HMIs developed for research and industrial use. The HMI notion is defined for operating control and for operator training. The paper present three aspects of plant diagrams design. The first aspect deals with task-oriented usage of screen space for plant diagram and other GUI elements. Second aspect covers all methods of image creation for process diagrams, including photography, schematic diagrams, use of predefined normalised 3D graphical elements, and creative possibilities of 3D scene. The third aspect stresses capability of dynamic visualisation with the use of animated graphics.

Current wide availability of personal computers changed the situation, in which the big automation manufacturers forced ideas of SCADA designing. Operating consoles based on PC are cheap and readily obtainable. Diversity of the operating control software and the competition on the market makes it possible to easily and cheaply develop operating panels (nowadays called SCADA for Supervisory Control And Data Acquisition) according to the needs of a specific user. This paper focuses on proper choice and design of GUI being the main part of the HMI for the SCADA control operating system.

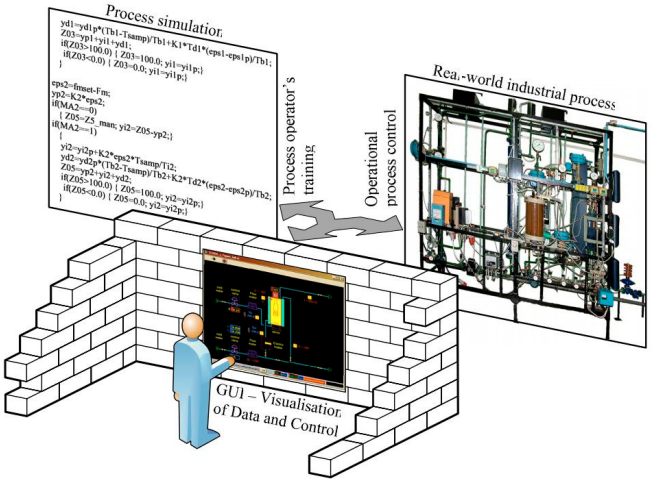


Fig. 1. General interpretation of GUI for process control.

Fig. 1 symbolically presents the role of the GUI as perceived by the user of the system – in this case an operator of industrial process. As it was stated in the literature review, it is a GUI itself what is perceived by an operator as the system. This statement is physically backed up by the fact, that in real plants, operating stations are located in the control room, which is spatially distant from the process. Until an emergency situation arises, there is no need for an operator to see and/or interact with the process, all the physical phenomena are represented for him with the GUI.

The discussion in the paper [III.17] deals with such a GUI, which can be used both for operating control of a real process and for control of a real-time simulated process for operators training.

Distributed parameters model of neutralisation process

K. Stebel, M. Metzger

Control of the pH neutralization process plays a very important role in chemical and food industries such as the biochemical processes, wastewater treatments. Wastewater neutralization is one of the most common and most difficult control applications due to the multicomponent, buffered nature of the system whose composition is unknown and non-stationary. For the purpose of control, efforts have been made in modelling of pH processes. Most of works consider continuous stirred-tank neutralization reactor with assumption of ideal mixing. In opposite to this fact publications considering distributed parameters process are not present in literature. It is possible to find only a few examples where pH gradient formation is investigated under the influence of applied voltage. But these types of issues are far from problems of systems where pH depends on the shape of reactor, intensity of mixing or additional chemical reactions influencing reagent concentration and indirectly pH value in individual points of reactor. Application of such model is much more computationally demanding but enables to include some features strongly connected with distribution in space. Some chemical reactions might be simulating more properly and accurate using distributed parameters model. The work was focused on finding the model reflecting most of phenomena's during in-line neutralisation. It was assumed that ratio of reactor length and diameter is large. Flow rate is sufficient to assume piston flow, ideal across mixing and no diffusion along the length of reactor. Under such assumptions distributed parameters process was modelled [III.40] (Fig. 1.)

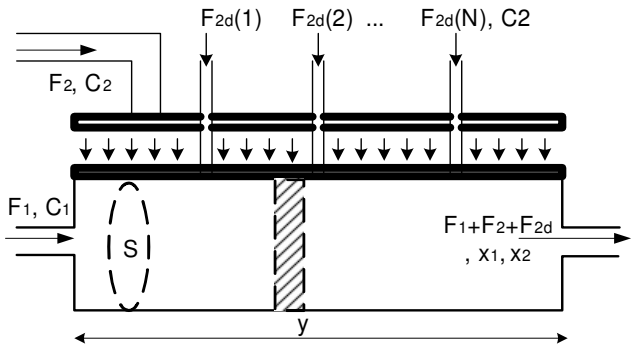


Fig. 1. Complete form of distributed parameters process.

Where: $x_1(y,t)$ - acetic acid concentration in reactor [mol/l], $x_2(y,t)$ - potassium base concentration in reactor [mol/l], S –intersection of reactor, C_1= acetic acid inlet concentration [mol/l], C_2= potassium base inlet concentration [mol/l], F_1= acetic acid inlet flow [l/min], F_2= of potassium base inlet flow [l/min]

Experiments were started for multipoint injection and than distributed injection along the length of reactor. Combination of those two approaches allows simulating process for wide range of process parameters. At the final stage of researches additional first order reaction was added what also enriched simulation possibility. Resuming obtained model allows simulating wide range of distributed parameters neutralisation processes and it is good base for testing of control algorithms.

INDUSTRIAL BIOTECHNOLOGY

Hybrid control of flocculation for improvement of carbon and nitrogen removal in SBR process

D. Choinski, M. Metzger, W. Nocon

The problem deals with the two-dimensional aeration phase control in SBR. The sludge density forcing is proposed as an additional independently controlled parameter to classical time sequencing control in SBR for improving the efficiency of the carbon and nitrogen removal. A two-tank SBR system has been designed in order to realise and experimentally verify the proposed control scheme. One of the tanks works as a sequentially aerated reactor, while the other tank is not intended for biomass separation (as is the case in continuous activated sludge processes) but is designed for thickening and periodical storage of sludge. The papers [III.6, III.33] present experimental verification of the proposed hybrid control of sludge density and influence of such control on the carbon and nitrogen reduction reaction.

The major problem deals with the state hybridisation. The biotechnological pilot plant under consideration consists of two tanks, which can work in different configurations. For advanced control, in case of big loads, a two tanks system is used (Fig. 1a), in which the flocculation process in the R2 tank is performed.

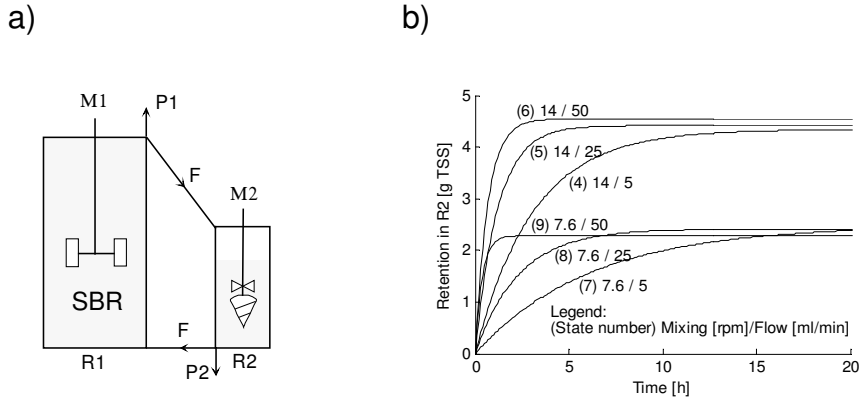


Fig. 1. a) Simplified diagram of the two-reactor process, b) Dynamical retention responses in R2 representing 6 of 9 modes (discrete states of the hybridised space).

Maximum ranges of flow through R2 reactor and rotational speed of the M2 mixer have been selected, for which flocculation has been observed. Detailed measurements have been taken for 9 combinations of flows and mixing speeds, corresponding to minimum, average and maximum flow and mixing speed. State numbers (1-9) have been assigned to those combinations of flocculation forcing states. For these discreet states (modes of the hybrid system), time variations of retention changes caused by changes in flocculation have been determined. For the pilot plant used in experimental studies, those modes correspond to the following values of mixing speed and flow values: (1) 22 rpm, 5 ml/min; (2) 22 rpm, 25 ml/min; (3) 22 rpm, 50 ml/min; (4) 14 rpm, 5 ml/min; (5) 14 rpm, 25 ml/min; (6) 14 rpm, 50 ml/min; (7) 7.6 rpm, 5 ml/min; (8) 7.6 rpm, 25 ml/min; (9) 7.6 rpm, 50 ml/min. Chosen dynamical responses are shown in Fig. 1b.

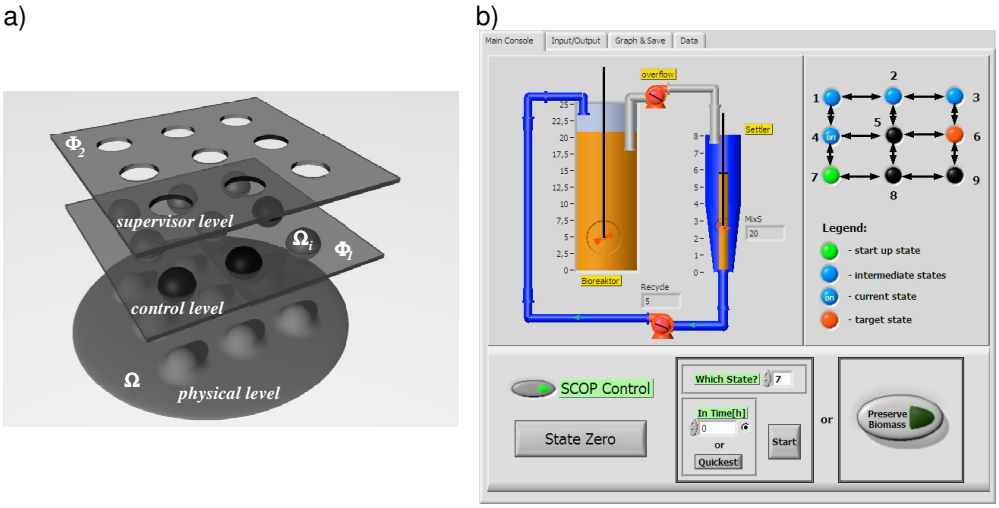


Fig.2. a) Idea of hybridisation for biotechnological process, b) GUI for SCADA.

Experiments carried out in order to determine the parameters in particular modes showed, that by changing the mixing speed of M2 and flow F, it is possible to influence the flocculation in R2, and hence the retention of sludge in this reactor, in a repeatable way. Fig. 1b presents selected approximated results for selected retention states. As seen in the results, it is possible to control the steady state by M2 mixing, while flow F may be used to adjust the time constant of the process.

A hybrid system possessing 9 modes of operation defined in such a way is capable of realising those 9 states of the process in a repeatable way, as has been show experimentally [III.33]. If needed, the number of states may be enlarged, but in every case, the new state must be experimentally defined. For such a defined physical state space, equivalent agent states exist on different levels of the hierarchy (Fig. 2a). In the work [III.6] it is proposed to use a multi-agent system for the proposed hybrid control, from which two specialised agents assist during cooperation of experts working on these levels of hierarchy. The main graphical user interface (GUI) dedicated for both experts is shown in Fig. 2b, in which the visualisation of actually attained agent states is most important for support of experts' cooperation (upper right corner of the GUI presented in Fig. 2b).

Multiscale Three-Phase Flow Simulation Dedicated to Model Based Control

Dariusz Choiński, Mieczyslaw Metzger, Witold Nocoń

Unsteady two-phase flow is a challenging problem for control engineering. Such type of flow is typical for vacuum pumping technology like vacuum sewerage system and also in petrol applications. Complexity of the problem is increasing when three-phase flow is considered by means of particles movement in a pipe. Such system needs unsteady flow in order to avoid plugging by insoluble parts and particles. The sawtooth lifts, which are used for uphill liquid transport and the same type of pipe profile are necessary for uphill liquid transport and when no valves are opened, no liquid transport takes place, causing medium in the pipe to lie in the low spots. Only part of the pipe cross section is occupied by liquid, so that momentum transfer from air to liquid takes place largely trough the action of shear stresses. Although, the complex system of pipes with complicated profiles as well as with three-phase flow control is difficult for

investigation, the control system can improve vacuum pumping system ability with an application of model based control algorithms after simulation for model validation. The mathematical model based on multiscale and multiphysics methodology [III.7] (see Fig. 1 and Fig. 2).

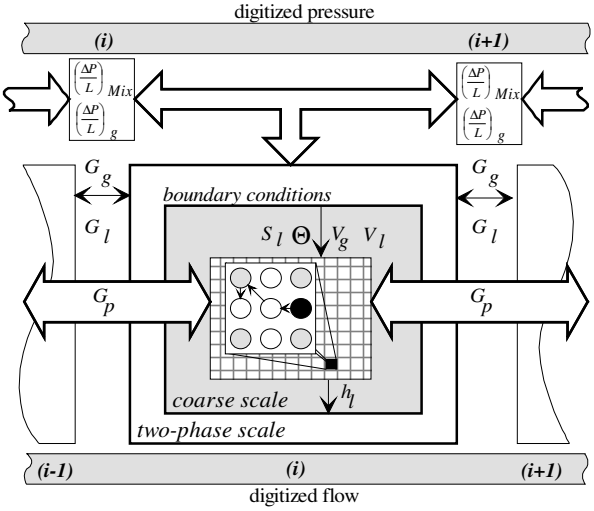


Fig. 1. Multiscale diagram of computing; l – liquid, g – gas, Mix – gas+liquid, p – particle, S – cross section of the pipe, α - pipe inclination angle, h – friction head loss, G – superficial mass flux, V – velocity, P – pressure, L – pipe segment length.

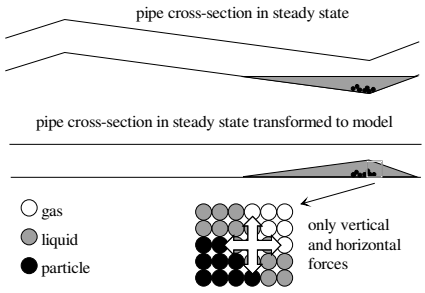


Fig. 2. Model simplifying for coarse scale.

MAS-based cooperative control for biotechnological process - a case study

Dariusz Choiński, Mieczyslaw Metzger, Witold Nocoń

The MAS-based control seems to be better suited for manufacturing control because of its discrete event character. Nevertheless, for continuous industrial processes the MAS-based control can be also very attractive. In the paper [III.10], a synthesis of the MAS-based control system for the continuous process is presented. A biological reactor is controlled using respirometric approach. In this approach, both standard control loops and additional experiments are performed to obtain measurements not available on-line. Therefore, the system consists of different control agents being able to cooperate or to inhibit each other in order to achieve the appropriate goals. A case study experiments are realized using an experimental wastewater treatment pilot plant.

The problem under consideration is controlling the aeration process in a biological reactor and at the same time monitoring respiration related activities in the reactor in order to influence biological processes. The need for cooperation of agents arise from the fact, that in order to measure the parameters characterizing respiration related activities in the reactor, the control of dissolved oxygen in the reactor must be suspended. The two parameters that need to be estimated are Oxygen Uptake Rate (OUR) which characterizes the amount of oxygen being taken up by biomass per unit of time, and an oxygen mass transfer coefficient k_La that characterizes the ability of aeration device to force oxygen from bubbles into the liquid phase in the reactor. Information about respiration of biomass may than be used by other agents to influence the mass balance of activated sludge in the plant, thus indirectly controlling metabolic processes occurring in living organisms that depend on biomass concentration.

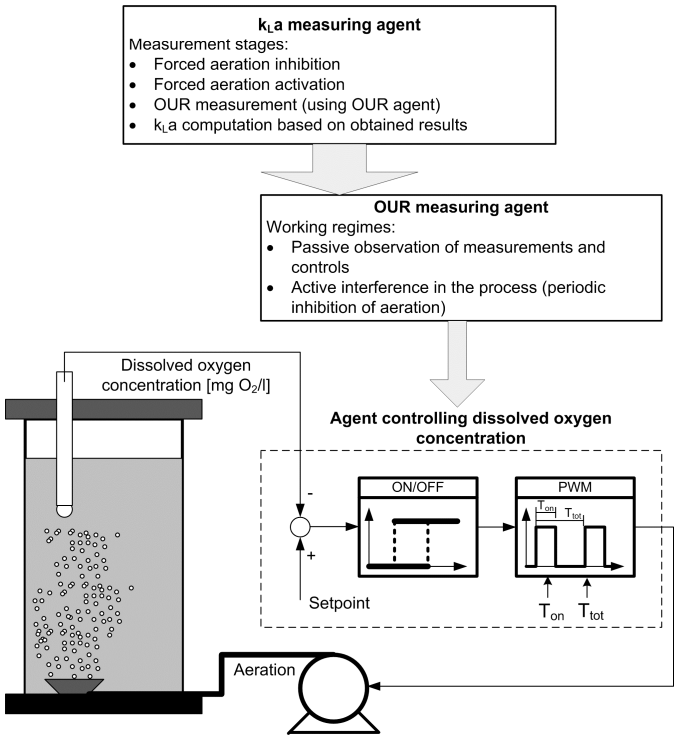


Fig. 1. Schematic of the three agents realizing the presented MAS enabling measurement of OUR and k_La values.

Lipase-based bioaugmentation

Dariusz Choiński

Fats (triacylglycerides, TAG) are the major components of municipal and industrial sewage. At the same time, the fats are also the most troubled component. Literature indicates that fatty substances in the urban waste constitute about 30 - 40% of the total organic matter, expressed as chemical oxygen demand (COD). Fats cause difficulties in operating a treatment plant, since conventional mechanical or chemical methods of removing fat from the municipal and industrial sewage are often inefficient, and resulting sediments need an additional treatment. For this reason, studies focus on purification technologies that use the microorganisms potential of activated sludge.

Decomposition of fats contained in sewage involves the lipolytic enzymes produced by a microflora of activated sludge. As a result of hydrolysis reactions, free fatty acids come into being, which, when oxidized in the process of β-oxidation, may be used by microorganisms as a source of carbon and energy.

The basic research problem which was to be solved (see: III.24, III.25, III.26), was determining how well-known hydrolysis reactions of fats proceed with the cooperation of microbial lipase in an aqueous solution of activated sludge. Even cursory analysis showed that the lipase activity measured within a reactor is at a relatively low level, both when the removal of fats is observed and when it is not. This observation led to the hypothesis that for the hydrolysis of fat reaction to happen, a space where lipase and fat are contained must be limited and shared.

Conducted experiments have confirmed the hypothesis. When drops of fat were present in a floc, in contact with the bacteria that are a source of lipase, the hydrolysis reaction happened. It turned out that an immobiliser of this reaction were flocs of activated sludge. However, the occurrence of reactions with high kinetics within a floc, results in local environmental changes which affect the creation of the active sludge. Further studies have confirmed, that in order to keep the hydrolysis reactions within the floc possible, it is important to cyclically change its flocculational properties (see: Fig.1). This assumption enabled to develop a mathematical model [III.34] facilitating the best control strategy for a reactor. The reactor supports the removal of readily biodegradable biogenic compounds. When bioaugmented with the activated sludge with the lipolytic capabilities, the reactor also supports the fat removal. Researches carried out with the automatically controlled pilot plant confirmed the reactor capabilities. However, further work is advisable to provide better understanding of the dynamic character of the processes, especially when accumulation properties of the activated sludge are taken into account.

During the research the methodology and software were developed, providing reach and promising results, analysis of which is the basis of many publications, both published and planned.

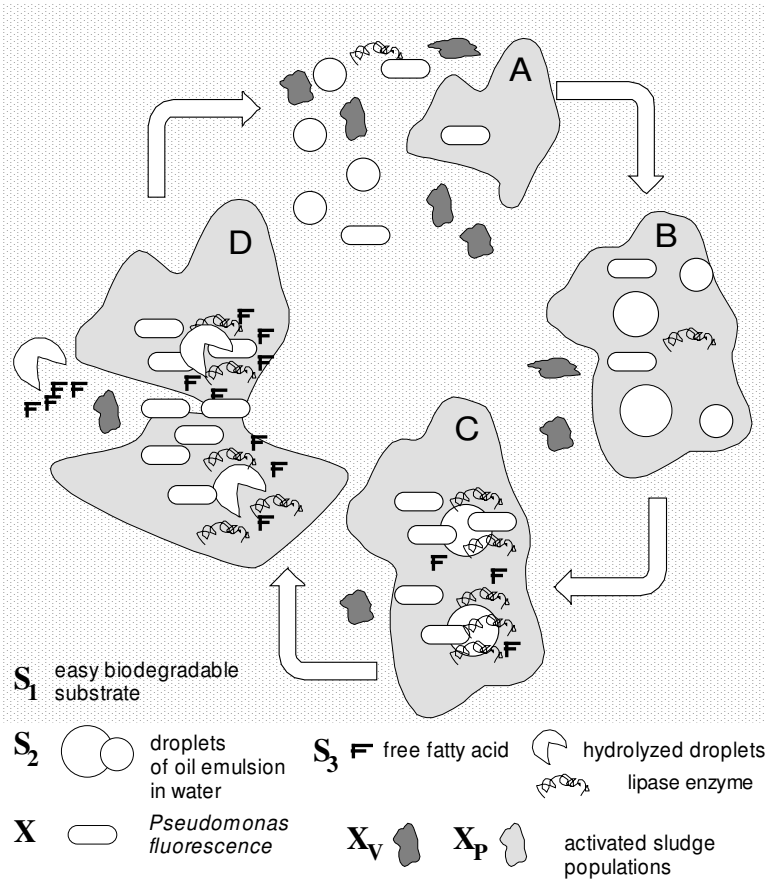


Fig. 1 Diagram of periodicity of formation and destruction of activated sludge flocs, under bioaugmentation, taking into considerations the role of *Pseudomonas fluorescens* cells. A – Floc forming phase, B – Adsorption of *Pseudomonas fluorescens* bacteria to the surface of flocs, C- Intensive hydrolysis of lipids by lipase produced by *Pseudomonas fluorescens* cells, D – Destruction of flocs due to excess of *Pseudomonas fluorescens* cells.

Modelling and simulation of stimulated oscillations of flocullation in bioreactor

Dariusz Choiński, Mieczyslaw Metzger, Witold Nocoń

The mathematical model, proposed in the preceding note and experimentally validated *in-situ* for the bioprocess carried out in our pilot plant, can be very helpful for simulation experiments in which some new ideas can be experimentally verified in a cheapest way. The state variables S_1, S_2, S_3 and X were defined in the preceding note in Fig. 1, while the simplified diagram of bioreactions presents Fig.1 below.

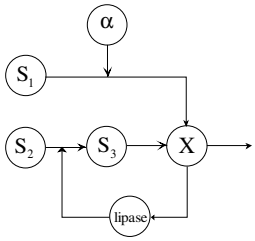


Fig. 1. Simplified diagram of bioreactions under consideration

The real-time simulator (in the scaled fast-time mode) of the bioaugmented process based on the mathematical model has been designed and carried out. Fig.2 presents the operating GUI of the simulator (the mathematical model is depicted in the upper right corner of the GUI window). The bioprocess can be stimulated in several different ways. A very interesting explanation of self-sustained oscillations deals with the oscillating behaviour of flocs formation and disintegration (state variables X_p and X_v).

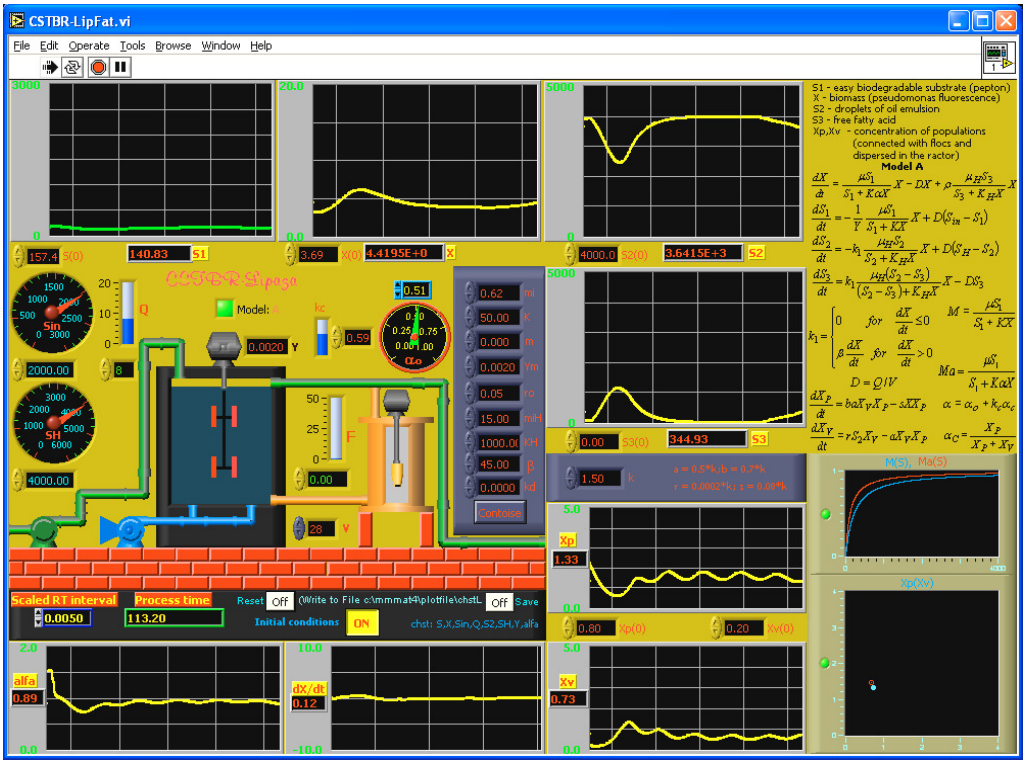


Fig. 2. Operating front panel of the real-time simulator (the mathematical model is depicted in the upper right corner of the GUI window).

Measurement of physical properties of biomass using microscopic camera

Dariusz Choiński, Witold Nocoń, Mieczysław Metzger

The biological pilot-plant installation is being equipped with additional measurement instruments in order to better understand the dynamics behind both biological and physical processes involved. One example of such a measurement device is an optic sensor based on microscopic camera and used to quantify physical properties of the activated sludge.

Figs. 1a and 1b present the sensor together with a flow-through cell. The cell is made of quartz glass enabling experiments with ultraviolet light to be performed as well. The activated sludge the properties of which are being measured flows through this cell and is photographed by a microscopic camera (Dino-Lite).

a) b)

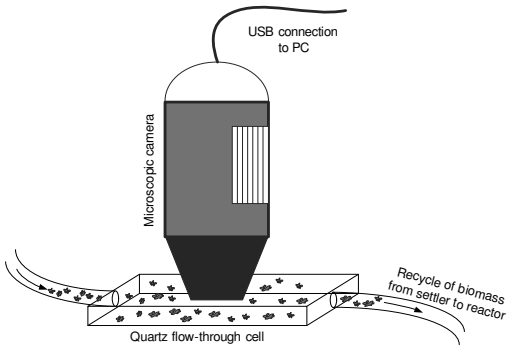


Fig. 1. a) Photo of the sensor, b) Q flow-though cell is used in the sensor.

The microscopic camera is connected to a PC computer using USB interface. The software used for image acquisition and image processing is realized in LabVIEW environment. Additionally, MATLAB functions are using within LabVIEW. The image acquisition module of this application has been created using MATLAB's Image Acquisition Toolbox, while image processing module uses functions of MATLAB's Image Processing Toolbox. The application connects to the pilot-plant control and monitoring software using Data Socket technology (Fig. 2).

The presented measurement system may be used to perform a variety of measurements based on image processing. Figs. 3a and 3b present a raw image and a processed image used for assessing biomass concentration.

Fig. 4a and 4b on the other hand present an example of image processing in which the quantity and size of flocs are assessed.

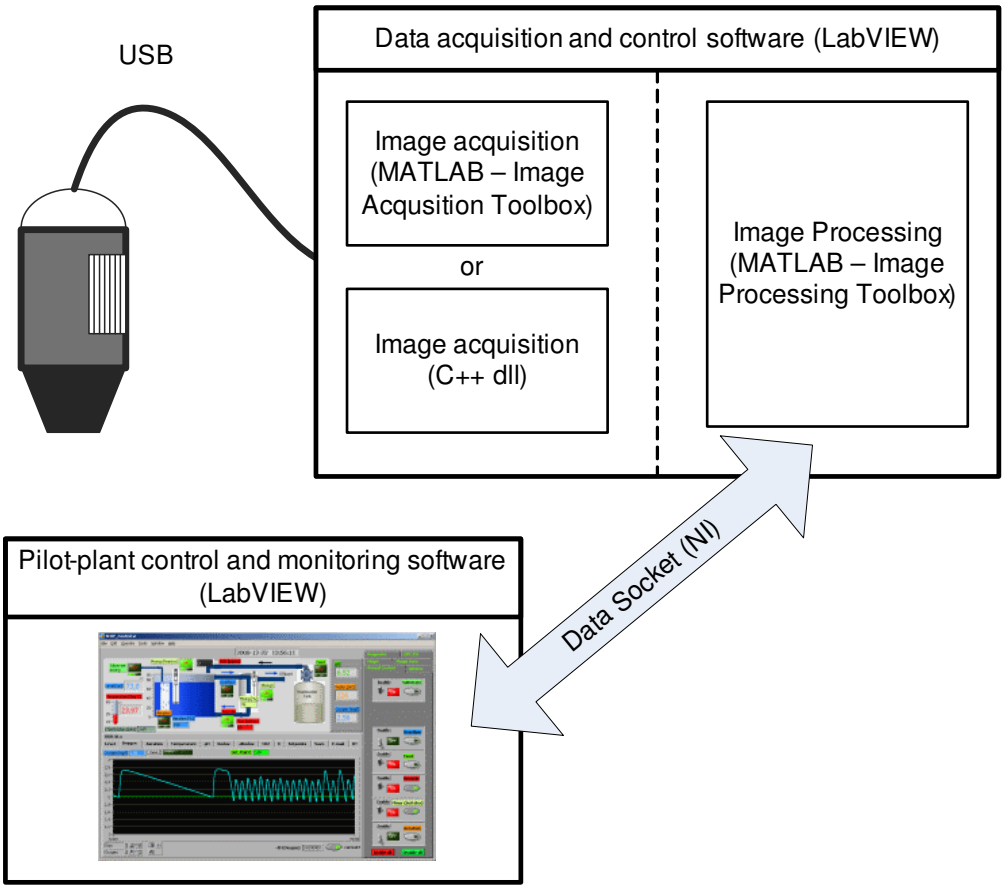


Fig. 2. Connection of the microscopic camera to the pilot-plant control and monitoring software.

a) b)

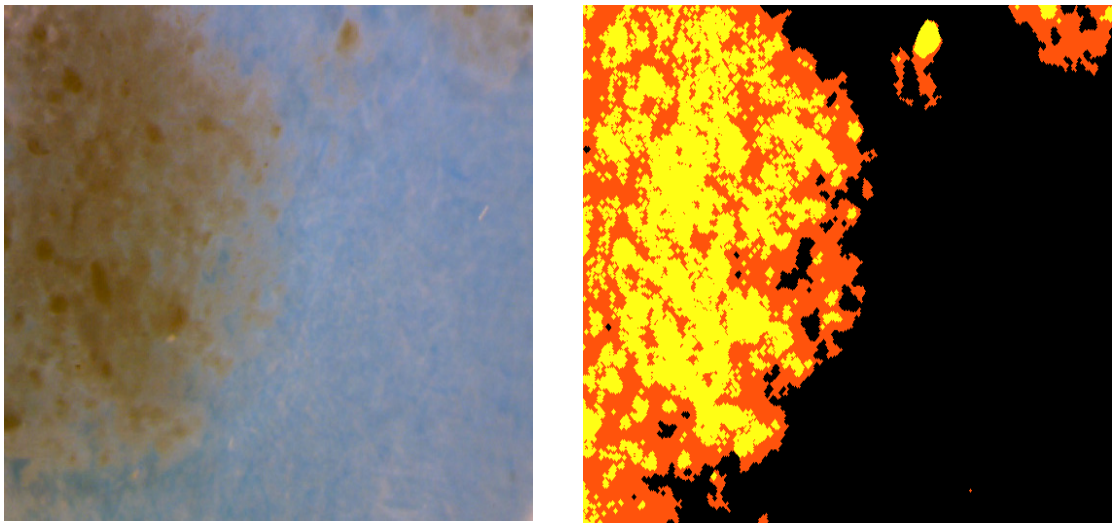


Fig. 3. a) Activated sludge floc. b) Segmentation of the image into regions of high concentration (yellow), medium concentration (red) and background (black).

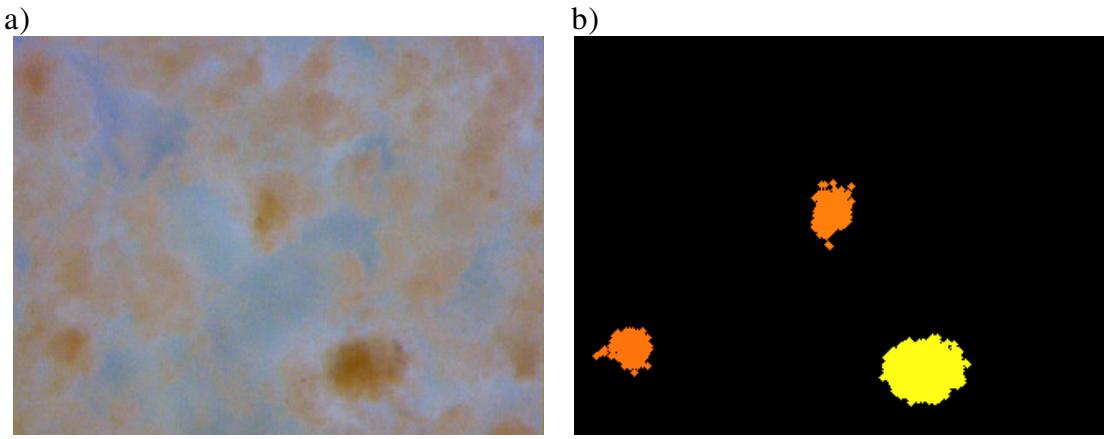


Fig. 4. a) Activated sludge floc; b) Result of image processing presenting flocs presenting large (yellow) and medium (orange) size flocs.

The presented sensor is used to measure physical properties of activated sludge being recycled from the pilot-plant's settler back in to the reactor (Fig. 5)

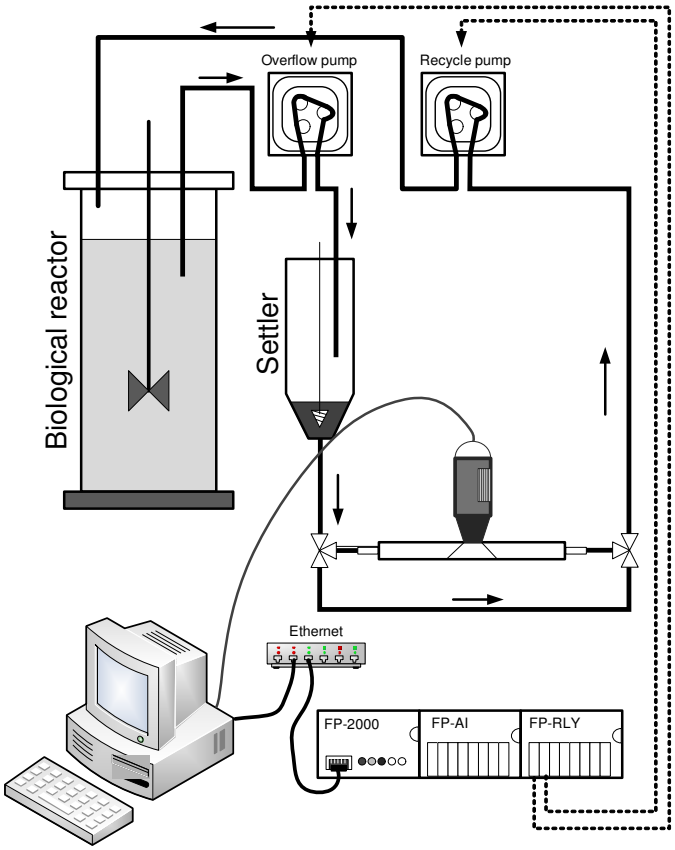


Fig. 5 Sensor together with the biological reactor and settler.

In some cases, this flow must be stopped in order to ensure good quality of the image. The mass balance of activated sludge between the settler and the reactor should not be disrupted in the long term. Therefore, the control software must compensate for any stoppages of flow. Fig. 6 presents the idea of compensating the recycle flow.

Additionally, the flow-through cell may be “taken off-line” using a set of valves and a bypass which enable all the biomass to be directed around the sensor.

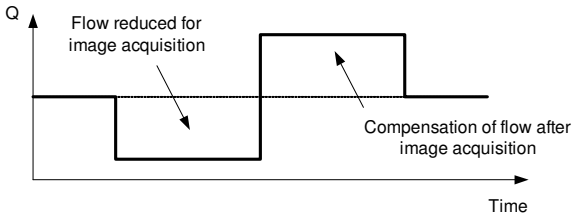


Fig. 6. Compensation of recycle flow after image acquisition.

Model-based operating control of the CSTB in order to improve its productivity

Mieczysław Metzger, Piotr Skupin

This newest work presents the alternative method for improvement of the CSTB productivity. Treating flow rate as an operating control and both substrate concentrations S_{1in} and S_{2in} as control variables (see Fig. 1) two different approaches are taken into account. The aim is to improve productivity of the CSTB. The first approach consists in finding such a substrate, which is characterized by a constant yield coefficient. The latter approach consists in adding another substrate to the system with self-sustained oscillations. In both cases there is a significant productivity improvement in steady states in comparison to the results obtained by A.Balakrishnan and R.Y.K.Yang (Chemical Engineering Communications 189, 2002, 1569–1585).

One of the simplest model of the bioreactor with two different substrates has been shown in Fig.1. The mathematical model consists of three nonlinear differential equations with the state variables X(t), S_1(t) and S_2(t).

In Fig.2 one chosen time transient is presented for S_1 with variable yield coefficient (Y_1=0.03S_1+0.01) and D=0.2[h^{-1}]. Subsequently, at instant t_0=710[h] the second substrate is added to the system. Time response of X(t) (Fig.2) explicitly shows that after instant t_0=710[h] i.e., after addition of the second substrate S_2 self-sustained oscillations have vanished and productivity (X*D) has increased.

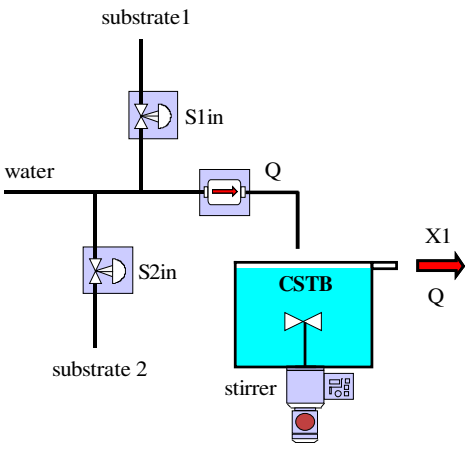


Fig.1. Scheme of the CSTB with two substrates.

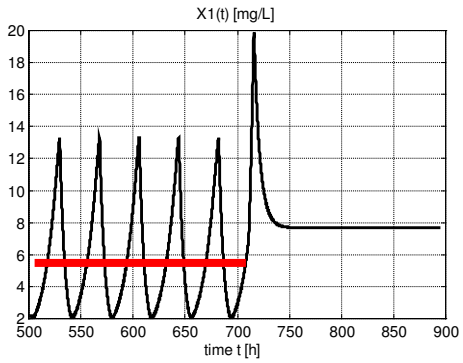


Fig. 2. Time response of X(t)[g/L] for D=0.2[h^{-1}]; at instant t_0=710[h] the second substrate is added to the system; the bold red line represents averaged value of X(t) for self oscillations.

AGENT 007

Introduction

Mieczysław Metzger

Nowadays automation and information systems designed for industrial plants are complex, large and include a lot of different components such as control instrumentation, control software and communication networks. An integration of the process control system and finally an operation of the process during normal exploitation as well as in emergency situations are difficult tasks. For this reason an advanced control system (apart from standard controllers and computers) should include several additional techniques such as real-time communication with databases or agent-based and holonic control systems.

Fundamentals of agent-based theory seem to be well-defined in recent publications over the last decade. Such technology is very convenient for network–based distributed database systems, artificial intelligence and computer science. One can found some propositions for manufacturing control and mobile multi-robot systems.

A big effort was made over the last years in the CSCI group for adaptation the agent and the holonic technologies for process control. The year 2007 (in which our first publications were published in the Springer Lecture Notes serie) was crucial for our investigations. The following notes present the most interesting results.

Holonic and Multi-Agent Systems for hybrid hierarchical control of bioprocesses

D. Choiński, W. Nocoń, M. Metzger

For biotechnological processes, which include very complex biological, chemical and thermodynamical processes, the distributed control system should take into consideration a flexible cooperation with database in different levels of control and remote access for experts, especially in emergency situations. Therefore, biological processes are especially sensible to inadequate decisions. Hence, a complex control systems should bundle different hardware and software technologies, the later being especially important, for accomplishing such tasks. The major problem deals with appropriate synthesis of flexible network-based computer and control instrumentation system, which should make a flexible access and update of control data, process events, operator and external expert decisions and negotiations possible – all viewed and actualised in real time.

The papers [III.3, III. 8, III.10] present a hierarchical and multi-agent control and information system with real-time update of a self-organising database, as well as with negotiation capability for control events and decisions. Architecture of the multi-agent system is presented in Fig.1, while Fig.2 shows an example of object states transition in hybrid hierarchical and multi-agent control system.

A practical application is presented, that utilizes the OPC technology in the continuous-time part, and scripts using XML in the discrete-time part of the system for negotiation and cooperation in multi-agent environment. The multi-agent feature is

applied as an improvement to a advanced biotechnological process control in the pilot plant.

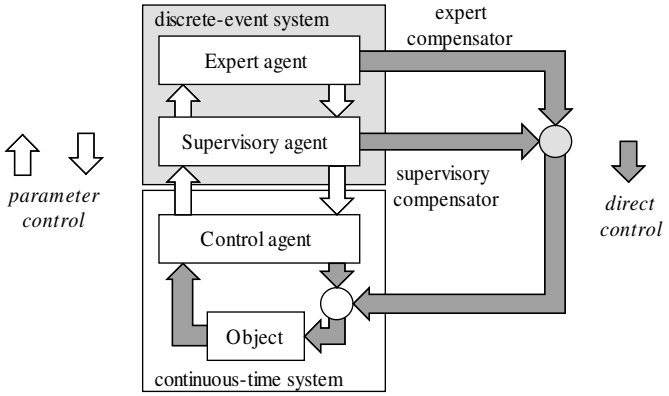


Fig. 1. Architecture of the multi-agent system.

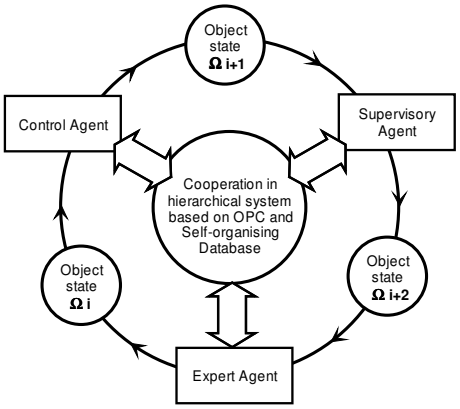


Fig. 2. An example of object states transition in hybrid hierarchical and multi-agent control system.

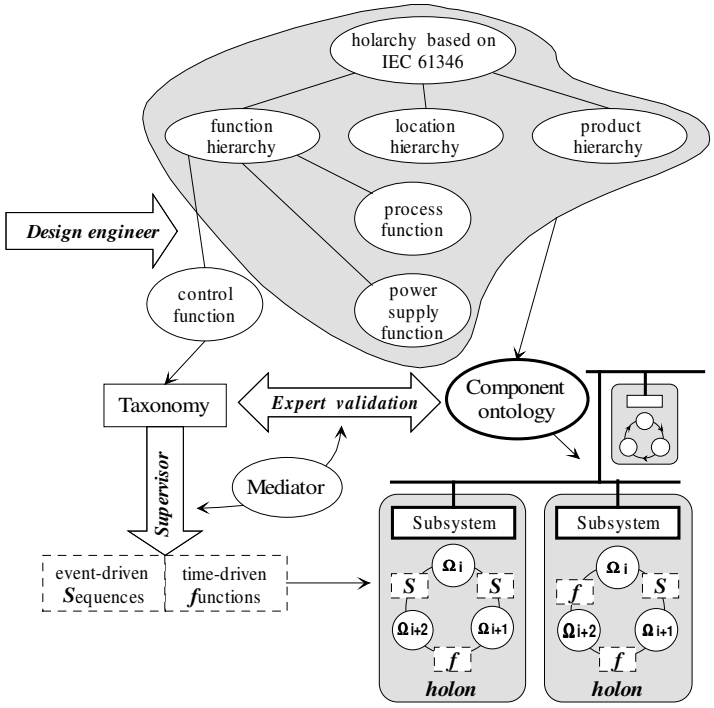


Fig.3. Holonic composition for MAS.

Design of a multidisciplinary project is a complicated process requiring cooperation of different designers specialized in particular branches of engineering (technology, construction, power supply, control etc. Every entity of the system being designed is not only an element of the designed hierarchical structure, but is also assessed and validated with respect to the stated requirements.

The main problem is validation, which requires a new structure to be realized within the existing structure, so that the new functions do not violate the previously designed and used functions. Therefore, the validation stage must usually be preceded with a reduction stage, for summarizing entities to an appropriate level of abstraction. Such a presentation of the problem enables employment of a holonic system paradigm. Realization of this paradigm requires a data model that represents a set of concepts

within a component and the relationships between those concepts, namely an ontology. The ontology-based division into subsystems may further be exploited by extending each subsystem with a software part. The paper [III.4] proposes a holonic approach to validation of distributed control systems considering also its hybrid architecture. The proposed holarchy (Fig. 3) includes a multi-agent system (MAS), connected with a self-organization database and ontology-based technology rules decomposition.

LabVIEW-based framework for distributed control systems, distributed real-time simulation and IEC61499 compliant device

G. Polaków, M.Metzger

Idea of networked software agents is particularly popular in the field of information sciences dealing with distributed content, whereas in industrial automation its use is usually limited to manufacturing systems. The work [III.23] presents a concept of multi–agent networked system for automation of continuous processes. Some properties of typical software agent (i.e. advanced high level languages and social skills) had to be dropped in exchange for determinism and satisfying time performance in negotiations between network–connected control components. The proposed environment is National Instruments LabVIEW, very popular solution for automation and measurement. LabVIEW is equipped with advanced data acquisition tools and is capable of artificial intelligence methods, although it lacks agentification mechanisms. A framework is presented, providing LabVIEW the required functionality.
System built of such agents offers large potential for integration of hardware and software modules of varying types and construction (see Fig. 1).

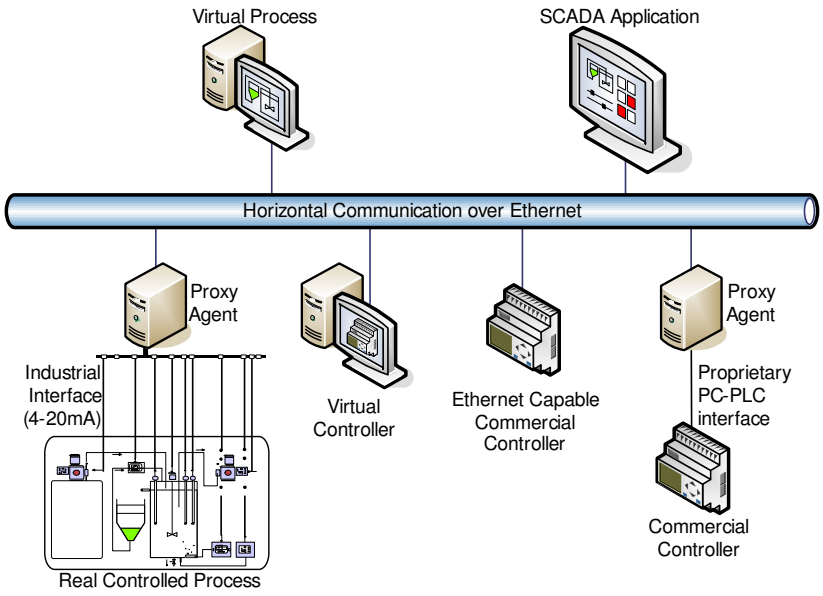


Fig. 1. Example of system structure achievable with the presented framework.

Most common types of agents include:

- HMI interface (visualisation of system performance, acquisition of user input);
- Virtual process (embeds mathematical model of process in the real-time – see III.26);

- Control algorithm (embeds a set of mathematical equations forming algorithm);
- IEC 61499 Compliant Device for Holonic Systems (see III.27).

Such modules may be implemented in:

- software (computer program running on desktop PC);
- hardware (commercially available programmable logic controller, some of them are connectible to Ethernet and can implement full framework functionality).

Special type of module is Proxy agent. Its role is translation of messages transmitted with the common protocol to/from custom hardware, which is physically incapable of the framework connectibility itself. Usually such hardware is connected with a kind of specialized interface card to personal computer (for example Simatic controllers are connectible to PC using the MPI/PPI interface). Such computer can run custom designed proxy agent, thus integrating hardware into framework. Two most often kinds of proxy agents are ones interacting with:

- Commercial programmable logic controllers (often executing control algorithm but not limited to them);
- Real process plants (sensors and actuators connected to specialized PC card by analog industrial standard 4–20mA or 0–10V).

Proper use of the framework and proxy agents allows for integration of various proprietary communications systems into working uniform control system.

Context Model for Multi-Agent System Reconfiguration

K. Stebel, D. Choinski

This paper presents a reconfigurable multi-agent system (MAS) applied to distributed control system (DCS). Agents co-operate, evaluating the system on different levels of information abstraction (see Fig. 1).

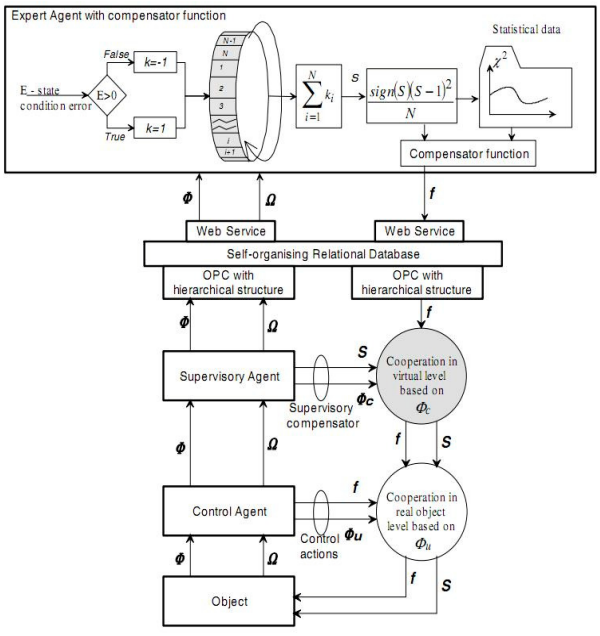


Fig. 1 Reconfigured agent-based hybrid system.

Context-based statistical remote expert agent or local supervisory agent are used to evaluate control agent performance (see III.30). Using expert-selected period of good performance the reference distribution function is proposed. Periodically, for any monitoring period, a sample of observations is taken for local or remote system performance monitoring. Because evaluation may also be carried out remotely two cases should be considered. Remote expert observes changes of parameters that come from process performance degradation. Second case refers to communication problems when data transmission is corrupted and can not be used for system evaluation.

Because of that application, context model is necessary to inform the remote expert about transmission quality. For evaluation of transmission channel, the idea of a context tree is utilised.

Holonic Multiagent-Based System for Distributed Control of Semi-industrial Pilot Plants

M.Metzger, G. Polakow

Semi-industrial pilot plants [III.15] are the best experimental domain for advanced control systems testing with the real-world instrumentation. At the same time, inexpensive flexible process real-time simulators and virtual soft controllers are indispensable in the research and education field. Integrating control instrumentation of varying manufacturers, plant simulators, and virtual controllers into uniform system capable of flexible research and educational experiments is a complex problem to solve. A tool is needed to describe and organise knowledge on such integrated structure involving many communication channels and using distributed processing power. In the presented case-study [III.15], holarchy paradigm is applied, resulting in an untypical holonic multiagent system. The concept, architecture and development of application framework for the system are also presented.

The physical structure of system under consideration is shown in Fig.1, whereas Fig. 2 shows holarchy as a method of system integration.

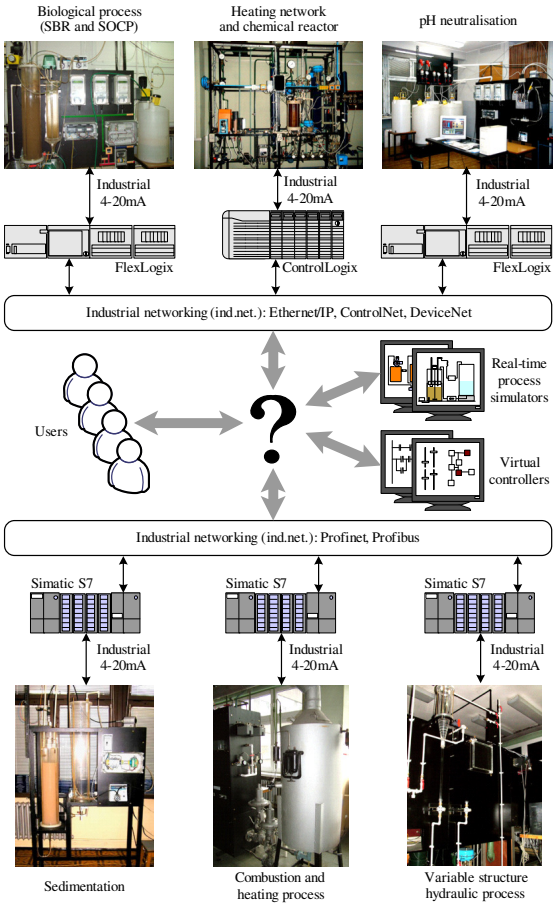


Fig.1. Physical structure of system under consideration.

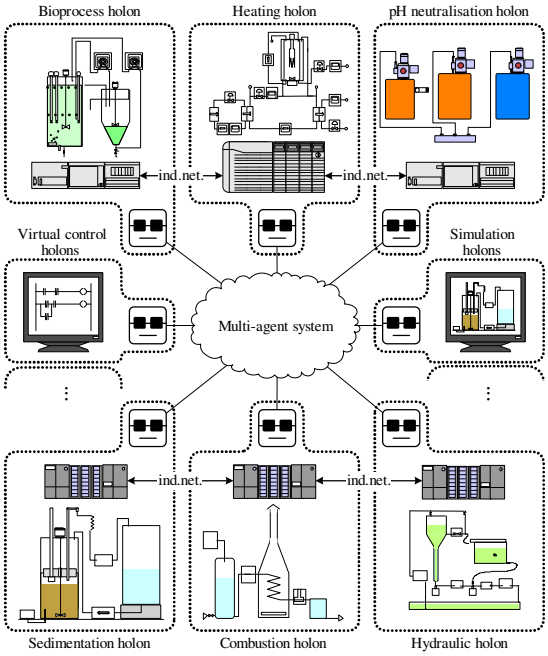


Fig.2. Holarchy as a method of system integration.

DCS, COOPERATIVE AND SELF-ORGANIZING SYSTEMS

ppPDC Communication Framework

Grzegorz Polaków, Mieczysław Metzger

Parallel processing Producer-Distributor-Consumer (ppPDC) transmission scenario is proposed and developed for improving communication features of the Ethernet-based switched industrial networks. First version of ppPDC-based communication infrastructure was developed in the LabVIEW graphical programming platform as a flexible and low cost framework. Further development of the framework turned it into a fully functional real-time middleware, which has the main advantage of running the message processing in the protocol stacks in parallel, thus minimising the impact of nodes processing times on network efficiency. The proposed ppPDC-based communication infrastructure, amongst many other possible uses such as intelligent multiagent systems, can be well-suited in distributed robotics [III.25].

The ppPDC data distribution scheme is the result of works on implementation of the classical PDC scheme in Ethernet networks. During the development it turned out, that some of the functionalities of the PDC scheme are redundant. The PDC scheme fulfils a double role in the networking stack. On one hand, it is the internal mechanism of distributed database of variables and messages, and on the other hand it manages the shared physical medium to avoid frame collisions. In switched networks functionality of medium access control is performed by hardware and it can be dropped from the protocol itself. The ppPDC scenario keeps the original idea of division of network nodes into two groups i.e. *producers* and *consumers*, while the communication between all the nodes is maintained by the additional privileged node called *the distributor*. It is the order of transmission of frames which was changed in the ppPDC protocol. A comparison of sequences of transmissions between PDC and ppPDC communicational schemes is presented in Fig .1.

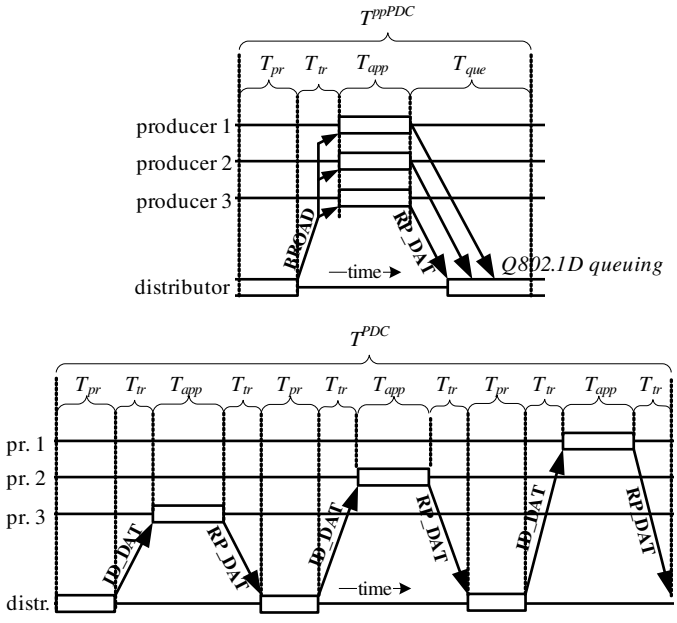


Fig. 1. Comparison of sequences of transmissions between PDC and ppPDC communicational schemes.

Decomposition of Information for Plant Collaborative Design, Validation and Set-Up in Distributed Control Systems

Dariusz Choiński, Mieczysław Metzger, Witold Nocoń

A problem of coordinating engineers working in different fields during design and control of an industrial installation is especially difficult during start up and modification of the process. Any work carried out in such a case must be coordinated in real time. Moreover, level of access to information is differentiated for different branches of engineers. In the work [III.6] a hybrid agent-based system for cooperative plant design and set up of the biotechnological pilot plant is proposed. The major contribution deals with decomposition of biotechnological plant information by hybrid agent system for enhancing cooperation of experts having different knowledge about the process (see Fig.1). Hybridisation of the process is performed considering nine states, while estimation of the information distance is performed based on partial Kullback-Liebler cross-entropy function. Experience gained during design and exploitation of the mentioned biotechnological pilot-plant suggest this solution to be promising.

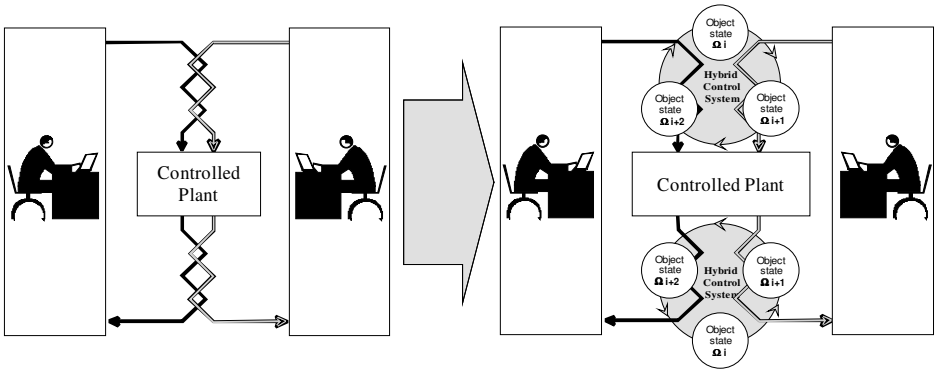


Fig.1. Information decomposition by MAS based on hybrid control system.

Our research, using a biotechnological pilot-plant as an example, has proven that the control system may be represented by a hybrid system model. This system consists of an automaton having a finite number of states. Transition conditions between those states are described by two sets defining controllable and uncontrollable events. Control of a system modelled in this way is realized within MAS. The control agent tries to maintain the given state despite disruption caused by uncontrollable events, while the supervisory agent tries to change the current state into another desirable state, by applying a sequence of controllable events. Any transition functions that are missing or not specified, may by developed by an expert.

Because of technological constraints and limited capabilities of measurement, control and powering devices and also because of the information structure of the distributed communication equipment, the system has been divided into subsystems. This division is based on ontology that takes the semantics used in CAD systems into account. Apart from the subsystems, the system possesses defined functions, the taxonomy of which is based on phenomenological models. The main technological concepts are based on those phenomenological models. Architecture of the proposed system [III.5] is presented in Fig. 2. The latest results deal with cooperative operating control based on Virtual Resources and User-Suited HCI [III.9].

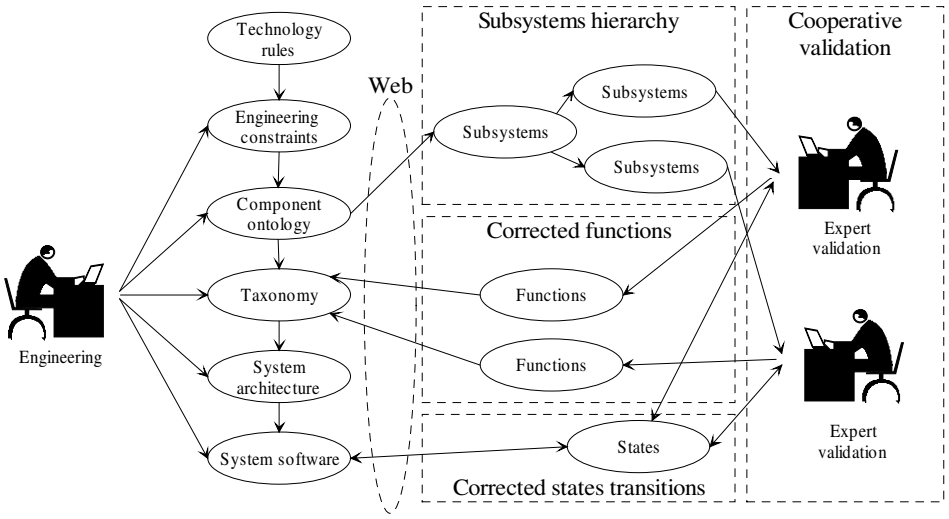


Fig. 2. Concept of the hybrid system.

Web-Based Monitoring and Visualization of Self-organizing Process Control Agents and Human Cooperation

Grzegorz Polaków, Mieczysław Metzger

The work [III.24] addresses the problem of visualizing interactions between agents self-organizing in a non-codified way. This kind of behavior emerges from a human factor, which is heavily involved in the presented case of multiagent system. Tasks and intentions of users present in the system are unknown and the proposed method of analyzing and debugging temporary structures emerging in the system is the eavesdropping of the communication between the actors. A separate software service is proposed, which makes the inferred structure data accessible by an external higher scale system. An example of visualization is provided in the form of SVG-based interactive dynamic block diagram.

The approach to the visualization of the agentified system takes into the account a presence of the specialized visualization interface. Such an interface is usually implemented in all control systems using some type of data access standard (Web Service, OPC standard). A typical structure of a SCADA (Supervisory Control and Data Acquisition) system connection with the control system is shown in Fig. 1a.

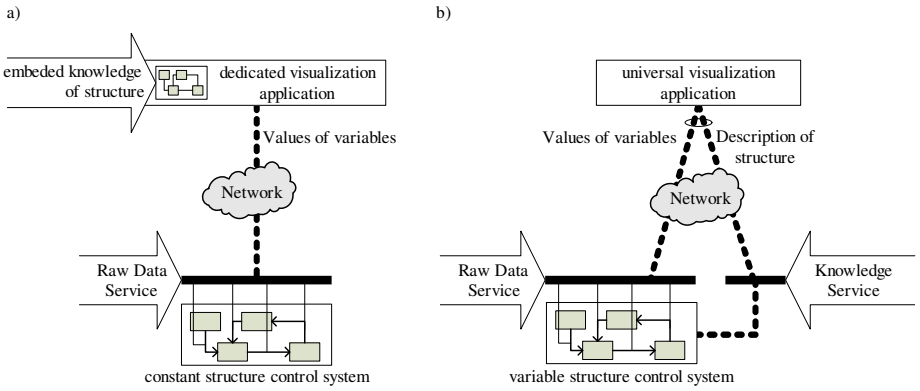


Fig.1. a) Architecture of visualization for constant structure systems b) Architecture with complementing knowledge service for systems with variable structure.

The control system's data in the form of numerical values of measurements are available through the standardized interface, designated here as Raw Data service. The content of the transmission stream gives no knowledge on current state of the system until raw data are correctly placed in the system's structure according to its meaning. In a traditional visualization application, this knowledge on data's meaning is embedded in the executable code of an application, because the mesh of connections in the system is constant, and can be stored once and for all. In case of a system with variable structure, a method of a structure description has to be developed. The proposed architecture shown in Fig. 1b introduces an additional interface, called the Knowledge Service, whose main task is serving the knowledge on the current state of the structure. The union of abstract knowledge from the proposed service and the raw data from the classic interface gives the full state of the system in a given moment.

Implementation of the proposed Knowledge Service enables the system to be treated as a part of higher-level large-scale system, which may incorporate multiple local self-organizing systems, visualizing and comparing them. The proposed framework can be also introduced for visualization of collaboration between humans (students performing experiments [III.28]).

An example of the achievable visualization of the user collaboration is shown in the Fig. 2. It is seen that there are three clusters of agents and users, a skilled supervisor can easily infer that there are currently two process control experiments performed and one additional monitoring process is executed. Students involved in each part of each experiments can be clearly identified, and their role can easily be distinguished.

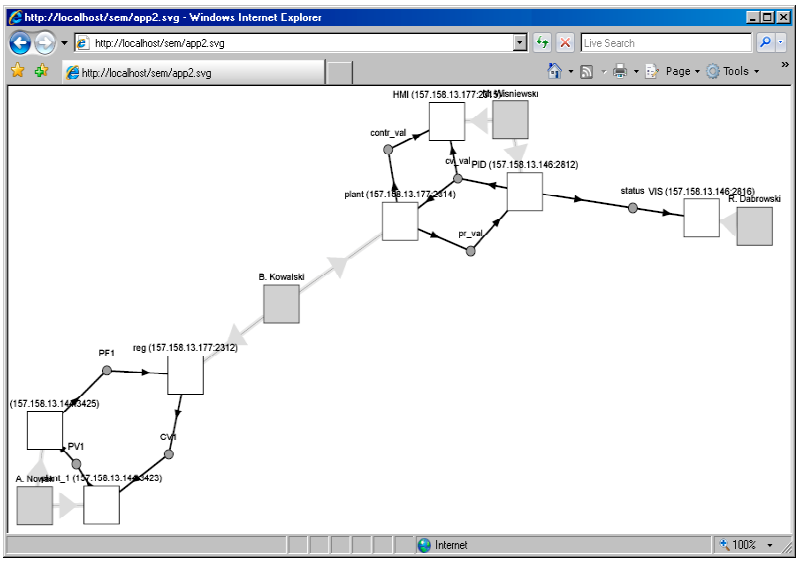


Fig.2. The visualization of the logical connections in the system with user associations taken into account.

Cooperative Internet-Based Experimentation on Semi-industrial Pilot Plants

Mieczysław Metzger, Grzegorz Polaków

In the work [III.16] a framework for cooperative experimentation with semi-industrial pilot plants is presented. A software solution designed to support multi-user cooperative experimentation is described, along with the supporting hardware, which was specifically designed for the task. A structure of dual networking is proposed, with

horizontal real-time protocol for hardware integration and vertical multi-user access points for human interaction. To avoid potential conflicts between users, prioritisation is performed, as resources available (time, hardware, and data) are limited. An important sub-problem is described in details, i.e. large groups of students splitting into smaller subgroups, collaboratively performing partial experiments in order to achieve solution of problem stated by an instructor. Work and data flows have to be carefully designed to keep control of the collaboration, an example of such schedule is provided and described.

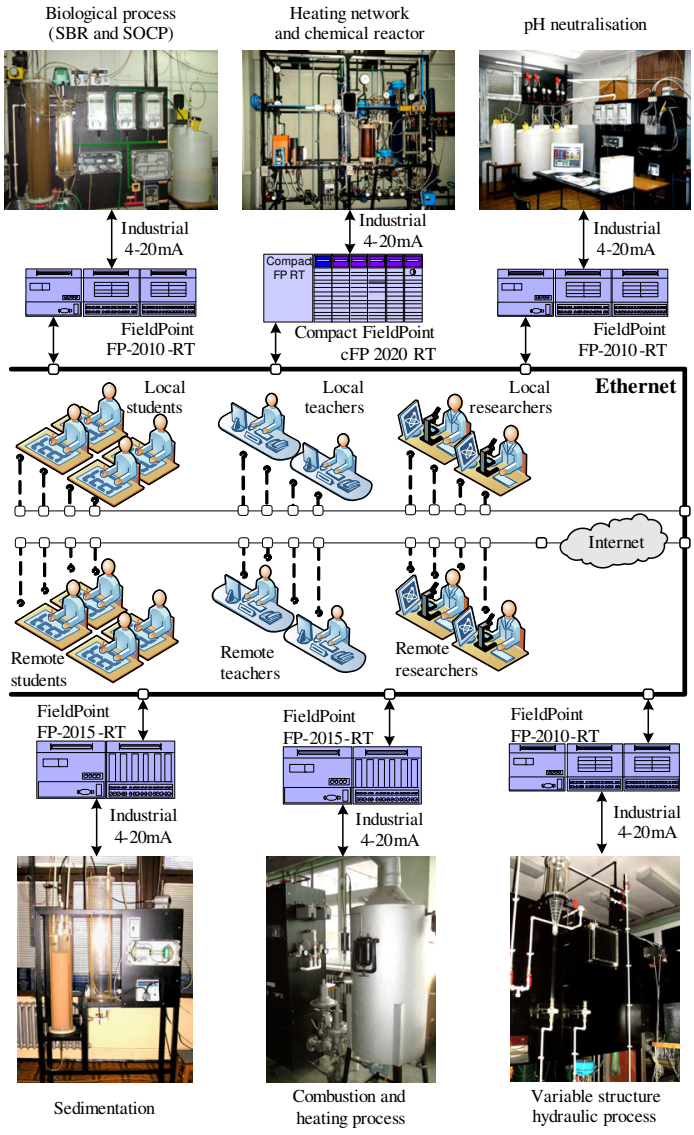


Fig. 1. General structure of the system.

Experimental Testing of TCP/IP/Ethernet Communication for Automatic Control

Przemysław Plesowicz, Mieczysław Metzger

The TCP/IP/Ethernet protocol is considered not suitable for use in real-time control systems. It deals with a lack of time determinism, which characterizes fieldbuses. Nevertheless several corporations propose networking based on the TCP/IP/Ethernet

even for control purposes with some modifications of the standard however. The paper [III.22] examines possibility of application of the TCP/IP/Ethernet communication without modifications (introducing also Internet as one of tested cases) for feedback control purposes. Experimental investigations have been performed in four stages. In the beginning tests of network properties, including tests of transmission time and packet loss measurements have been performed. Three following stages show experimental testing of feedback control, when TCP/IP transmission occurs between PI controller and control plant. Three representative platforms have been chosen for testing: LabVIEW, RSLogix (see for example Fig.1) and Simatic. The main and original contribution presented in this paper is design and construction of three test stands as well as methodology of testing experiments. Standard control over analog channel has been also presented as comparison. The results of testing show acceptable performance of control via TCP/IP/Ethernet networking.

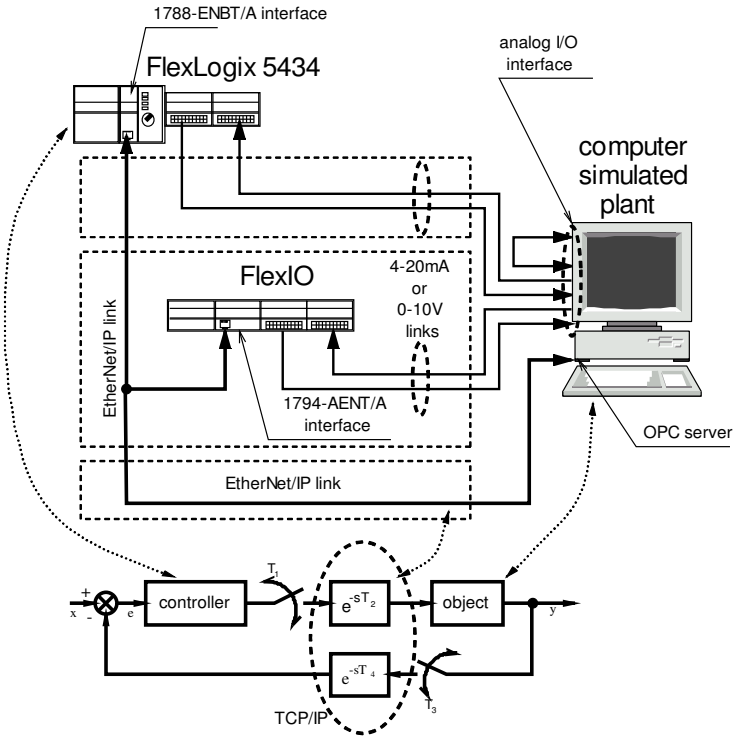


Fig. 1. Architecture of comparative test setup (Logix, EtherNet/IP)

Systems Engineering Group

The activity of the **Systems Engineering Group** is concentrated in three main domains:

- biological applications of system theory and bioinformatics,
- image processing and pattern recognition,
- discrete events systems and computer integrated manufacturing.

It is interesting that these three branches in spite of their different roots can be efficiently applied in a number of projects in genetics, functional genomics, molecular biology as well as support medical diagnosis and design of therapy. Therefore, along with theoretical research activities, which are still performed in collaboration with researchers from other groups (mainly Control and Robotics Group), the Systems Engineering Group is engaged in a number of projects developed in collaboration with the Institute of Oncology. These are directed towards classification, clusterization and selection of gene expression data from microarray experiments, modeling and control of cancer population growth, statistical analysis of DNA damage/repair process, pattern recognition, filtration and disturbance enhancement of biological images including gene and protein gels, DNA micoarrays, and results of various diagnostic investigations and finally operation research and artificial intelligence tools in genomics and molecular biology.

BIOMATHEMATICAL RESEARCH

Peak alignment in protein spectra

M. Marczyk, J. Polanska

Accurate classification of patients with complex diseases such as cancer is crucial for successful treatment of the diseases. High-throughput proteomics techniques based on mass spectrometry (MS) have made it possible to investigate proteins over a wide range of molecular weights. The advancement of these techniques has generated many analytic challenges, among which a central task is to discover 'signature' protein profiles specific to each pathologic state (biomarkers). Algorithms of extraction of biomarkers have been a topic of numerous studies. An important issue in analyzing MS data to screen for disease-associated proteins is to extract as much information as possible from a limited number of noisy samples and to avoid selecting biomarkers whose performances are influenced mostly by non-disease-related artifacts in the data. Effective and appropriate use of bioinformatics tools becomes very critical.

In the study a testing of different methods of protein mass spectra pre-processing is conducted, evaluating their influence on peak extraction results. Thanks to the cooperation between the Silesian University of Technology and Institute of Oncology in Gliwice, there is an access to many real mass spectrometry data, however, to increase a range of comparison of the algorithms virtual mass spectrometer is also used for data generation. Peak alignment is a very important element of MS data pre-processing. For some datasets, generated in single batches of mass spectrometers, aligning different spectra may be omitted. However, it becomes crucial when different batches, different machines are used to generate spectra, or spectra are generated over an extended period of time.

Molecular Genetics at the Institute of Automatic Control

J. Rzeszowska-Wolny

The opening of the biotechnological direction of studies at the Silesian University of Technology had the stimulatory effect of organization of a molecular genetics laboratory. This laboratory, organized by the Institute of Automation, is equipped with most of the instruments needed for studies in modern molecular biology and genetics such as microcentrifuges, eqipment for electrophoresis, cell and tissue culture, high performance liquid chromatography (HPLC), light and fluorescence microscopes, and polymerase chain reaction (PCR) apparatus for standard and real time reactions.

The scientific program of the laboratory is realized in cooperation with the Center of Oncology in Gliwice and focuses on molecular mechanisms of cellular response to DNA damaging factors and on differences of individual sensitivity to such factors in human populations.

The role of poly (ADP-ribose) polymerase activation in cellular response to oxidative stress

Poly(ADP-ribosyl)ation, a reversible post-translational modification of proteins in eukaryotic cells, is believed to be important for the regulation of many fundamental cellular processes including DNA repair and genome stability, transcription, replication, cell division, apoptosis and necrosis. ADP-ribose polymers are rapidly synthesized from nicotinamide adenine dinucleotide (NAD^+) in cell nuclei by the polymerases PARP-1 and PARP-2 in response to DNA strand interruptions and proportionally to the level of DNA damage. We studied the role of ADP-ribosylation in recovery from damage using cultured cells exposed to different DNA damaging agents in the presence or absence of PARP inhibitors or of some derivatives of dihydropyridine that were able to stimulate PARP. We showed that the poly(ADP-ribose) level during the first minutes of recovery of cells from exposure to H_2O_2 or ionizing radiation determines the speed and efficiency of DNA break rejoining. These studies demonstrate the importance of an early synthesis of poly(ADP-ribose) in DNA repair, and support the idea that poly(ADP-ribose) formation reflects rapid assembly and efficient functioning of repair machinery. The changes of PARP activity during the cell cycle and intercellular differences in PARP activation are currently under study. These studies induce cooperation between molecular biologists and bioinformaticians specializing in image analyzing methods, as most of the results originate from fluorescence microscopy and images of cell populations are labeled with more than one antibody or fluorescent dye (Fig.1). To be automatically analyzed, these images need some specific non-standard approaches to image segmentation and processing .

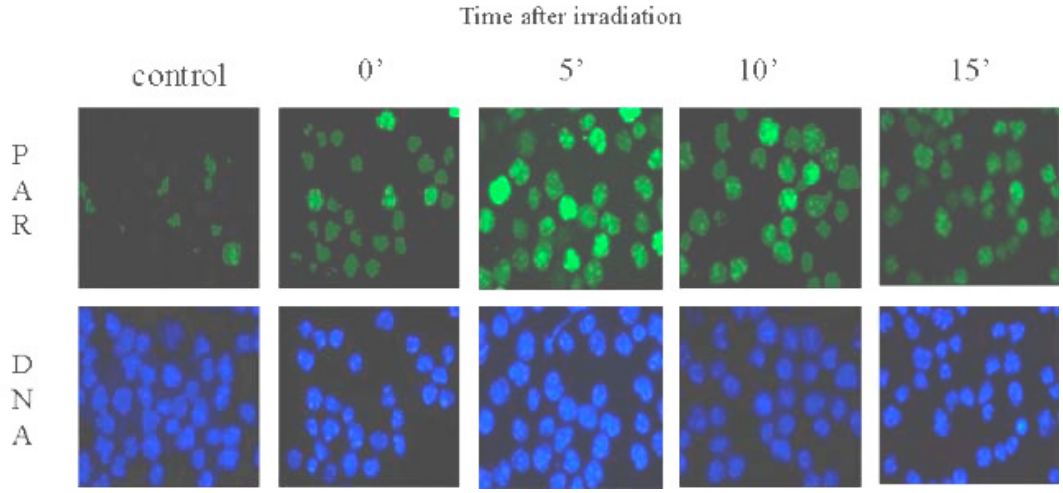


Fig. 1. The synthesis of poly(ADP-ribose) (PAR) in Raji cells exposed to X-rays. Upper row shows labelling with anti - poly(ADP-ribose) antibody in control cells and at different time after exposure to X-rays, and lower row the same cells stained with DAPI dye that stains DNA

Radiation-related changes in gene expression profiles assessed by oligonucleotide microarray methods

The relative abundance of different transcripts is a molecular phenotype characteristic of cell type and physiological state. In our investigations we analyzed the influence of ionizing radiation on gene expression in human cell lines: melanoma Me 45, leukemia K 562, colon cancer RKO, and HCT cells. Cell cultures were exposed to 4 Gy of ionizing radiation and total RNA was isolated at different times after irradiation (immediately, 12, 24 and 36 hours) and used for microarray and real-time PCR analyses. The data from microarrays (Affymetrix) were normalized and analyzed with the FatiGO tool. Irradiation induces damage in cellular macromolecules by direct ionization or indirectly through oxyradical products of water radiolysis, with DNA as the most critical target, and damaged cells initiate DNA repair processes and intra-and inter-cellular signalling pathways that delay the cell cycle and modulate gene expression. Characterization of the transcriptional reprogramming induced by radiation is an important step in understanding these processes, and microarrays with different experimental and analytical approaches have been used for this purpose in our and other laboratories. In Me45 and K 562 cells ionizing radiation caused rapid, synchronous down- or up-regulation of similar large groups of genes in both cell lines; however, during the next 36 hours differences between melanoma and leukemia cells appeared. Genes involved in six processes showed significant changes of transcription, as recognized by statistical tests. The lowest p values were shown by groups of genes coding for proteins that take part in detection of external stimuli which were mainly down regulated, and those coding for proteins that take part in DNA metabolism which showed the greatest increase of transcription. Table 1 presents the biological processes to which the largest numbers of genes that changed transcription immediately after irradiation were assigned by the FatiGO program.

Table 1. Processes in which genes up- or down-regulated immediately after irradiation participate* Process* Up Down

Transcription	123	202
Nucleotide, nucleoside, and nucleic acid metabolism	121	196
Transport	93	216
Surface receptor-linked signal transduction	93	206
Intracellular signaling	79	137
Response to biotic stimulus	77	171
Protein modification	76	111
Cell proliferation	71	123
Phosphate metabolism	53	88
Pathogen/parasite response	41	104
Organization, biogenesis	36	67
DNA metabolism	36	30
Macromolecule catabolism	34	91
Detection of external stimuli	13	78

*defined by the program FatiGO

Microarray experiments produce massive amounts of data, and mathematical tools to analyse genome-wide expression in terms of single genes have therefore been developed. Cooperating with bioinformaticians, we have developed a few procedures to study changes in genome-wide expression profiles which are induced by external stimuli and one of the most profitable was the approach with the Gaussian mixture model. In this unsupervised method the Metropolis-Hastings algorithm was used to determine the Gaussian fractions best fitting to experimentally obtained histograms. The Gaussian fraction patterns were characteristic for cell type and changed after irradiation with gamma rays.

The role of intercellular communication in cellular response to genotoxic factors; the ionizing radiation-induced bystander effect

Cells exposed to ionising radiation (IR) transmit signals which induce DNA and chromosome damage, mutation, and apoptosis in non-irradiated cells, termed bystander effects, which are also induced by growth in medium from irradiated cells (irradiation conditioned medium, ICM). These signals released by irradiated cells may cause heritable genome instability in neighbouring unirradiated cells. Our studies on the irradiation-induced bystander effects in different cell types were performed by placing

control non-irradiated cells in culture medium collected from irradiated cells and observing the changes. We confirmed most of the observations concerning the induction of DNA damage and chromosomal aberrations by ICM and proved the engagement of some oxidizing agents in the process. To examine possible changes in transcript profiles following transfer of cells into ICM we used oligonucleotide microarrays, sampling after different time periods to detect early and persistant effects. In two different cell lines studied until now, the effects of direct irradiation and ICM were very similar. It seems therefore that signaling factors in the medium of irradiated cells cause reprogramming of transcription, revealing a new facet of the bystander effect.

Molecular and genetic background of radio-resistance and radio-sensitivity in human population; polymorphism of cancer-related genes

Cells of the same type from different individuals show differences in the level of DNA damage and in the kinetics of its repair in response to the same dose of a genotoxic factor (Fig. 2) . These differences in DNA damage and repair may depend on the genetic background, and particularly on the existence of polymorphic variants of genes coding for DNA repair enzymes .

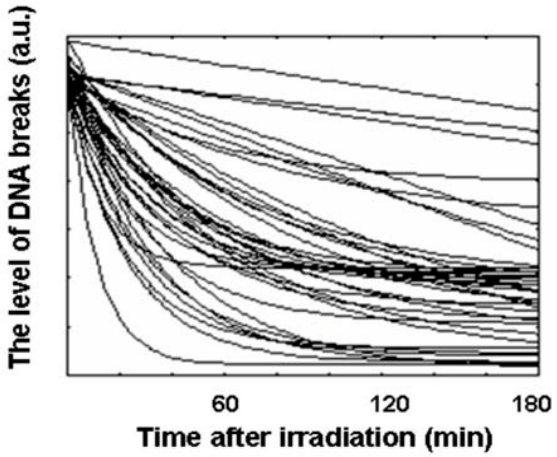


Fig. 2. Interindividual differences in DNA repair. Lymphocytes obtained from the blood samples of individual donors were irradiated and the level of DNA breaks was measured by comet assays at different times after irradiation. Each curve shows the results obtained for lymphocytes of one individual donor.

To explore factors which cause cells of the same type from different individuals to respond differently to ionising radiation, we examine the relationship between the frequency of DNA breaks and the kinetics of their repair after γ-irradiation *in vitro* of lymphocytes and the presence of common polymorphic forms of genes coding for DNA repair proteins. We perform this type of studies on blood cells obtained from healthy donors and also from patients with different types of tumors to investigate the genetic patterns that may predispose to cancer or to complications during the anticancer therapy. An example was the investigation of polymorphic variants of the genes XRCC1 (polymorphism Arg399→Gln), XPD (Asp312→Asn or Lys751→Gln), and

MGMT (Leu84→Phe) in lymphocytes from 87 individuals by PCR and restriction fragment length polymorphism. All these genes code for proteins that take part in DNA repair pathways. Homozygosity for the variant form of XPD with Asn at codon 312 showed a strong statistical correlation with a higher rate and the efficiency of DNA strand break repair. Homozygotes with Asp in this position showed the inverse phenotype, a lower initial level of SSBs and a higher level of unrepaired breaks. Eighty % of all individuals were characterized by one of these phenotypes, possibly reflecting the existence of alternative repair pathways. Lymphocytes homozygous for variant forms of XRCC1, MGMT or XPD751 did not show statistically different responses to irradiation compared to those homozygous for the normal form. These results suggest that XPD protein participates in the repair of DNA damage induced by γ-radiation and that its polymorphism influences individual responses to ionizing radiation. Other polymorphisms and other population groups are presently being studied.

In addition to analysis of DNA microarray data, members of the group are involved in mathematical modeling and analysis of signaling pathways, i.e. cascades of biochemical processes that regulate cell responses to environmental stimuli. In particular, this research is concentrated on Interferon-β and NFkB pathways, critically involved in the control of normal and pathological inflammatory responses. The aim of this research is to apply mathematical methodology to understand dynamical properties and uncover unknown regulatory feedbacks.

Studies of individual radiosensitivity as potential predictor of response to radiotherapy and normal tissue complications in cervix cancer patients

Maria Widel, Bozena Lubecka[1], Joanna Rzeszowska-Wolny

[1]Department of Experimental and Clinical Radiobiology, Maria Sklodowska-Curie Memorial Cancer Centre and Institute of Oncology, Gliwice,

It is observed that patients with the same type of tumour treated with similar dose of ionizing radiation and according to similar scheme often exhibit divergent grades of side effects in normal tissues. Individualization of cancer radiotherapy based on predictive assays of normal tissue tolerance may lead to improvement in the results of treatment. The ionizing radiation as well as most of anticancer drugs are genotoxic agents which induce diverse types of DNA damage. The variability in DNA damage induction and repair ability are features of not only cancer bearing patients, but also healthy persons. Efficient DNA repair not only modulates individual response to radiation (and to other genotoxic agents), but also affects the risk of cancer. Many experimental data indicate that peripheral blood lymphocytes (PBL) can reflect genetically determined radiosensitivity. For example, an increased lymphocyte radiosensitivity of individuals bearing *Ataxia telangiectasia*, *Fanconi anemia* or *Nijmegen Breackage Syndrome* in which some genes responsible for DNA damage recognition and repair, or signal transduction are mutated, is observed. However the most of patients do not bear any mentioned above mutated genes, but they may have some impairment of DNA repair mechanisms. The impairment of DNA repair processes can diminish normal tissue tolerance to radiotherapy. It seems reasonable to expect that knowledge of radiosensitivity before treatment can be useful for prediction of normal

tissue response.
The ionizing radiation is one of the genotoxic agents and it induces different types of DNA damage as single strand breaks (SSB), double strand breaks (DSB), apurinic/ apirymidinic sites, and DNA-protein cross links. The DSB are considered to be the most danger, potentially lethal damage for cells, since correlation has been found between radiosensitivity and repair of DSB in tumour and normal cells. DSB are directly or indirectly induced by radiation, and can be also induced during processing of another type of DNA damage.

We evaluated spontaneous (basal, background) DNA damage and damage induced in lymphocytes by irradiation *in vitro*. The basal level of damage is very variable and it is dependent on previous exposition to genotoxic agents and on individual health status. Two tests, cytogenetic micronucleus assay and single cell gel electrophoresis were used to evaluate individual response of lymphocytes of cervix cancer patients to irradiation *in vitro* and then to compare these biomarkers with patients' response to radiotherapy.
In our study on the group of patients with cervical carcinoma treated with radiotherapy or radiochemotherapy we found significant correlation between lymphocyte micronucleus frequency induced by 4 Gy *in vitro* and both, acute and late side effects. It proves that severity of late complications after radiotherapy is also determined by genetic predisposition, which can be tested in lymphocytes (Fig.1).

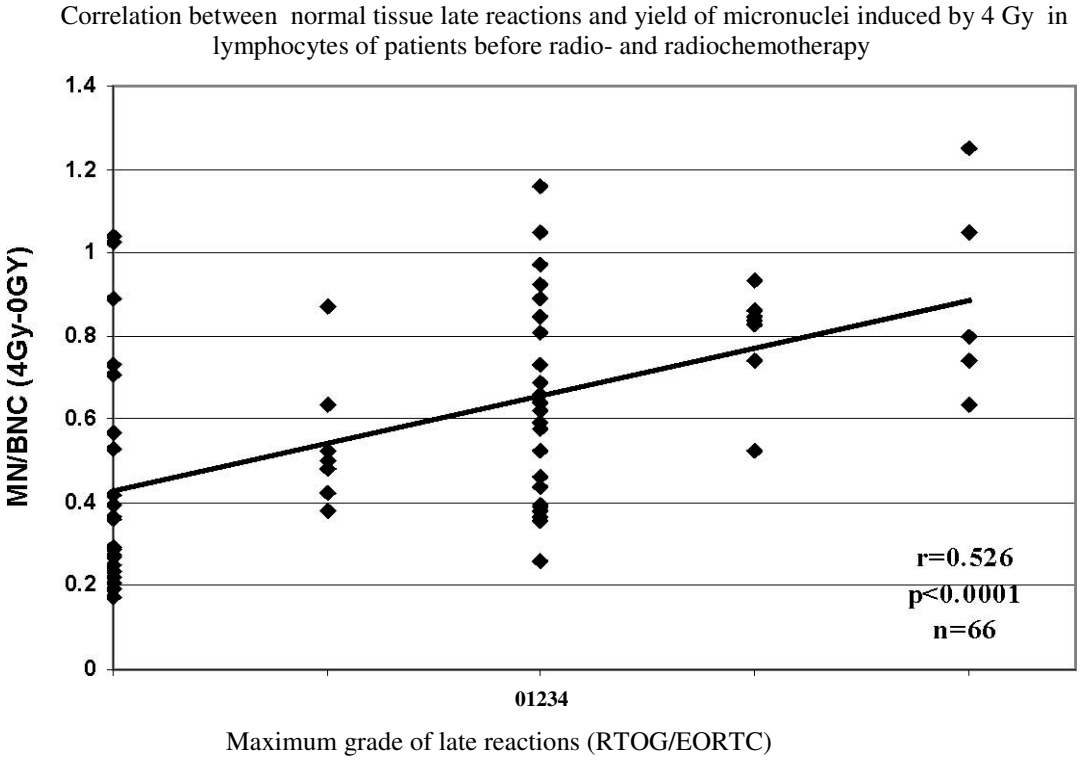


Fig. 1. Correlation between normal tissue late reactions and yield of micronuclei induced by 4 Gy in lymphocytes of patients before radio- and radiochemotherapy

The study on individual radiosensitivity with application of comet assay, performed by us in the group of cervix cancer patients also showed the significantly higher basal damage, higher level of damage induced by 2 Gy and worse repair efficiency in comparison with healthy donors.

Furthermore, we observed inverse correlation between initial damage, induced in lymphocytes by 2Gy in vitro and late effects in normal tissue due to radiotherapy (Fig.2). We suggest that patients whose lymphocytes present higher level of damage just after irradiation must have more efficient mechanisms of DNA damage repair, especially mechanisms of base and nucleotide excision repair, and these breaks could be induced by immediate incision of oxidatively damaged DNA chains.

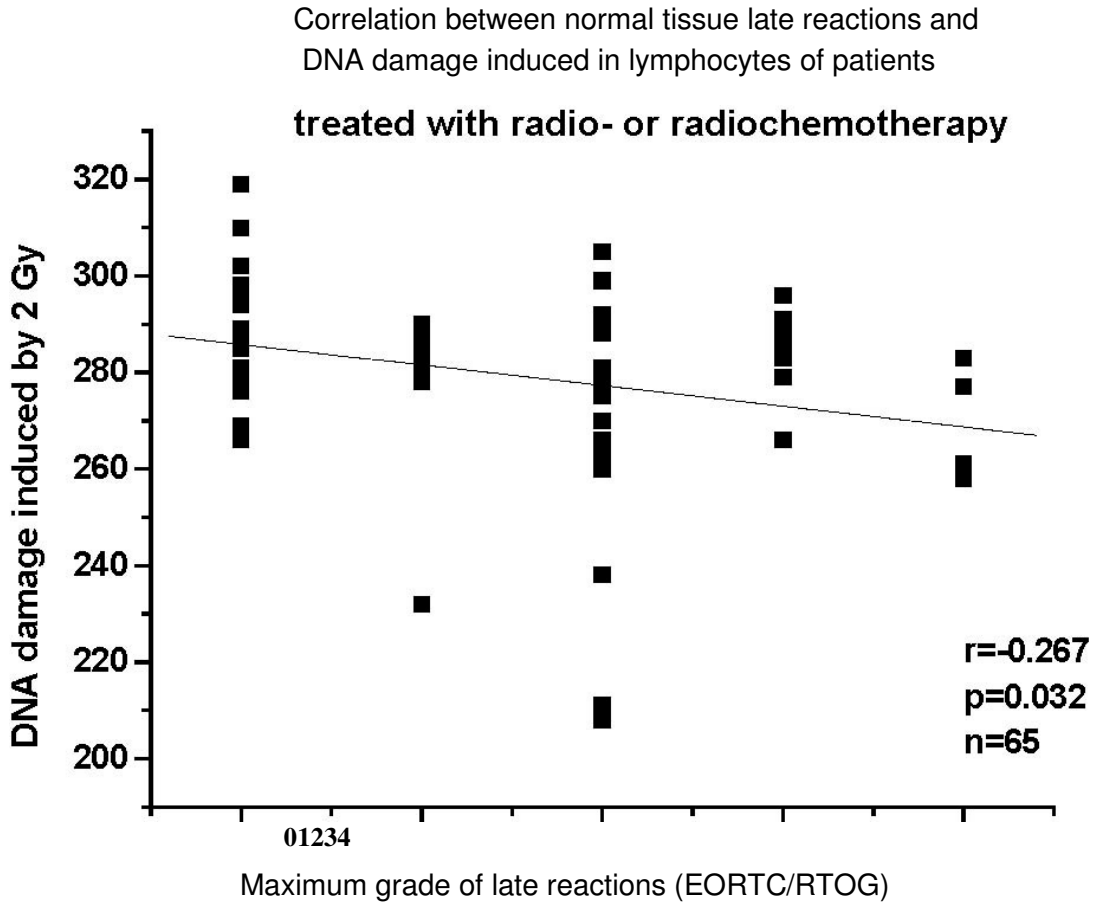


Fig. 2. Correlation between normal tissue late reactions and DNA damage induced in lymphocytes of patients treated with radio– and radiochemotherapy

Our results suggest that prediction of appearance and severity of normal tissue damage could be possible on the basis of normal cell response measured in vitro.

Radiation-induced Bystander Effect

Maria Widel, Waldemar Przybyszewski[1], Agnieszka Szurko[1,2], Maria Konopacka[1], Joanna Rzeszowska-Wolny

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According to classical radiobiological theories, the cellular damage induced by ionizing radiation results from direct ionization of critical target (mainly DNA), or from reactions of water radiolysis products with biological macromolecules. However, during last several years attention is paid on third mechanism, called **"bystander effect"**.

Bystander effect is induced in non-irradiated neighbour cells *via* biochemical agents and signalling molecules emitted by directly irradiated cells. This phenomenon appears at:

- genetic level as genetic damage (micronuclei, chromosomal aberrations), changes in gene expression, and DNA strand breaks
- biochemical level (lipid peroxidation, cytokine production)
- cellular level (apoptosis, necrosis). This effects can potentially contribute to development of radiotherapy side effects (local and distant), might induce genomic instability and mutations and might be a risk of secondary cancers. Nature of agents responsible for bystander effect is not defined as yet. Experiments on different cell lines *in vitro* indicate that bystander effect is mainly observed at low doses of radiation. Thus it may have particular role in modern radiotherapy, where novel techniques are introduced as 3D-CRT (3D conformal radiation therapy) and IMRT (intensity modulated radiation therapy), the aim of which is diminution of dose delivered to the normal tissue included in radiation field. In the Department of Experimental and Clinical Radiobiology at the Centre of Oncology-Gliwice, where authors are employed, the studies are undertaken to explore the biochemical and molecular nature of bystander effect. Most of researches involved in bystander effect use "conditioned medium" taken from irradiated cells to induce some bystander effect in non irradiated cells. We used the multicultural mega colonies model to study bystander effect, namely: cells are growing as separated multicultural mega colonies in culture flask. Megacolonies growing on one half of flask are irradiated, whereas megacolonies on second half are shielded. After irradiation megacolonies are co-cultivated for required period, cells are harvested separately and effects are observed on cellular and molecular level. Up to date we were able to observe increase in induction of micronuclei, apoptosis and necrosis not only in cells directly traversed by gamma rays but also in cells isolated from megacolonies not irradiated. We are also using the special type of multiwell plates with inserts to cocultivate normal and tumor cells of different radiosensitivity to study the reciprocal influence of both types of cells, when only one of them are irradiated. For genetic studies we use the oligonucleotide microarray analysis. Characterization of the transcriptional reprogramming induced by radiation is an important step in understanding these processes and differences of response to radiation and to practice for treatment of neoplastic diseases.

The knowledge and better understanding of bystander effect phenomenon might be useful for radioprotection of normal tissue damage and for diminution of long term harmful radiation effect(s).

Photodynamic therapy (PDT)

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Photodynamic therapy (PDT) is a relatively novel and promising anticancer therapy based on combined use of a photosensitising agent and visible or near-infrared light (600-800 nm). Generally, PDT is based on photoactivation of a sensitizer taken up by targeted (i.e. cancer) cells. Two types of reaction can occur after photoactivation of the photosensitizer. The first involves generation of free radicals like superoxide anion, O_2^- (type I); the second produces singlet molecular oxygen $^1O_2$ ($^1\Delta_g$) (type II), possibly the main species responsible for oxidizing neighbour molecules .

I mechanism *(generation of radical species)* ^{3}**F* + RH = FH$^{\cdot}$ + R$^{\cdot}$** *(H atom transfer)*

^{3}**F* + RH = F$^{\cdot-}$ + RH$^{\cdot+}$** *(electron transfer)*

The radical species then reacts with ground state oxygen so that overall the reaction is photochemically initiated

autoxidation, thus:

FH$^{\cdot}$ + ^{3}O$_2$ = ^{1}F$_0$ + HO$_2$

F$^{\cdot-}$ + ^{3}O$_2$ = ^{1}F$_0$ + O$_2^{\cdot-}$

II mechanism *(generation of singlet oxygen, in presence of molecular oxygen)*

^{3}F* + ^{3}O$_2$ = ^{1}O$_2$* + ^{1}F$_0$

^{3}F* = *excited photosensitiser*

^{1}O$_2$* = *singlet oxygen (life time: a few μs, penetration distance ~ 0,02 μm)*

Highly reactive oxygen species formed within cell membrane, cytoplasm or organelles lead to peroxidative reactions causing damage to DNA and other molecules and finally resulting in cell death. PDT can induce two modes of death of targeted cells, apoptosis and necrosis.

Among the first-generation photosensitisers the most popular is Photofrin, used in clinical practice for treatment of neoplastic and pre-neoplastic diseaseses. However, its applications remain limited. First of all, Photofrin is a complex mixture with low

extinction coefficient in the red spectral region. This implies administration of relatively large amounts of this drug in order to obtain satisfactory phototherapeutic response. In consequence, due to high drug accumulation, patients have to stay several days out of sunlight to avoid sunburn reactions. These drawbacks prompted us to search for photosensitising agents with improved optical and pharmacokinetic characteristics.

In cooperation with University of Silesia we have undertaken physical-chemical and biological studies of new synthetic porphyrin derivatives with the aim to find effective photosensitizer with the better properties than that characterizing Photofrin.

The group of amino acid-derivatives of porphyry and two derivatives with long carbon chains (C16 – TTP – 5 - (4 -hydroxyphenyl)- 10, 15, 20 - tritolylporphyrin, TPYR – PP – 5 - (4 -hexadecyloxyphenyl)-10, 15, 20-tri-pirydylporphyrin) were studied up to date.Particular attention was given to the time-resolved singlet oxygen phosphorescence as a measure of singlet oxygen quantum yield, since, the higher the singlet oxygen quantum yield, the higher photodynamic activity of sensitizer.

Biological activity of these agents e.g. cytotoxicity and photodynamic activity were studied on different tumor cell lines (human melanoma Me45, human colorectal carcinoma HCT116, murine melanoma (B16(F10)). Chemicals were applied as liposomal emulsion, and cellular localization was evaluated by confocal microscopy. On the basis of our studies we selected two porphyrin derivatives TPYR-PP and C16-TTP as the most effective, relatively nontoxic agents. Among amino-acid derivatives, glycin-porphyrin appeared also effective photosensitizer. All of them are promising agents for further in vivo studies. We are going to continue this type of study using further modification of porphyrin.

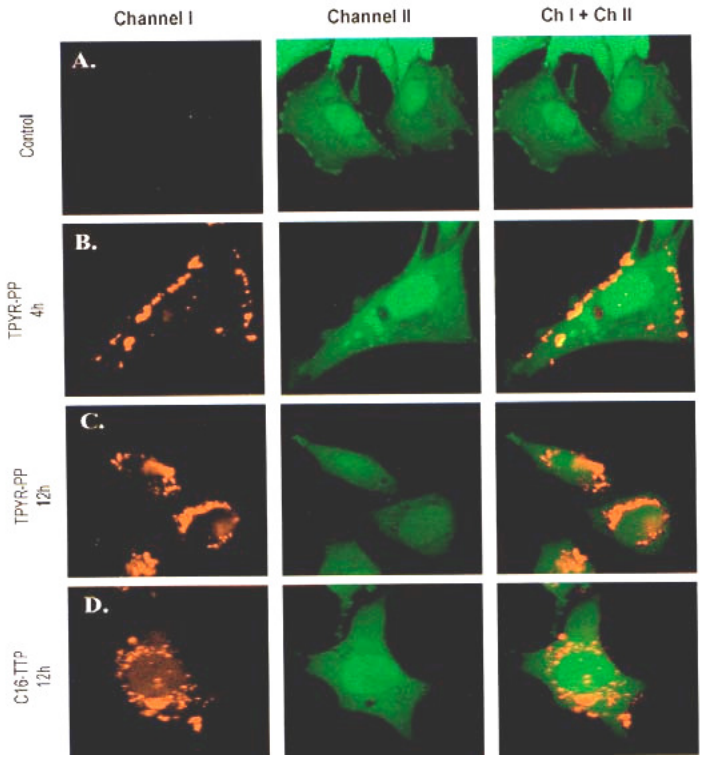

Fig.1. Example of porphyrin localization in human melanoma cells Me45 evaluated by confocal microscopy

Analysis of signaling pathways

M. Kimmel, J. Śmieja

Following rapid developments in new experimental techniques, mathematical modeling of regulatory pathways that control intracellular biological and chemical processes is gaining increasing interest in the biomedical research. Though the models are unavoidably much simplified they can significantly contribute to the biological field. Knowledge about dynamics of the processes involved in a given pathway facilitates better planning of experiments. Mathematical models can help to formulate or reject new hypotheses about unknown processes underlying results observed in experimental work. As a result, directions to be taken in experimental work may be suggested by mathematical models. Moreover, modeling can be used to analyze perturbed behavior even before experiments are undertaken, and answer the question if the desired effects are possible. Finally, analysis of dynamics can indicate time points, at which measurements should be taken to gain maximum information from experiments. Two pathways are analyzed in this study – a pathway activated by Interferon-β, that is used in defense against viral infection, and NFkB pathway, involved in many processes crucial to cell survival. Both deterministic and stochastic models are being developed and their properties studied. This is done in cooperation with experimental groups, providing data used form model validation and benefiting from predictions of our models. Ultimately, the models built in this researched will be linked to those used for investigation of cell population behavior.

Direct cooperation with other research groups

1 Cooperation with Rice University, Houston, USA - biomathematical studies.
2 Cooperation with University of Texas Medical Branch, Galveston, USA – analysis of signaling pathways

Classification and selection of DNA microarray data

K. Fujarewicz, M.Kimmel, A. Świerniak

DNA microarrays are relatively new technique allowing biologists to perform genome-wide studies. They can measure abundance of mRNA in cells which corresponds to expression levels of particular genes. The main advantage is the huge number (tens of thousands) of genes which expressions can be measured. While the technique of production of different types of DNA microarrays (cDNA, oligonucleotide) is well established, computational methods for data analysis still requires modifications to take into account the specificity of the data. A standard problem stated by biologists is to build the classifier which can classify (predict the class) of a new sample based on previously collected and annotated set of microarray experiments. Another problem which is closely connected with the classification problem is to find a set of differentially expressed genes based on which we can build the classifier. The common approach is to rank all genes and to choose the high scored genes. This univariate approach gives the set of the best genes. An alternative is a multivariate analysis which looks for the best set of genes. We have tested several, new and existing, methods of gene selection. A new method of selecting differentially expressed genes, called

Recurrent Feature Replacement (RFR), based on support vector machines technique, has been presented. It has been successfully applied to classification problem of thyroid cancer.

Parameter estimation for models of cell signaling pathways

K. Fujarewicz, M. Kimmel, A. Świerniak

Mathematical models of cell signaling pathways frequently take a form of sets of nonlinear ordinary differential equations. To compare different models and to test their ability to model processes, for which experimental data are available, an efficient method of parameter fitting is needed. Unfortunately, while the model is continuous in time, all available measurement techniques, such as: Western blot expression analysis, electrophoretic mobility shift assays or gene expression microarrays, provide measurements at discrete time moments only. Moreover, these time moments may be non-uniformly distributed and may be different for different signals measured. Hence the problem of estimation of model parameters has dual nature: the model is continuous-timed but the performance index is discrete, sum-quadratic.

Generalized Backpropagation Through Time (GBPTT) method, developed by us in the past and recently extended to continuous-discrete systems is a tool which can be applied to solve the problem stated above. Papers describe how the GBPTT can be applied for estimation of parameters of signaling pathways models.

Unfortunately, in practice the data are produced by blotting techniques. These methods produce images and the information about concentrations of particular substrates are only semi-quantitative. In most cases concentration levels may be compared within one blot and cannot be compared to concentrations estimated based on other blots. This is the second difficulty appearing in practice. To solve it we assumed existence of unknown multipliers (one multiplier per one blot) and estimate them using the same GBPTT methodology. The proposed approach has been applied to estimate parameters of the model of NFkappaB transcription factor, recently proposed in literature.

Characterization of colon cancer cell lines.

A. Lalik, M. Skonieczna, S. Student, J. Rzeszowska-Wolny

Colon cancer is one of the most common type of cancer in the developed world. It is one of the most common leading cause of cancer-related death, too. The only curable treatment for colorectal cancer is resection, but recurrence occurs in most resected cases. Accordingly to improve the overall survival of patients with colon cancer there is need to develop an early diagnosis method and an effective treatment. Our research have concentrated on changes in the gene expression pattern and alterations in the molecular mechanisms induced by radiation in human colon cancer cell lines. We have collected data from experiments such as comet-assay, micronucleus assay, western blotting, RT-PCR, DNA microarray. Then we have analyzed the received data by advanced mathematical analysis to extract useful biological information. We believe our work improve understanding of the colon cancer spread and metastasis.

Control theoretic approach to antiangiogenic therapy

A. Swierniak

Angiogenesis is a complex process which leads to the formation of new vessels and it is stimulated and controlled by molecular factors called activators (stimulators) and inhibitors (blockers) of angiogenesis. During progression of tumor these factors are released by tumor itself to develop its own vascular network which enables its growth and in the next stage determines possibility of cancer metastasis. Since this network is necessary for tumor development in late sixties of the last century a new anticancer therapy was proposed target of which was not directly the cancer cells but the new born vasculature. This therapy is known as antiangiogenic therapy and the idea is to reduce the tumor volume reducing its vasculature. It has been first time hypothesized by Folkman more than thirty years ago.

The most important obstacle against successful chemotherapy is drug resistance acquired by cancer cells while the normal tissues retain sensitive to the drugs.

This negative feature of chemotherapy may be used as an advantage in the antiangiogenic therapy which is directed towards special part of normal tissues and only indirectly destroys tumor cells and it is why it has been called by Kerbel a therapy resistant to drug resistance. Therapy directed against tumor vasculature does not exploit tumor cell sensitivity, relying instead on tumor suppression consequent to inhibition of associated vasculature. For more than ten years Folkman's ideas were not followed by experimental or clinical investigations but now tumor angiogenesis belongs to the most inspiring areas of cancer research in oncology.

The complexity of the process of vascularization as well as the way in which inhibitors, stimulators and antiangiogenic drugs act results in the complex models applicable for simulation of the process but less useful in synthesis or even analysis of therapy protocols. The exception is a class of models proposed by Hahnfeldt et al who suggested that the tumor growth with incorporated vascularization mechanism can be described by Gompertz type or logistic type equation with variable carrying capacity which defines the dynamics of the vascular network.. Roughly speaking the main idea of this class of models is to incorporate the spatial aspects of the diffusion of factors that stimulate and inhibit angiogenesis into a non-spatial two-compartmental model for cancer cells and vascular endothelial cells. The models considered in our research.belong to this class.

In our study which has been developed in cooperation with A. D'Onoffrio from European Centre of Oncology, Milano and A. Gandalfi from Institute of Information Analysis and Systems, Rome we have compared different modifications of Hahnfeldt model of vascular tumor growth and their application to rationales of antiangiogenic therapy. We discuss advantages and drawbacks of such models in context of their possible application, agreement with clinical data and difficulties of mathematical analysis. We have found protocols optimal in the biologically reasonable sense. We also contest results of some other authors and discuss possible approaches to optimization problems resulting from therapy protocols design. Moreover in cooperation with R. Tarnawski from Centre of Oncology, M.C. Memorial Institute , Branch Gliwice we have discussed optimization of.. combined radio- and antiangiogenic therapy.

Control and Estimation in Cell Populations

M. Kimmel, A. Świerniak, Z. Duda (Control and Robotics Group),
A. Polański, J. Polańska, J. Śmieja

Two major obstacles against successful chemotherapy of cancer are (1) the cell-cycle-phase dependence of treatment, and (2) the emergence of resistance of cancer cells to cytotoxic agents. One way to understand and overcome these problems is to apply optimal control theory to mathematical models of cell cycle dynamics. In the elaborated models the control actions represent drug dosage or, more generally, therapeutic protocols and a region of the disease parameters considered as admissible defines a target set for the state. In the case of cancers the disease state should be represented by the size of the tumor defined for example by the number of transformed cells. Unfortunately any control action i.e. treatment by drugs does not selectively disturb cancer tissues. Both chemotherapeutic agents or radiation act on normal tissues. Thus, the control problem becomes much more intricate than in many industrial applications, the more that the unperturbed system (i.e. when therapy is not applied) leads always to undesirable outcome. The study of these models leads not only to new results in optimisation and estimation theory as well as in their applications in oncological practice.

Supervised and unsupervised analysis of gene expression data

K. Fujarewicz, K. Simek, M.Kimmel, A. Świerniak

Recent development of experimental techniques like cDNA microarrays and oligonucleotide chips attracted a lot of research interest. The novel methods permit to measure expression levels of thousands of genes in a massively parallel way. Their main advantages are reproducibility and scalability of obtained data and short time of one experiment. The new data resulting from the experiments promise to enhance fundamental understanding of life on the molecular level, from regulation of gene expression and gene function to cellular mechanisms, and may prove useful in medical diagnosis, treatment and drug design. Analysis of these data requires mathematical tools that are adaptable to the large quantities of data, while reducing the complexity of the data to make them comprehensible.

So far gene expression data have been used successfully to classify the cancer type of a given sample or classify groups of co-regulated genes. Our research follows the mainstream of the analysis. We have tested several, new and existing, methods of classification , and showed that a selection of proper (optimal) set of genes, which expression can be used for classification, is still an open problem. It has been tested on different data sets and compared to other selection methods, recently proposed in literature. The best results have been obtained when the RFR method has been combined with Recurrent Feature Elimination (RFE) method .

Recently, data on multiple gene expression at sequential time points were analyzed, using Singular Value Decomposition (SVD) as a means to capture dominant trends, called characteristic modes, followed by fitting of a linear discrete-time dynamical

system in which the expression values at a given time point are linear combinations of the values at a previous time point. We attempt to address several aspects of the approach To obtain the model we formulate a nonlinear optimization problem and present efficient way to solve it numerically. We use publicly available data to test the approach. We discuss the possible consequences of data regularization, called sometimes ``polishing", on the outcome of analysis, especially when model is to be used for prediction purposes. Then, we investigate the sensitivity of the method to missing measurements and its possibilities to reconstruct missing data. The results point out that approximation of multiple gene expression data preceded by SVD provides some insight into its dynamics but may also lead to unexpected difficulties, like overfitting problems.

Radiation induced bystander effect – the important part of ionizing radiation response. Potential clinical implications

Maria Widel

It has long been a central radiobiological dogma that damaging effects of ionizing radiation are caused by direct ionization of cell structures, particularly DNA, or by reactive oxygen species (ROS) created due to water radiolysis . These biological effects such as cell death, chromosomal aberrations, micronuclei, apoptosis, mutagenesis and carcinogenesis have been attributed to irreparable or miss-repaired DNA damage in cells directly hit by radiation. However, in the last several years the increasing number of studies revealed a phenomenon termed “bystander effect” or “radiation induced bystander effect”, RIBE, i.e. the induction of damage in cells not directly targeted by radiation The mechanisms responsible for bystander effect are complex and still poorly understood. It is believed that molecular signals released from irradiated cells induce signalling ways in non-irradiated neighbour cells leading to observed events. The molecular signals may be transmitted through gap junction intercellular communication and through medium transmitted mechanism.

The nature of these transmitted factors are diverse, but still not definitely established. The bystander effect is mainly observed in *in vitro* experiments using very low fluency of α particles from single-particle microbeam, but also after conventional irradiation (X-rays, gamma rays) with very low as well as conventional doses, and after treatment of non irradiated cells by medium harvested from irradiated ones (irradiation conditioned medium, ICM). To study the bystander effect in *in vivo* resembling systems which contain cells at various stages of cell cycle and differentiation, cultures of tissue explants, cell clusters and animal systems were used. It seems that RIBE may have important clinical implications for health risk associated with radiation exposure. It may be either potentially harmful or useful event in radiotherapy. The elevation of damage in tumor cells not directly hit by radiation or initiation of tumor cell differentiation may increase therapeutic ratio. If however molecular species secreted by irradiated tumor cells *in vivo* would damage neighbor normal cells (epithelial and endothelial cells, fibroblasts or lymphocytes), the bystander effect would be harmful, and may lead to increase of normal tissue side effects. This is especially important in modern radiotherapy as 3D-conformal radiation therapy (3D-CRT) and intensity-modulated

radiation therapy (IMRT) that are aimed to diminish of radiation dose in normal tissues. Probably factors releasing by irradiated cells may be also a risk factors for genome instability and secondary cancer development. Furthermore, recent experimental data indicate that nonirradiated neighbor cells might diminish radiation induced damage in targeted cells. The issue of bystander effect may also be relevant to the biological effects of radionuclide applied in diagnostic and therapeutic nuclear medicine due to nonuniform distribution of radioactivity. The recent *in vivo* studies on animals indicate that bystander effects may appear in organs and tissue of distant location from irradiated field. Less is known about bystander effect during fractionated irradiation. Thus clinical implications of bystander effect and its possible modification for radiotherapeutic usefulness are still under debate.

P53 gene function is not required for bystander signals induction and transmission

Maria Widel[1,2], Agnieszka Szurko[1], Waldemar Przybyszewski[1], Lidia Brodziak[1], Anna Lalik[2], Joanna Rzeszowska-Wolny[1,2]

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The radiation induced bystander (non-targeted) effect is now widely accepted phenomenon which changes a central radiobiological dogma that damaging effects of ionizing radiation are the results of direct ionization of cell structures, particularly DNA, or of indirect damage *via* water radiolysis-derived reactive oxygen species (ROS). Different molecular signals mediated by ROS and other factors released from irradiated cells induce signalling ways in non-irradiated neighbour cells leading to biological effects such as cell death, chromosomal aberrations, micronuclei, apoptosis, mutation and neoplastic transformation, the damage resembling that observed in targeted cells. The bystander effect can be induced by very low doses of alpha particles (cGy-mGy) as well as low LET radiation even at doses conventionally used in radiotherapy. The phenotypic expression of bystander effect may depend on cell type and genotype. The involvement of *p53* gene in bystander phenomenon has been documented in literature data mainly as p53 protein increase *in vitro* and *in vivo*.

In our study we used human colorectal carcinoma cell lines differing in *p53 gene* status, HCT116 wild type with functional *p53* gene and *p53* knock-out cells HCT116p53-/- to compare response of both lines to direct radiation targeting (2-4Gy X rays) and to signals involved in bystander effect. Co-cultivation system which allows separation of irradiated cells growing in 6-wells plates and bystander cells growing in inserts, with medium freely circulating through the separation membrane (pore size 0.4 μm) was applied (Fig.1.).

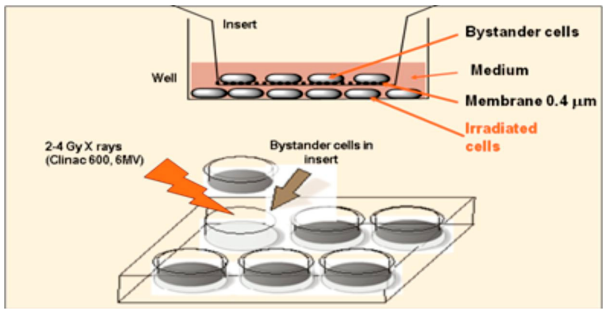

Fig.1. Schematic representation of bystander effect experimental design.

Micronucleus frequency and apoptosis were used as the end-points in the first step of bystander experiments. Since radiation-induced oxidative stress is associated with p53-dependent cell cycle arrest, DNA repair and apoptosis, these assays were followed by flow cytometry analysis of cell cycle distribution, and by antioxidant defense measurement on the base of antioxidant enzymes activity.
We observed that HCT116p53+/+ cells were slightly more sensitive to radiation- and bystander signal-induced micronuclei formation than HCTp53-/- cells. However, apoptosis was more efficiently induced in radiation targeted and especially in bystander p53 knock-out cells (Fig. 2a and Fig. 2b).

The flow cytometry indicated that HCTp53+/+ irradiated and nonirradiated bystander cells accumulated in G1 phase. HCT116 p53-/- cells did not show G1 accumulation. However, HCT116 p53 knock-out cells showed block in G2/M phase 12h post radiation which lasted up to 72 h in targeted and bystander cells. HCT116p53+/+ cells also accumulated in G2/M phase, but at 72 h this block disappeared.
The antioxidant enzyme glutathione peroxidase (GSH-Px EC.1.15.1.1) presented much higher basal activity and slow increase in irradiated and bystander HCT116 p53-/- cells. HCT116p53+/+ cells showed very low basal GSH-Px activity which increased only at 24h following irradiation. In contrast, superoxide dismutase (SOD EC.1.15.1.1) activity did not show any differences between cell lines (data not presented).

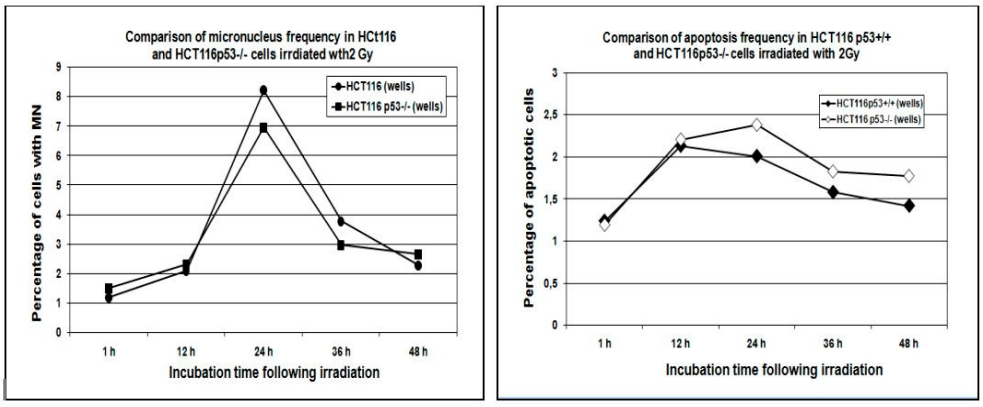

Fig 2a Frequency of micronuclei and apoptosis in directly irradiated and bystander HCT116 colorectal carcinoma cells differing in p53 status

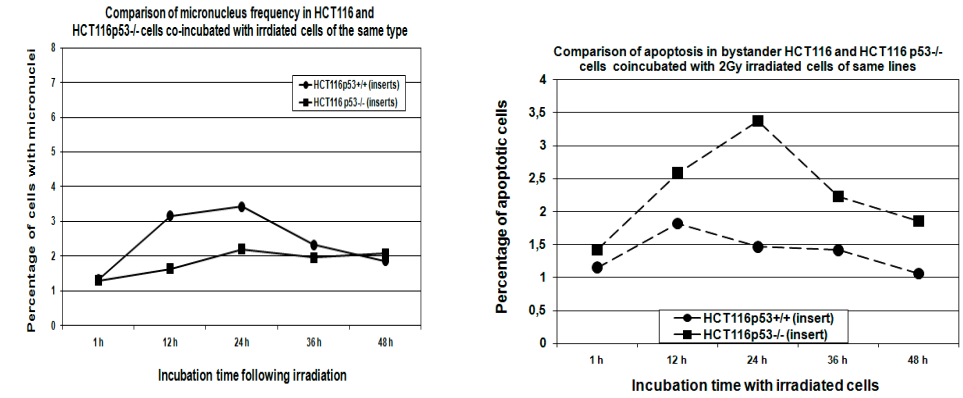

Fig.2b. Frequency of micronuclei and apoptosis in directly irradiated and bystander HCT116 colorectal carcinoma cells differing in p53 status.

It seems that signaling factors emanated to the medium by irradiated cells induce in p53 positive and p53 negative cells different pathway leading to apoptosis. Our initial study of some apoptosis-related gene expression on the transcript levels indicate that apoptosis pathway in HCT116p53-/- line may be related to nuclear factor kB (NFkB) signaling pathway. We are currently studying this possibility.

Non-irradiated bystander fibroblasts attenuate damage to irradiated cancer cells - opposite bystander effect?

Maria Widel[1,2], Waldemar Przybyszewski[1], Agnieszka Szurko[1], Robert Herok[1], Lidia Brodziak[1], Joanna Rzeszowska-Wolny[1,2]

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There are a lot of evidences that irradiated cells emanate signals (soluble factors) through gap junction intercellular communication, or trough the medium which in turn produce some biological effects in neighboring non-irradiated cells. The classical bystander effect appears predominantly as damaging events (SCE, micronuclei, genomic instability, apoptosis induction, mutations), although other pro-survival effects as cell proliferation, cell differentiation and radioadaptation has also been observed. Bystander effect might bear some implications for coexisting normal cells non-targeted by cancer radiotherapy. However, communication of irradiated and non-irradiated cells must be bilateral. Our experiments indicate that non-irradiated fibroblasts co-cultivated with irradiated tumour cells attenuated damage induced in radiation targeted cells. Using co-cultivation system, described above, we performed experiments in which cancer cells, LLC (mouse Lewis lung carcinoma) growing in 6-well plates were irradiated (2-4 Gy) and co-cultured with growing in inserts either LLC, or with mouse normal fibroblasts (NIH3T3), or at last with empty inserts. We observed classical bystander effect in nonirradiated LLC cells (increase of micronuclei and apoptosis in

comparison with control cells). The bystander effect in mouse NIH3T3 fibroblast induced by signals transmitted by 2-4 Gy irradiated LLC cells was weakly expressed as micronuclei and to higher extend as apoptosis. However, opposite, protective effect caused by fibroblasts was observed; the cytogenetic damage and apoptosis was significantly diminished in irradiated cancer cells co-incubated with fibroblasts in comparison with damage in cancer cells co-incubated without fibroblasts (empty inserts), (Fig. 1.).

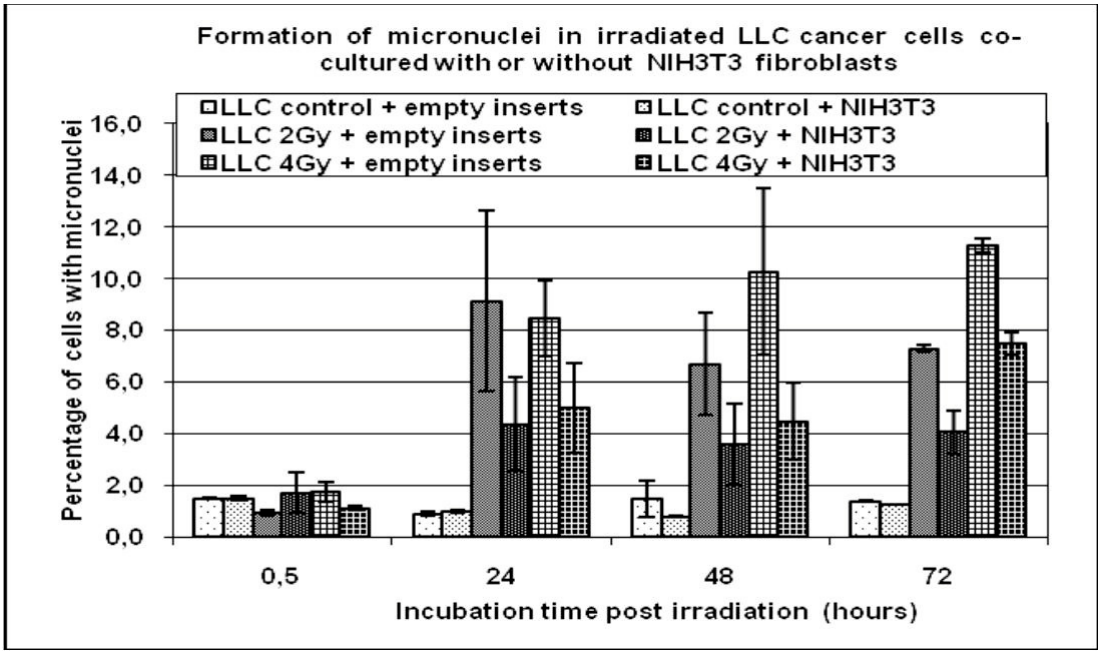

Fig. 1. Formation of micronuclei in irradiated LLC cancer cells co-cultured with or without NIH3T3 fibroblasts.

Flow cytometry analysis did not show considerable differences in cell cycle distribution of irradiated LLC cells when they were co-cultured with or without NIH3T3 fibroblasts. The preliminary results showed differences in the level of TGFβ in medium of co-cultivation systems suggesting the role of this cytokine in the phenomenon. TGFβ produced by almost all type of cells, may be either membrane-bounded or in soluble form. Using anti TGFβ monoclonal antibodies in ELISA Kit we found some differences in the level of TGFβ in our system. This protein was more abundant in medium from LLC irradiated cells co-cultured with empty inserts. There are some data showing that TGFβ can induce basic fibroblast growth factor (bFGF) and influence differentiation of fibroblast. Probably FGF can also influence cancer cells in some way. This is only supposition, which needs experimental explanation. The RT-PCR is currently performing to confirm this observation on the transcript level. The similar, protective effect exerted by human NHDF fibroblasts co-incubated with irradiated human Me45 melanoma cells was also observed in our recent experiment. We suppose that this protective effect exerted by neighbor fibroblasts in cancer cells may have unpredictable meaning for radiotherapy.

Association of radiation induced DNA strand breaks rejoining with polymorphism of different DNA repair pathways genes in colorectal carcinoma

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The human DNA is continually damaged by endogenous factors such as metabolic products of oxidation, and by exogenous exposures to environmental genotoxic agents, among them ionizing radiation, thus efficient DNA repair mechanisms play crucial role in protection of carcinogenesis. Multiple DNA repair pathways remove different type of damage. Base excision repair (BER) corrects the DNA damage caused by oxidative stress. Nucleotide excision repair (NER) pathway is engaged in repair of a wide range of structurally unrelated lesions and mainly removes complex bulky lesions caused by chemical carcinogens, e.g. polycyclic aromatic hydrocarbons and photoproducts of UV radiation, although some data indicate that NER is associated with the repair of oxidative damage induced for ionizing radiation. DNA double strand breaks (DSBs) are extremely toxic lesions, which if not repaired may cause chromosomal breaks and genomic instability, and in consequence increase a probability to develop cancer. In humans, two pathways exist that repair DSBs, homologous recombination (HR) and non-homologous end-joining (NHEJ).

Genetic polymorphism of DNA repair genes may result in altered function and/or efficiency of DNA repair and may contribute to inter-individual variability in response to genotoxic agents.

Although sporadic colorectal cancer (CRC) is multifactorial disease resulting from the combined effects of numerous genetic, environmental and behavioral risk factors, some genetic association of low-penetrance alleles of DNA repair genes may be involved in susceptibility to CRC. Since ionizing radiation is effective inducer of divergent types of DNA damage, the involvement of different pathways is engaged for DNA repair. Looking for a possible marker(s) of susceptibility to colorectal cancer we concerned in the present study on relationship between polymorphism of genes encoding proteins which participate in different pathways of DNA repair: *XPD* 312 and 751 (NER), *APE1* and *XRCC1* (*BER*) and *NBS1* (HR and NHEJ) and on repair phenotypes characterized by lymphocyte efficiency to rejoin of radiation-induced DNA strand breaks in patients with colorectal cancer.

Study was performed for the group of 50 patients with colorectal carcinoma selected for the treatment with surgery or radio-surgery. DNA was separated from whole blood sample taken before the treatment. Polymorphism of genes was estimated in PCR-based restriction fragments length polymorphism (RFLP-PCR) assay. The ability of patients to repair DNA strand breaks was estimated using lymphocyte single cell gel electrophoresis (comet assay).

The significant increase of DNA strand breaks rejoining capacity measured by comet assay was revealed for polymorphic variants of *XPD* 312 (Asp →Asn) genotypes in comparison with wild type homozygotes (Asp312Asp), (p=0,0003). In contrast, *XRCC1* 399 (Arg →Gln) as well as NBS1 185 (Glu→Gln) polymorphisms were associated with significantly lower repair capacity (p=0.0005 and p=0.028 respectively). There were no association of *XPD* 751 (Lys→Gln) and *APE1* 148 (Asp→Glu), polymorphisms with DNA repair. A link between genetic polymorphism of *XPD*312, *XRCC1* and NBS1 and DNA repair efficiency suggests that colorectal cancer predisposition may be associated with defects in these low-penetrance gene of NER, BER and DSBs repair pathways.

Research Laboratory of Computational Biology

To solve complex problems more and more often we have to use very advanced and time and memory-intensive computations. These computations may last too long if we utilize personal computers. In addition, data generated and processed during the computations may have enormous size, impossible to store in common-use machines. To make such calculations possible our research laboratory was created.

The basic field of research realized in this laboratory is implementation of algorithms that facilitate the understanding of biological processes through the application of statistical and machine learning techniques. Because these methods are often compute-intensive and often accumulate huge amount of data from biological and chemical experiments such as DNA microarray chips and mass spectometry we attempt to create algorithms that are efficient, based on existing hardware architecture.

In the laboratory we have four high-end servers which compose the total of 7 CPU's (3 machines are dual processor systems based on Intel Xeon HyperThreading architecture), 12 GB of RAM and about 1.4 TB of disc space. Whole system is connected by low-latency local network (1 Gbit ethernet) to create High Performance Computing cluster, which is also named Beowulf cluster – a unified system for parallel computing.

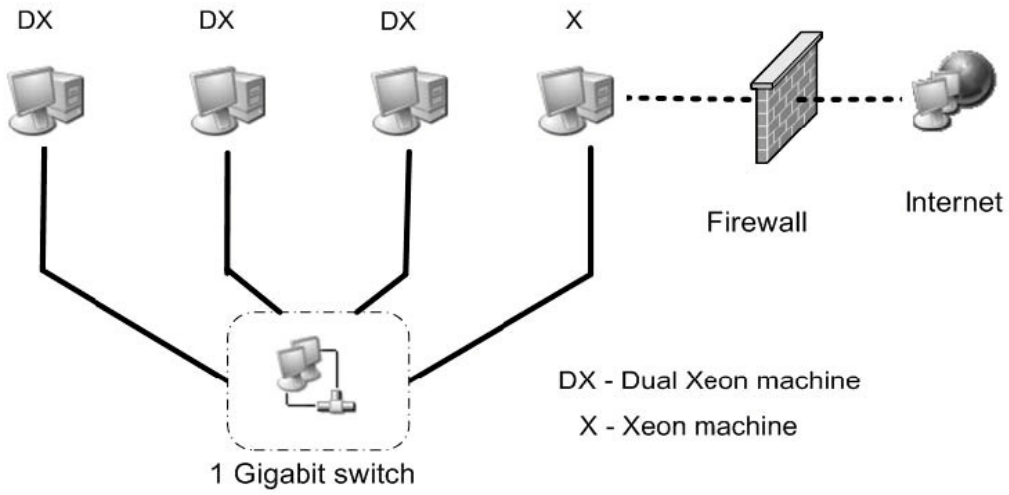

Fig. 1. Hardware cluster architecture.

This cluster is based on Linux platform and software package based on message-passing paradigm (distributed memory virtual computers such as PVM – Parallel Virtual Machine or MPI - Message Passing Interface). Users can create and execute programs written in C, C++ or FORTRAN programming languages or can take the advantage of highly developped scientific environments like Matlab, R or others.

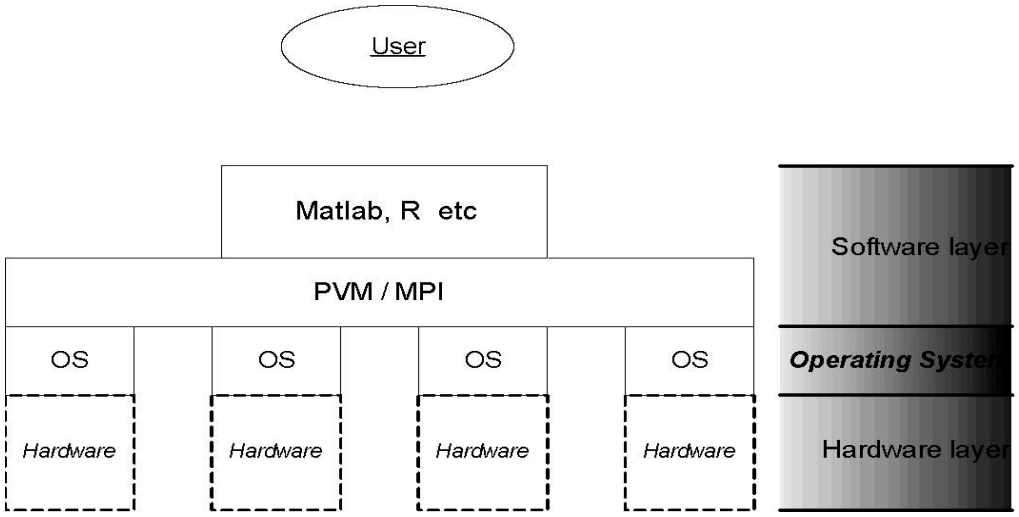

Fig. 2. Software architecture.

Fig. 3a. Equipment of laboratory

Fig. 3b. Equipment of laboratory

Fig. 3c. Equipment of laboratory

IMAGE PROCESSING AND PATTERN RECOGNITION

Selected Problems of Colour Image Processing

H. Palus

Colour images are the sources of rich information on objects in the scene. Therefore, its acquisition and processing can significantly simplify both object recognition and location processes. Nowadays an easy access to the equipment for colour image acquisition e.g. scanners, digital still cameras etc. and still grow-up of computational power are the reasons of colour images use instead of the grey-level images. Apart from the use of the methods popular for the monochrome image processing, the digital colour image processing uses the results of colour science, especially the colour measurement technique.

The research was concentrated around the low level processing problems starting from the representation of colour in digital images, colour image acquisition, preprocessing (filtering, colour quantization), to continue with the problems of colour image segmentation and its evaluation. In the vision systems processing colour images, peculiarity of colour at these low level stages is revealed. In the high level processing (feature extraction, object recognition, scene interpretation etc.) the colour of region can be one of many used features as shape, size or texture.

The first part of research concerns the stage preceding the image segmentation i.e., the preprocessing stage, in which the research has been restricted to the problems of colour quantization and denoising filtering. Three colour quantization methods: uniform quantization in *RGB* space, uniform quantization in *HSV* space and *k-means* technique, have been investigated. The following measures for evaluation of the quantization results were used: the fundamental signal processing measure *PSNR*, the colour difference *DeltaE* and additionally proposed difference of colourfulness, *DeltaM*. Within the framework of the filter testing a few nonlinear edge preserving filters have been compared. The use of evaluation function, originally proposed for the image segmentation, for denoising filtering, is also proposed. As a result of special interest in the image colourfulness was an application of this global perceptual attribute in comparison of scalar and vector median filters.

The second part of research is devoted to the problem of colour image segmentation that is very important in many applications. In general sense the image segmentation is an action on limited set of pixels with the aim of dividing into subsets (e.g. regions) with similar elements. The range of the considered segmentation techniques has been limited to the pixel-based (clustering) and region-based techniques. The *k-means* clustering technique with its parameters has been thoroughly tested. Two versions of region growing technique have been presented: seeded and unseeded versions. The latter automatic technique generates good results. Proper selection of homogeneity criterion, threshold and colour space allows to ignore shadows and highlights in the image. Postprocessing (e.g. small region removing) additionally improves the quality of the segmentation. Special evaluation functions, which usefulness has been confirmed in the research, can be used for the measurement of quality of the segmentation.

The most important results and achievements of this research have been summarized in just published monograph.

Laboratory of Digital Archiving

One of our research topics is the digital heritage preservation. As it is obvious that historical documents are one of the most valued cultural heritages of any nation, for centuries, incunabula, maps, music sheets, manuscripts, facsimile and old prints have been carefully stored, archived and protected over times of wars and natural disasters, in order to preserve them for future generations. Unfortunately, the historical documents deteriorate with time in many ways. Vellum, canvas, paper, ink and print are exposed to aggressive chemical, physical and biological factors, which in turn leads to slow but inevitable and permanent loss of valuable exhibits.

This great danger is forcing to take prompt counter-measures in order to preserve our cultural heritage for future generations. Because of the inevitable process of total natural destruction that is due to happen to many items in the nearest future, the only way of preserving the collection is to save the information content and make exact copies of originals using analog or digital acquisition of document images.

We are convinced that modern techniques of digital collection, storage and display are the only durable and relatively cheap way to preserve the information value of documents and the only effective method of making public the knowledge about collections of documents preserved in museums and libraries.

Such actions allow securing informational values of the documents and making them available to general public. It is especially important considering the fact that optimal document storage conditions, i.e. in separation from damaging external influences, often limit the access to the documents, even making them unavailable to larger groups of specialists.

Archiving the information layer of the document indirectly prolongs its physical existence, because the need to make the original document accessible is eliminated, at least in majority of the access requests where only the information contained in the document is needed.

Our research work is mainly focused on issues of digital acquisition, image preprocessing, archiving and multimedial presentation of collections.

Laboratory equipment (main elements):

- large format (4×5) view camera Cambo Ultima Digital,
- high-performance digital scan back Better Light 4000E-HS — technical data: uninterpolated resolution 3750×5000, single-pass color or monochrome scanning, continuously adjustable color balance in 0.1 CC steps, 11 f-stop dynamic range,
- four Bowens continuous light source utilizes a specially designed fluorescent lamp to produce a cold, daylight-balanced, safety for historical objects illumination,
- Manfrotto photo and light equipment,
- Lastolite light tens and reflectors.

Fig. 1. Laboratory equipment.

Graph based methods for image elements matching

A. Bal

Image elements matching problem belongs to the most important and difficult problems in computer vision domain. The importance of this problem is a result of its pivotal role in obtaining proper results from many practical issues like: patter recognition, visual object classification, stereo image matching and image data base retrieval. In this work problem of image elements matching is investigated. The ideas of novel methods for finding correspondence of image elements, using structural information, are presented. Task of matching image elements is reduced to the problem of inexact graph matching. For solving this problem modified method of finding graph matching by clique finding is used. By the usage of this novel method the inexact, also in sense of graphs structure, graphs correspondence can be finding.

DISCRETE EVENTS SYSTEMS AND COMPUTER INTEGRATED MANUFACTURING

Production control

J. Krystek

Every company must have the aim to stay in business – providing a high quality product or service for a customer to make a profit. Equally important is understanding the material flow process. The cost of material exceed the cost of labor in many companies now. Very important is also understanding philosophies and methods for manufacture, management, and planning.

The evolution of computer power has been closely followed by the power of planning tools for the manufacturing enterprise. In the 1960s, the first use of computer for planning material was used and was named MRP for Material Reguirements Planning. During the years that followed, began to use MRP not only to control material but also to plan and manage capacity. The closed-loop MRP was used to assure that the master plan was created as realistic in terms of not only materials but also capacity.

The next step was to integrate the material and capacity resource plan with financial resources of the enterprise. Material Resource Planning (MRPII) evolved in the integrated planning process. According to APICS – The American Production and Inventory Control Society, "MRPII is a method for the effective planning of all resources of a manufacturing company". MRPII evolved into Enterprise Resource Planning systems, which typically handle the manufacturing, logistics, distribution, inventory, shipping, invoicing, and accounting for a company. ERP software can control many of business activities, like sales, marketing, delivery, billing, production, inventory management, quality management and human resource management.

Equally important is to know how the integrated management systems work. This knowledge could be used in participation in the commercial implementation of the integrated management system in enterprise. Particular attention to some of the algorithms of planning and controlling the production processes (MRP - Material Requirements Planning, CRP - Capacity Requirements Planning, SFC - Shop Floor Control, MPS - Master Production Scheduling, JIT - Just In Time, Kanban, TOC Theory Of Constrains and follow-up production control) in industrial companies should be paid.

Simulation research of the follow-up scheduling algorithm

J. Krystek

The main purpose of an enterprise is to satisfy all customer requirements that do not exceed capacity of the production system. Therefore every production planning and control system may be considered as a system, which function is to adapt the assortment and the rate of production to currently accepted customer orders. The conformability of production and customer orders may never be ideal. However, it is possible to construct

a production management system in which the backlogs between the actual demand and production are under control, owing to feedback loops from material flows to corresponding decisions making procedures. Using backlog components as the sources of feedback signals in the multilevel production control system is the main idea of the follow-up production control.

In a follow-up production control system every work cell is a production subsystem (production island) with concurrent manufacturing processes. For each such a process the operations, executed in workstations of its routing, are synchronized. The partitioned flow production line, which may be variously divided into partitions designated to concurrent processing different product, is an example of the work cell. The particular case, without concurrent processes, is the ordinary flow production line. Another particular case of the work cell in a follow-up production control system is a single workstation. In every case the set of products, which may be manufactured by the cell, depends on the equipment installed in it. Such a set of products is named "preparedness variant" of the work cell. The variant with number zero corresponds to the idle time.

For a given work cell, after each period of work or idle time, the follow-up scheduling algorithm decides about the preparedness variant for the next period, as well as about length of this period. Thus, the next time when decision will be needed may be easily calculated. If the preparedness variant number is greater than zero, the algorithm gives lot-sizes of products corresponding to this variant. Parts of these lot-sizes, that fall to single executive planning periods belonging to a given work period, are executive plans. Their counterparts for operational planning periods, issued from the layer of planned orders coordination and distribution, are operational plans. Both, operational and executive plans are currently generated for consecutive planning periods (Fig.1). In contradistinction to executive plans, the operational ones, concerning a given work cell, do not have to satisfy the condition of mutual exclusion of different preparedness variants.

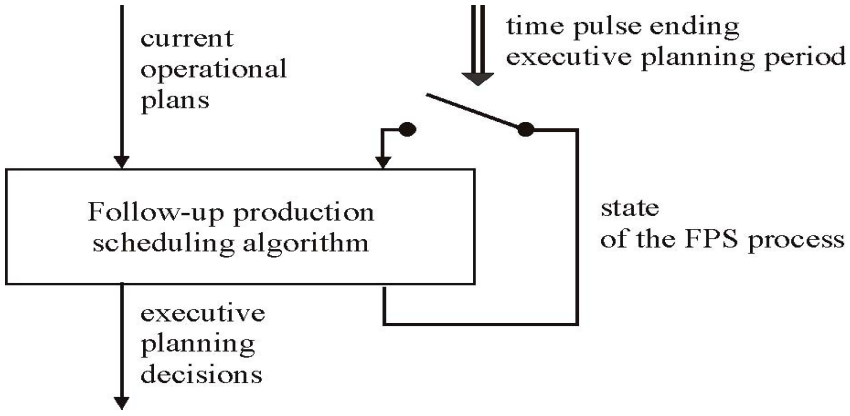

Fig.1. Application of the follow-up production scheduling to make current decision of the executive planning

The algorithm has been named "follow-up scheduling" because it ensures that its backlogs, that is running totals of differences between material flow rates, calculated on the ground of operational and executive plans, are limited for infinite time horizon. In other words, for each work cell the follow-up control system, with operational plans as

leading variables and executive plans as controlled variables, is stable. The main assumption of the stability theorem is that operational plans do not exceed capacity of the work cell which is the object of control.

Another quality of the follow-up scheduling algorithm is convergence of corresponding decision process. It means that if leading operational plans are constant or cyclic then following executive plans become cyclic after finite number of planning periods. The repetition period of these plans is the one of the algorithm parameters. The main assumption of the convergence theorem is the same as for stability. Convergence of current executive plans to cyclic schedules is important because repetitive production systems are usually designed to strictly cyclic work. Thus, after disturbances termination they should automatically pass on to the cyclic work mode.

An internet implementation of the follow-up scheduling algorithm was created (fig.2). This algorithm is designed to current generation of work cell executive plans which follow operational production plans coming from coordination unit. The application makes detailed researches of the algorithm operation. The simulation research goal was to verify if dispatch rules, that are applied to production variants selection, influence on duration of transient state and on features of cyclic schedules generated by the algorithm in steady-state.

Application „Algorytm Nadążnego Harmonogramowania Produkcji" in action can be at URL: http://nhp.f11.com.pl. seen.

ERP system IFS Applications and the MRP II environment

M. Jagodziński

In the MRP II (Manufacturing Resource Planning) standard system all decisions are made by people. The most detailed ones are shop orders and shop tasks. Each shop order points out the product to manufacture, the routing of the manufacturing process, the due date and the order quantity. Shop tasks are specification of a given shop order and concern particular operations of the manufacturing process. So, shop orders and shop tasks give answers to the questions what, how, where, when and how much to manufacture.

Shop orders are conformable with planned production orders from the MRP (Material Requirements Planning) module which, in turn, are conformable with master production schedule (MPS), but all these decisions are made without taking into account capacity of the plant. Such decision procedure is called "infinite scheduling". Afterwards, shop orders are verified in the CRP (Capacity Requirements Planning) module. If shop tasks exceed capacity of work centers allocated to them the planner modifies shop orders properly. If it is not sufficient another planners must modify planned orders and, perhaps, master production schedule.

Integrated enterprise management systems, including IFS Applications, coordinate flow and analysis of information regarding full product life cycle in framework of integrated supply chain SCM, it means from design to production planning, production, controlling, supplying and service (Fig. 1).

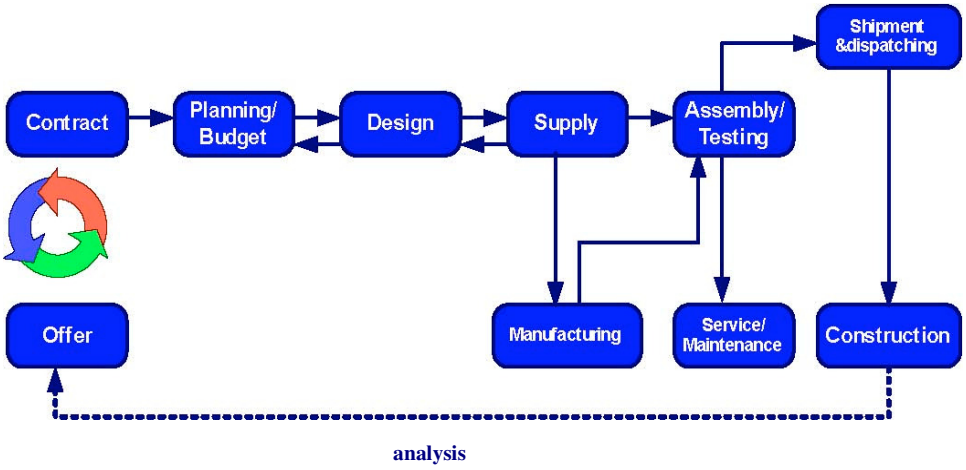

Fig.1. The product life cycle in IFS Applications system.

Assembly Line Balancing Problem

W. Grzechca

The line balancing problem is one of the most important problems of preliminary design stage for flow-line production systems. This problem was generally studied for assembly lines with a relatively simple structure (simple line, U-shaped line, parallel line, mixed line). For a given set of manufacturing operations and a given cycle time, the classical line balancing problem consists in assigning each operation to a workstation such that the number of workstations is minimized and precedence constraints are satisfied. The dual problem is minimization of the cycle time for a given number of workstations. A generalized line balancing problem consists of distributing operations among workstations while minimizing some criteria different than number of workstations (cost, productivity, reliability, maintainability, etc.) and taking into account some additional constraints. Many models for optimal line balancing are deterministic, the processing times are supposed to be fixed. Finally, production line balancing has usually several important criteria such as productivity, availability, investment costs, labor costs, utility costs, maintenance costs, etc. In this case, Pareto approach for multi-criteria optimization is a natural tool for dealing with various competing objectives of design problems. Other goal of investigations is comparing heuristic solutions, which are the only one available for most assembly line balancing problems. Also genetic algorithms are good tools in finding feasible solution of discussed problems.

TEACHING ACTIVITIES

Teaching activities of the System Engineering Group cover the following graduate courses:

- Electrotechnical and electromagnetic engineering,
- Automatic manufacturing systems,
- Pattern recognition,
- Computer aided Drawing and design,
- Final project seminar,
- Large scale systems,
- Computer aided decision making,
- Elements of artificial intelligence,
- Sensor systems,
- Operation research,
- Production control,
- Flexible manufacturing systems,
- Expert systems,
- Computer networks,
- Biosystem modeling,
- Digital acoustic and vision signal processing,
- Biometry,
- Artificial intelligence in biotechnology,
- Neural networks,
- Optimization and control in genetics and molecular biology,
- Information processing in ecosystems,
- Death – and – birth processes,
- System dynamics,
- Optimization methods,
- Computer Integrated Manufacturing,
- Robot Vision,
- Optimisation and Decision Making,
- Hierarchical Control,
- Biotechnical Systems.

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Professor Kimmel coorganized six international meetings on Mathematical Population Dynamics and edited refereed collections of papers from these meetings. Professor Kimmel is also on the editorial boards of *Mathematical Biosciences*, *Journal of Theoretical Biology*, *Journal of Biological Systems and Journal of the National Cancer Institute*. In 2002 he published a monograph "*Branching processes in biology*" (Springer, together with David E. Axelrod)

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Tadeusz Szkodny received the M.Sc. Ph. D. and D.Sc. degrees in control engineering from the Departament of Automatic Control in Silesian Technical University in Gliwice, Poland, in 1975, 1984 and 2005, respectively.

Since about 1985 his areas of interest are: mathematical modeling of kinematics and dynamics of stationary and wheel mobile robots (with using Matlab/Simulink and Real Time Workshop programming environment), planning of stationary and wheel mobile robots movement with taking into consideration the kinematics, dynamics of robots and drive characteristics of actuators, choice of the settings of controllers for stationary and wheel mobile robots, simulation of the movement and control of the stationary and wheel mobile robots, with using Matlab/Simulink and Real Time Workshop programming environment; computing algorithms of position coordinates of chosen points and manipulation object in relation to the cameras frame, calibration algorithms of camera in relation to robot base frame, solution algorithms of the inverse kinematics problem of stationary and wheel mobile robots, planning algorithms of movement robot with using the vision information of camera, modeling of kinematics of wheel mobile military manipulator.

He is a member of IEEE, Polish Society of Theoretic and Applied Electrotechnics, Automatics and Robotics Committee of Polish Academy of Science, Polish Committee of Theory Machine and Mechanisms of Building Machines Committee of Polish Academy of Science.

He is author or co-author of about 80 papers and 4 books and monographs.

ZDZISŁAW TRYBALSKI

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Zdzisław Trybalski received his Ph.D. (1958) and the D.Sc. (habilitation) (1962) degrees in industrial automation from the Silesian University of Technology in Gliwice. He is the author of about 40 papers and author 14 several paper-books for students. His research interests concern: automation in chemical engineering (flowsheetings - problems) and control of processes in biotechnology.

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Within the framework of TEMPUS program he investigated the sensor of vortex flowmeter in Ecole Supérieure de Physique et Chimie Industrielles de Paris in July 1996. He is co-author of 9 scripts and co-editor of one of them. His main fields of interest are: mathematical modelling of sampling flowmeter primary devices, metrological optimisation of sampling flowmeters, construction of ultrasonic flowmeters and averaging impact tubes, measurement of flow rate in closed conduits and in open channels, sensors for non-electrical quantities, didactic of metrology, fundamentals of measurement, radiation measurements and radiological protection.

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MARIA WIDEL

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Educational history: Master of microbiology, Faculty of Biology and Earth Sciences, University of Maria Skłodowska-Curie (UMCS), Lublin (1965), Doctor of Science, Faculty of Biology and Earth Sciences, Jagiellonian University, Kraków, (1986), assistant professor, Center of Oncology, Maria Skłodowska-Curie Institute, Warszawa (2002). Academic and professional appointments: 1965-1969 - Bacteriological Laboratory at Sanitary-Epidemiological Station Gliwice, 1970 –2006 -Center of Oncology Maria Skłodowska-Curie Institute Gliwice: assistant, assistant professor, head of Laboratory of Cellular Radiobiology Department of Experimental and Clinical Radiobiology, since 1.10.2007 – Professor of Silesian Technical University . Fields of interests: oncology, radiobiology, cytobiology, among them: radiation sensitivity of tumor cells , individual radiation sensitivity of patients, dose-rate effects, radiation-induced bystander effects, photodynamic therapy. Skilled techniques: cell culture, micronucleus assay, clonogenic assay, MTT-assay, single cell gel electrophoresis, cytometry. Publications: Over 130 publications in scientific journals and conference proceedings (50 regular papers published mostly in international journals). Research projects: Head or principal investigator in several projects financed by the Polish Ministry of Science Scientific and professional society membership: Polish Oncological Society, Polish Radiation Research Society European Radiation Research Society, Polish Association for the Support of Cancer Research.