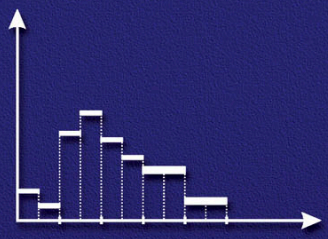

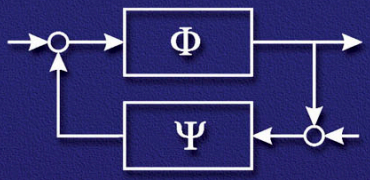

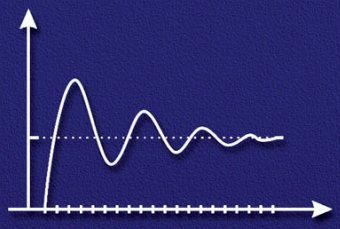

Institute of Automatic Control

Faculty of Automatic Control, Electronics and Computer Science

ACTIVITY REPORT 2005 2006

SILESIAN UNIVERSITY OF TECHNOLOGY GLIWICE 2007

SILESIAN UNIVERSITY OF TECHNOLOGY

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

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2005-2006

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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)

Marian Błachuta	- professor,
Adam Czornik	- professor,
Zdzisław Duda	- professor,
Jarosław Figwer	- professor,

Jerzy Frączek	- full and titular professor,
Ryszard Gessing	- full-titular professor,
Jerzy Kasprzyk	- associate professor,
Marek Kimmel	- full and titular professor,
Jerzy Klamka	- full and titular professor,
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Henryk Palus	- associate professor,
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Zdzisław Trybalski	- full-titular professor,
Stanisław Waluś	- associate professor,
Maria Wideł	- professor,

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Elżbieta Gajda, M.Sc.	- administrative manager,
Henryk Jakubiec, M.Sc.	- service for research instrumentation,
Elżbieta Król, M.Sc.	- service for research contracts and grants,
Laura Frydrychowska, B.Sc.	- service for teaching.

Structure and staff

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Ryszard Gessing, M.Sc., Ph.D., D. Sc., full-titular professor
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Marian Błachuta, M.Sc., Ph.D., D.Sc., professor,
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Sebastian Student, M.Sc., Ph.D. student,
Jan Staniek, M.Sc., Ph.D. student,

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 started in the fall 2003 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 for which enrollment will start in the fall 2005.

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 theory,
- robot control systems.

CONTROL AND OPTIMIZATION THEORY

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.

Sliding mode control with decreased chattering effect

R. Gessing

The idea of the system with sliding mode control and adaptation of the switched *Max-Min* amplitudes of the relay output is researched. The adaptation is possible owing to the observation that the sliding mode control is equivalent to bang-bang relay control of the sliding surface signal on the level zero. The rates of the increasing and decreasing parts of the sliding surface signal are used for independent adaptation of *Min* and *Max* values of the relay output, respectively. The adaptation causes that the difference (*Max-Min*) is decreased and both the values tend to be placed symmetrically with respect to the needed value of the control. Owing to this the chattering effect appearing in the sliding control is decreased, significantly and the system remains very robust. Simplified model of the proposed solution is elaborated and the condition of stability is derived. The proposed approach is applied also for the systems with delay. To compensate the delay of the plant the Smith predictor is used.

An original compensator has been proposed to implement sliding mode control with decreased chattering for nonminimum phase plants. The idea of the compensator is similar as that of the Smith predictor. The difference is that the compensator from the point of view of control “changes” the plant from nonminimum phase to minimum phase one. It is also shown that using the parallel compensator described below in a relay system it is possible to implement sliding mode control without application of higher order derivatives.

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.

Whether Delta Operator Models are Really Better for Small Sampling Periods

R. Gessing

It is known that in the case of small sampling period a large word length (WL) is needed for recording the shift operator (SO) model coefficients. Therefore the large WL is also needed for calculation of the frequency and time responses when the SO model is used. Somewhat different situation is in the case of the delta operator (DO) models which need for recording their coefficients a significantly smaller WL. The same remark concerns the analytical calculations of the frequency and time responses. However for calculations of the latter this statement is true only for such inputs which are described by some mathematical functions and for which there exists an analytical solution of the corresponding difference equation. This is a rather seldom case in applications. The superiority of the DO models over SO ones disappears in the simulation in which for any input the time response of the output is calculated. This is an important observation because in simulations usually this case appears. The same case appears in digital control implementation in which the output of the digital controller must be calculated for any current input. The superiority of the DO models over SO ones, for small sampling periods, disappears also in the case of model identification under limited measurement accuracy and relatively accurate calculations (information processing). This case is fully justified from practical point of view. The statement about the lack of the superiority of DO models is in contradiction with the common view. However this view results from different assumption that the errors result mainly from less accurate information processing (to short mantissa used in calculations). To summarize, since the simulation for any input signal and identification under a limited measurement accuracy are (from application point of view) more important, then the statement about the superiority of the DO over SO models, for small sampling periods, seems to be not fully justified.

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.

Implementability of Regulation and Partial Decoupling of MIMO Plants

R. Gessing

Some problems related with multivariable system, under using matrix transfer function (MTF) models has been considered.

First, a necessary condition of implementability of regulation of MIMO plant is formulated. For the plant described by the MTF *G(s)* with no integrators the condition $det\mathrm{G}(0) \neq 0$ is almost obvious but not formulated in literature in this context. The appropriately normalized determinant determines the *independence degree* ι introduced in the paper. For ι close to zero the plant has bad steady state properties. Less obvious are considerations concerning the plants with integrators.

Second question considered is the partial decoupling of steady states and of fast transients by means of the matrices D_s and D_f with constant elements. The considered decoupling of steady states, by means of the constant matrix D_s, consists in retaining the introduced *join gain* $\kappa = |det\mathrm{G}(0)|$ of the decoupled plant. The decoupling of fast transients is based on the observation that smaller relative degree of a TF gives faster initial changes of its step response. This observation is utilized for decoupling of fast transients by means of the constant matrix D_f. One may suppose that faster initial reaction on the control of each loop may cause a dynamic decoupling of the stable system with feedback. It has been noticed that for some plants the constant matrix D_c causes full decoupling.

Third question is accounting of control saturation. This problem is important for implementability of the proposed ideas. It becomes that the existence of saturations usually destroys the decoupling of fast transients. However, it has been shown that by

the appropriate choice of the values of saturations we may obtain a negligible influence of some, chosen, only one loop to the remaining loops.

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.

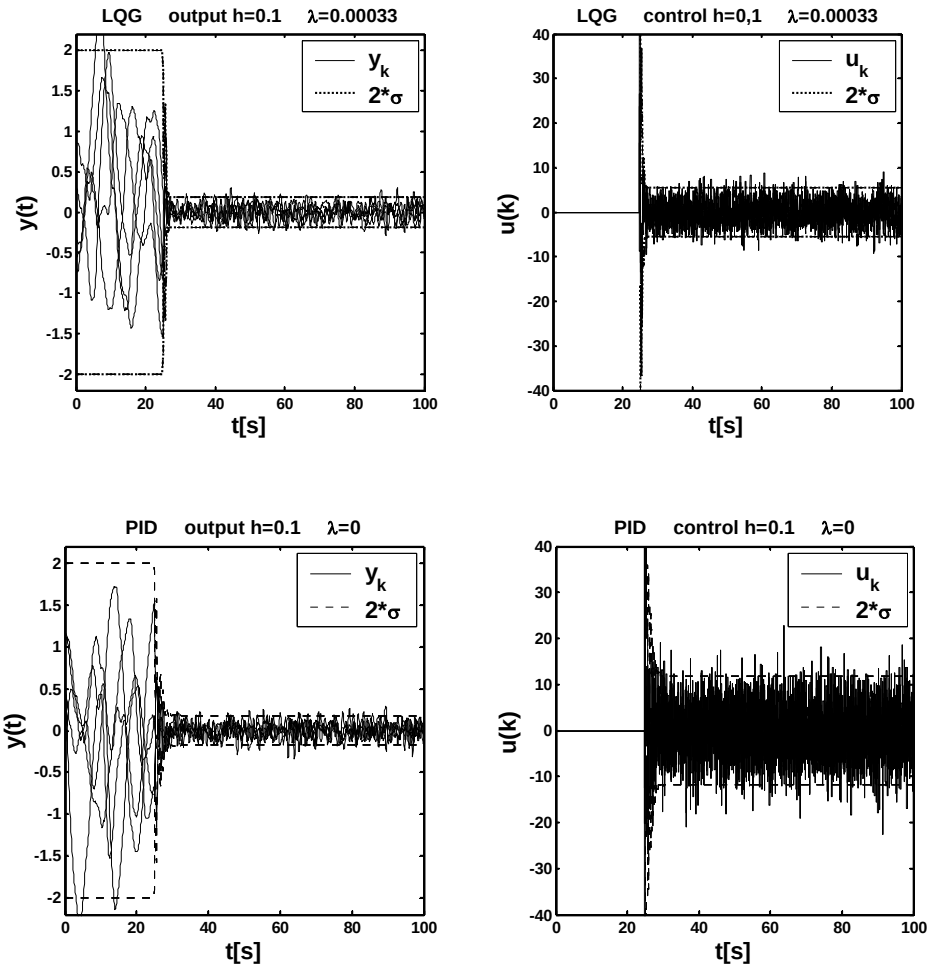


Fig. 1. Realizations of y(t) and u(t) for LQG and PID controllers with the same control quality (a → a').

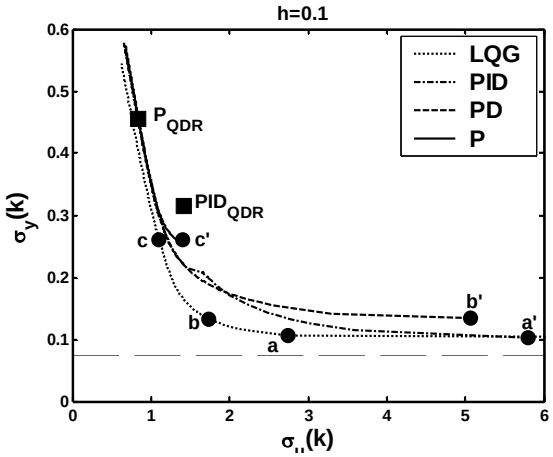


Fig. 2. Standard deviation of output vs control.

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.

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.

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.

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.

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.

The generalized spectral radiuses

A. Czornik, A. Bal

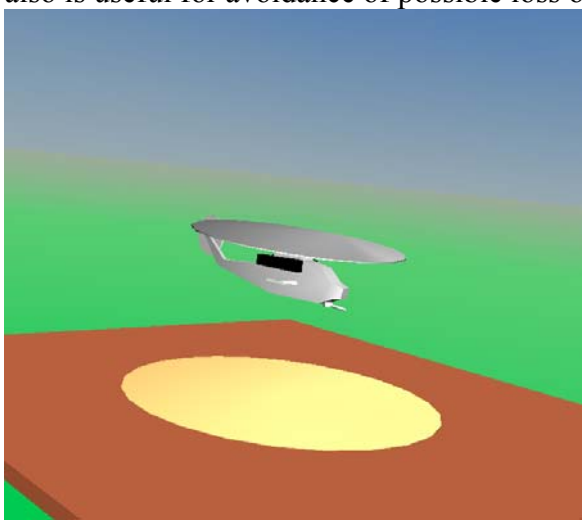
The concepts of joint spectral radius and generalized spectral radius for a family of matrices were introduced by G. C. Rota and G. Strang in 1960 and rediscovered by I Daubechies and J. Legarias in 1992. It turns out that the asymptotic behavior of all the possible products of the matrices of a family (as the number of factors goes to infinity) is determined by the value of them. In particular, the asymptotic stability is equivalent to the condition that generalized spectral radius <1 and the existence of switching strategy that leads to a stable system is equivalent to the condition that generalized spectral subradius <1 . We study the asymptotic behavior of all the solutions of a linear difference equation by studying the asymptotic behavior of the products of the companion matrices associated to the difference equation and the main tools of our investigations are different concepts of generalized spectral radiuses. When the difference equation has constant coefficients, there is just one constant companion matrix, everything being easy and well known. In fact, it is sufficient to control the spectral radius of the companion matrix. On the contrary, when the coefficients are variable, the companion matrices may be even infinitely many and, in any case, they do not reduce to one constant matrix. However it appears that a satisfactory stability analysis may be done by evaluating (or, at least, by approximating sufficiently well) the appropriate defined spectral radiuses of the family formed by all of the coefficients matrices. The concepts of generalized spectral radiuses has been also successfully

applied in wavelet theory, nonhomogeneous Markov processes, probabilistic automata, iterated function systems, hysteresis nonlinearities.

Modeling of Unmanned Model-scale Helicopter Dynamics for Needs of the Simulator

R. Czyba

Model-scale helicopters are popular platforms for unmanned aerial vehicles. The ability of helicopters to take off and land vertically, to perform hover as well as cruise flight, and their agility and controllability, make them ideal vehicles for a range of applications which can take place in a variety of environments. The one of the reasons for simulation model of helicopter coming into the focus, is that most multivariable control methods are model-based. For unmanned flight vehicles it is very common to use flight simulator before real flight tests. It helps to reduce time and costs during the testing phase, and also is useful for avoidance of possible loss of vehicle.



Investigation describes the process and results of the dynamic modelling of a model-scale unmanned helicopter HIROBO SST-EAGLE2-GS LONG. The helicopter is a complex nonlinear MIMO system, with high correlation of state variables. The simulation model was developed by using elementary laws of mechanics and aerodynamics, and then the model was implemented, using the parameters of the project helicopter, in a simulation environment. The main attribute of a simulator as an effective tool for controller design is the ability to produce desired results for a specific application and to operate over the full flight envelope (forward, rearward and sideward flight, hover, transition from hover to forward flight, vertical climb) with representative handling qualities. Qualitative tests show that the model behaves as expected with in the specified flight envelope.

Robust Regulation of Helicopter Model Based on the Highest Derivatives in Feedback

R. Czyba

Robust regulation of a helicopter model is a problem of both theoretical and practical interest. The applied model has two degrees of freedom and is treated as a multivariable system with significant crosscoupling. Dynamic properties of a controlled helicopter model depend on both its structure and aerodynamic qualities as well as on the control law applied. The applied method based on two ideas – the use of

higher order output derivatives jointly with high gain in feedback loop to suppress the disturbances and varying parameters.

The high gain and ”dynamics” of the controller are separated by means of the summing junction with set point signal placed between them. This structure is the implementation of the model reference control with the reference model transfer function which is equal to the inverse of the controller ”dynamics”. It becomes that the proposed structure and method is insensitive to plant parameters changes and external disturbances. Experiments results for tracking a reference signal confirm the effectiveness of the proposed method and theoretical expectations.

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

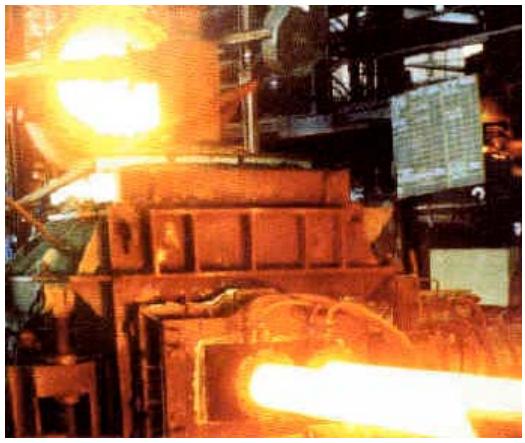
Two so-called diseases of civilization were taken into account in this research: arterial hypertension and neoplasm with bad prognosis. These diseases were explored under 'psychological' point of view, i.e. such psychological properties like: hope, anxiety, meaning of life, coping with stress, different 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.

Identification of ingot-mould thermal resistance in continuous casting of metals

A. Nawrat

One of the most important technological parameter which influences the process of solidification of the metal in stationary or continuous casting technologies is thermal resistance of the gap between the mould and ingot. It is developed the inverse technique for identification of thermal resistance on the base of temperature measurements within the wall of the mould in the process of continuous casting of metals. Analysed problem belongs to the group of inverse problems. A research shows the possibility of applying the least squares adjustment method with *a priori data* for solving inverse problem of identification of unknown thermal resistance of gap in the process of continuous casting. The identification is based on the mathematical model of the process and on the



results of temperature measurements within the wall of the mould. To apply the method the mathematical model of the process has been evaluated. The finite element method has been used for evaluation of the mathematical model of steady-state temperature field and interphase location in the analysed process of continuous casting of metals. In the researches is also considered the problem of appropriate location of the sensors for identification of ingot mould thermal resistance during continuous casting of metals is the subject of the paper. Location of the sensors is based on the results of sensitivity analysis for the steady-state inverse heat conduction problem. Validation of the proposed inverse method is realized by comparison results taken from solution of inverse and direct problems.

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.

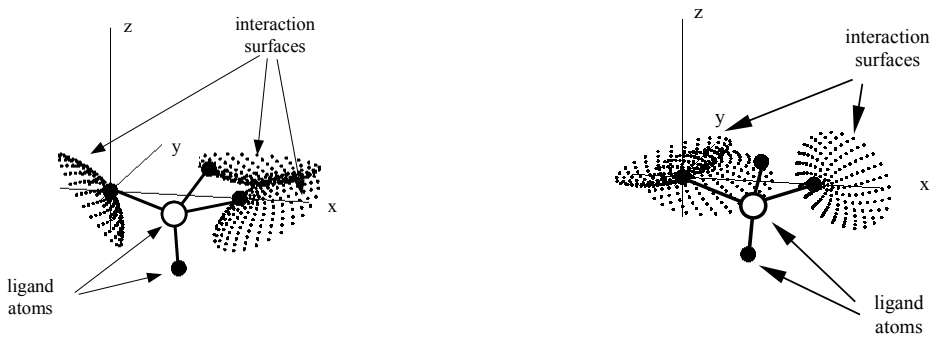


Fig. 1. The reconstructed pose of SO4 ligand – results obtained with geometric hashing technique

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.

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.

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.

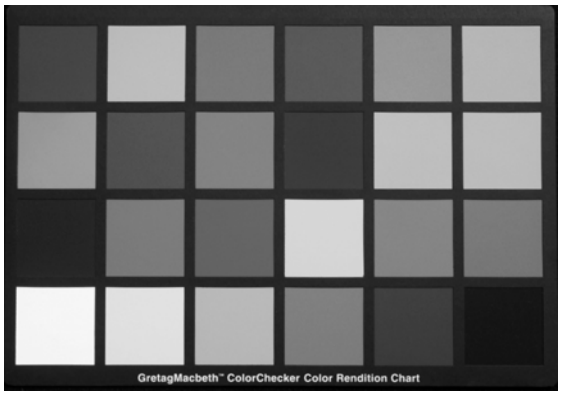


Fig. 1. ColorChecker Chart from Gretag Macbeth.

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.

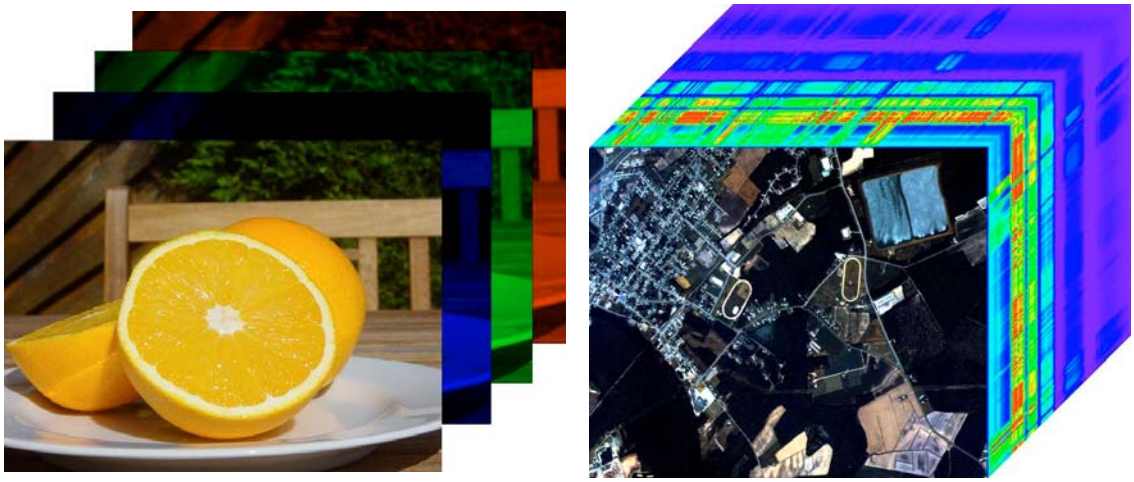


Fig. 1. Example of colour images witch three channels and hyperspectral cube image with 224 –channels.

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.

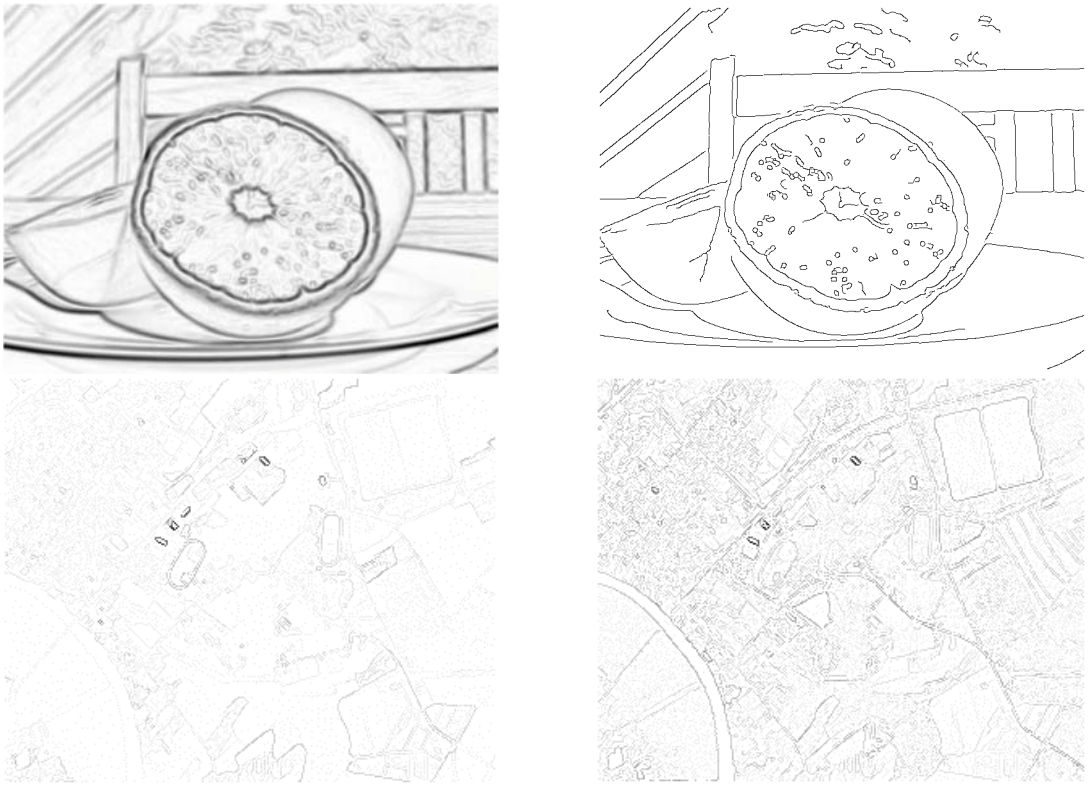


Fig. 2. Example of gradient map and contour of colour image (top row), and gradient map of hyperspectral images for 190-channel with Triangular kernel and 55-channel for Gaussian kernel (bottom row).

Research on modelling, planning and simulation of robot manipulator movement

T. Szkodny

The fundamental problems of robotics are concentrating in following topics:

- modelling of robot manipulator movement,
- planning trajectories of manipulator,
- simulation robot movement and control,
- control of robots.

These problems are solving for robots located in laboratory of Robotics and Discrete Events Automation Group. Mathematical models of movements of these robots were

developed. Based on these models, the motion planning algorithms for some manipulators were obtained. The description of motion planning algorithm designed for the IRb-6 manipulator is presented below.

The design of motion planning algorithms bases on formulas, which are solutions of an inverse problem of manipulator kinematics. The natural coordinates correspond to the reference trajectory of manipulation object described in the Cartesian space of robot. The planning algorithms calculate the natural coordinates of actuators using data from a tier of reference trajectory computations, which is an element of the functional structure of an intelligent robot control system. These algorithms are indispensable for programming tools, which connecting a vision tier with a drive control tier.

Author has designed the PLAN2, the program based on motion planning algorithm for a series of IRb-6 manipulator tasks. The reference Cartesian coordinates of the points through which a planned trajectory will pass, will be called main fulcrums. Planning requires a preliminary description of the trajectory, in the form of values of Cartesian coordinates at least two main fulcrums, optionally distant from each other. In case of a kinematics singularity occurrence, the PLAN2 algorithm announce the state, gives the values of acceptable natural coordinates for the links, and asks the user which of the given values are to be accepted. The PLAN2 algorithm calculates additional fulcrums for either defined or non-defined kinematics between the successive fulcrums.

The algorithm for defined kinematics contains four basic segments; the computations from there are transmitted to 22 ancillary segments. The basic segments are: the master segment, the ROZ1 segment, the ROZ2 segment, and the ROZ3 segment. To simplify the description, the following abbreviations will be used: MRF - main fulcrum and AFP - additional fulcrum.

After starting, the PLAN2 algorithm asks about the l_6 and λ_6 parameters, which described the task. Then, it asks about the number MP ($\leq$50), Cartesian coordinates and reference parameter T for the consecutive MFP, and whether the consecutive MFP orientation is defined. If the orientation is defined, the algorithm asks if it is computed. If so, the next question is which coordinate system is used: Cartesian, cylindrical or spherical. After setting required coordinate system, z-y-z Euler angles are computed, describing the orientation of a given MFP. If the defined orientation is not computed, a question about MFP Euler angles appears. For a non-defined MFP orientation, the Ψ_{ref} angle is being set arbitrarily. The Φ_{ref} and Θ_{ref} angles are calculated from the x_{ref}, y_{ref}, z_{ref} Cartesian coordinates.

For the so computed x_{ref}, y_{ref}, z_{ref}, Φ_{ref}, Θ_{ref}, Ψ_{ref} Cartesian coordinates, describing the consecutive MFP, the algorithm calculates the $\mathbf{T}_{ref}$ matrix, checks whether the key equation is satisfied, and computes $\Theta'_1 \div \Theta'_5$ natural coordinates from the formulas, which are an analytic solution of an inverse problem of kinematics. Then, the algorithm asks about a coordinate system describing the shape of a trajectory segment between the consecutive MFPs. For a rectilinear system, a Cartesian coordinate should be chosen; for a curvilinear segment, either a cylindrical or a spherical system should be chosen. Next algorithm asks about the discretization step ΔT along the present reference trajectory segment. After the shape and discretization step along each segment between the consecutive MFPs have been defined, the algorithm asks about the admissible DP error of position and the DF error of orientation. If an optional task orientation was set earlier, the algorithm arbitrarily accepts DF=360°.

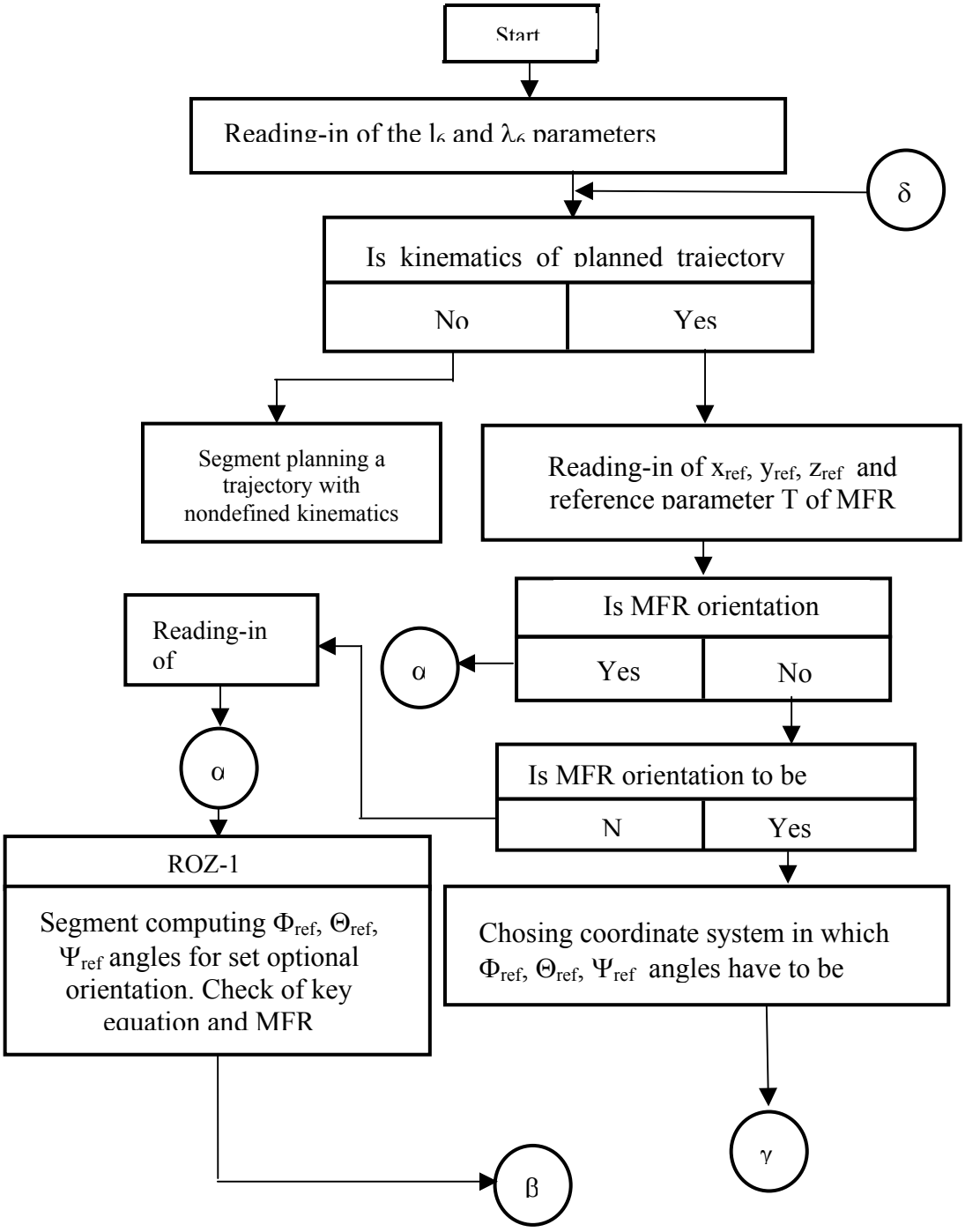


Fig. 4. PLAN2 algorithm block diagram (part 1).

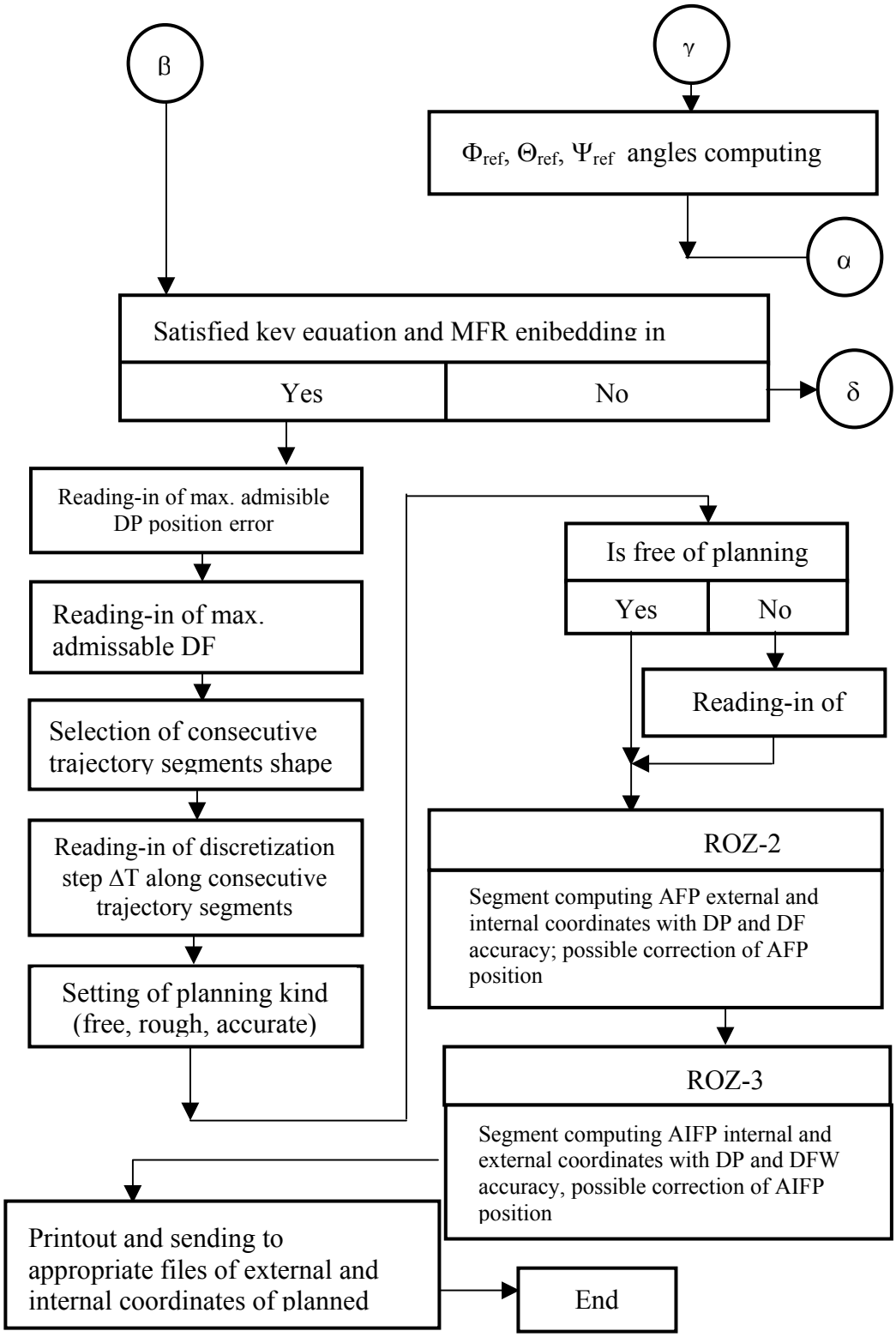


Fig. 4. PLAN2 algorithm block diagram (part 2).

Next, the algorithm asks about kind of trajectory planning, which may be set as: free, rough or accurate. When either rough or accurate planning has been set, a question about an admissible DFW error of orientation is formulated. This parameter is necessary for the manipulator internal space discretization. For a free planning, the algorithm computes the AFP Cartesian coordinates coming from the pre-set DP, DF and step ΔT, which ensure the declared shape of the trajectory segment in Cartesian space.

For a rough or accurate planning, the algorithm computes two groups of fulcrums: additional external fulcrums and additional internal fulcrums. The additional external fulcrums are computed in the same way as in the case of trajectory free planning, and will be denoted as before, using the abbreviation AFP. Additional internal fulcrums result from the division of actuator natural coordinates (within ranges corresponding to consecutive AFPs) and are denoted using the abbreviation AIFP. Each range of actuator natural coordinates corresponding to consecutive AFPs is divided into N+1 parts. For a rough planning the number N results from the minimal angular ratio orientation errors. For an accurate planning the number results from the longest effective radius of task displacement in Cartesian space.

The final result of the algorithm is to generate sets describing all manipulator internal and Cartesian coordinates. Figure illustrates a block diagram of the PLAN2 algorithm for the defined kinematics of the task reference trajectory.

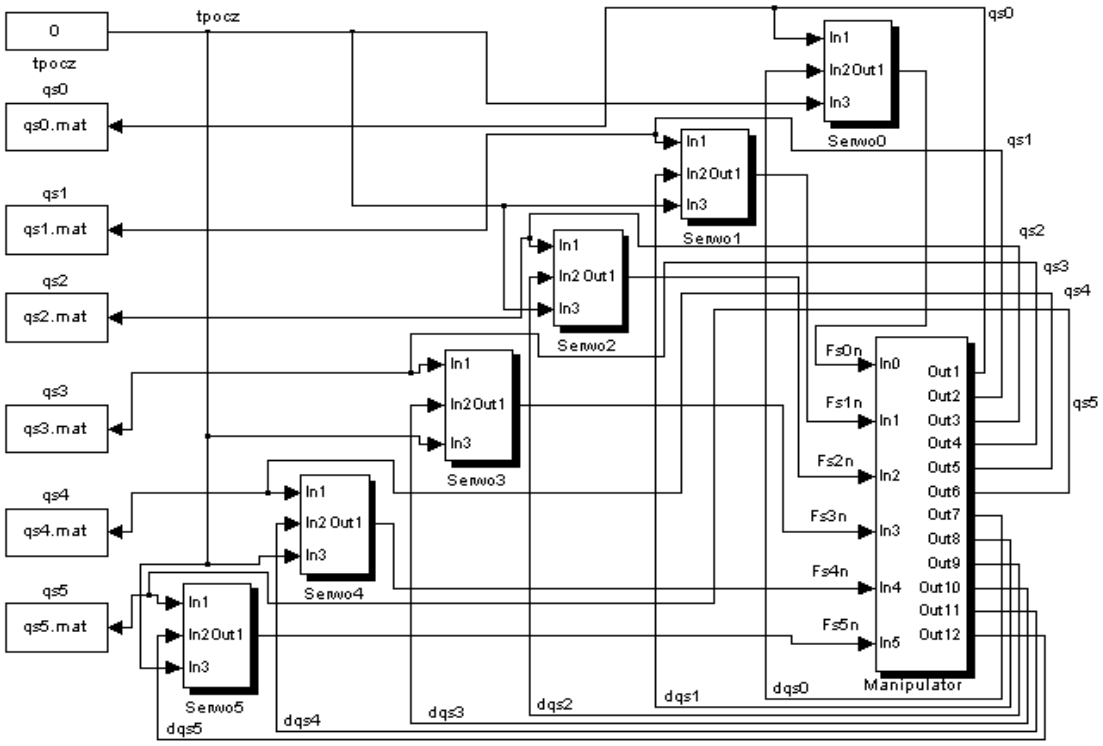


Fig. 5. The graphic model of experimental robot.

This algorithm has been implemented partially to control system of experimental robot. Implementation allows to reach by experimental robot points, which were determined

by optical measurements. Ones allows on straight line movement of the experimental robot task.

To simulation of movement and control of these robots the graphic model was designed. The model was worked in Simulink integrated with Matlab and it is in Fig.5 presented. The graphic model contains mathematical models of kinematics and dynamics of manipulators, models of motors, servos, master and slave controllers. The kinematics models describe a movement of links and a movement of chosen elements transmitting drive and motors. In this model the friction moments and distribution mass of following elements: links, chosen elements of transmitting drive, gripper, manipulation object and motors are taking into consideration. Closed form of kinematics and dynamics coefficients was obtained using Symbolic Toolbox Math. The motors model describes voltages, currents and drive torques. The graphic model contains the mathematical model of servo controllers and power amplifiers too. The simulation programs in C were obtained automatically from the graphic model, by means of the Real Time Workshop extension of Simulink. With the aid of the extension Real Time Workshop we may automatically create also a source code for the simulation program in the assembler of various processors.

Methods for simplifications of manipulator dynamic models were developed. The methods based on research on the sensitivity mass forces to mass parameters, which appear in closed form of dynamics equations.

Now the laboratory stations containing four Robix Robot are preparing to teaching of planning trajectories in Cartesian Space. These robots will allow illustrate algorithms designing of the solving methods of direct and inverse kinematics problems, and implementation of this algorithms in robot program environment.

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).

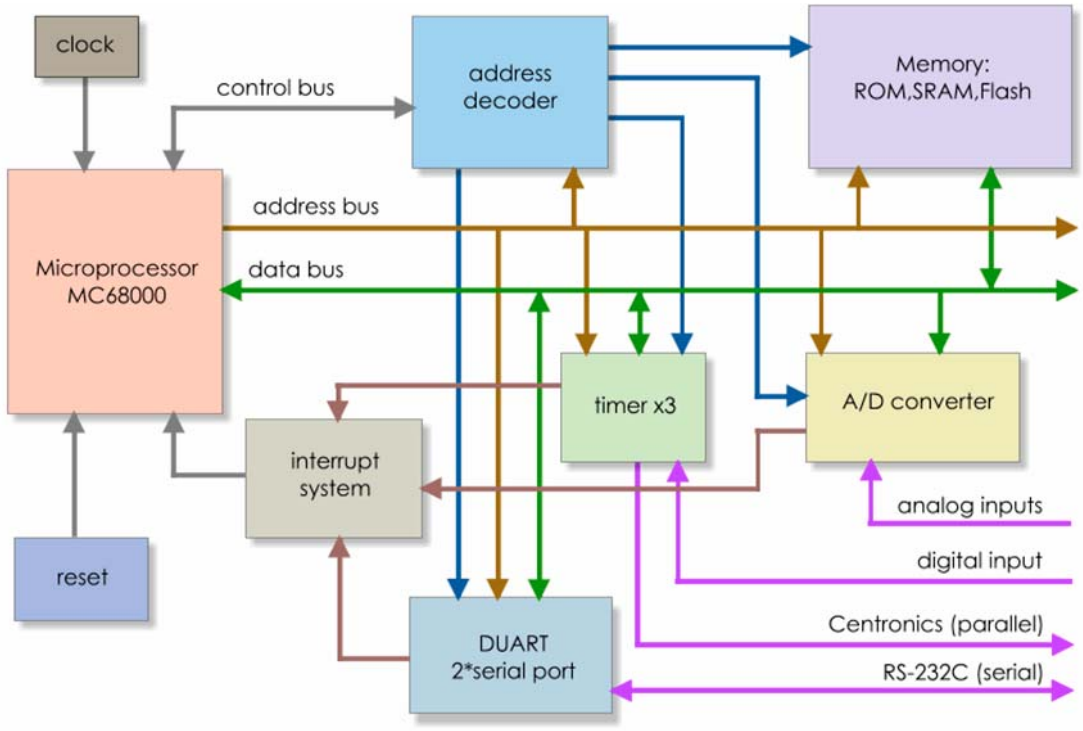


Fig. 1. Block diagram of the diagnostic system.

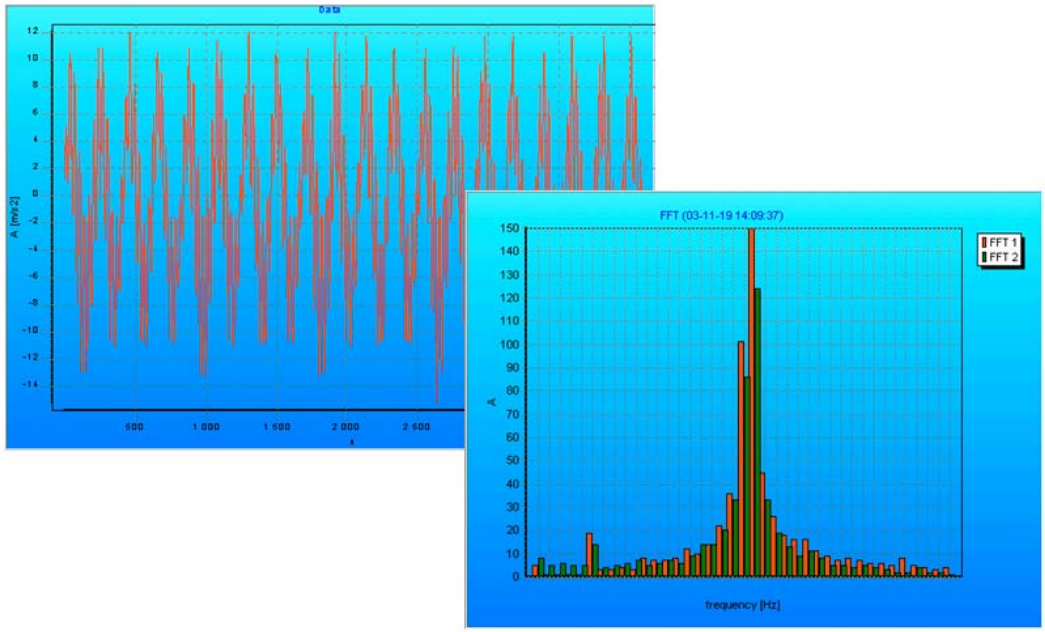


Fig. 2. FFT analysis of vibrations - sample result.

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

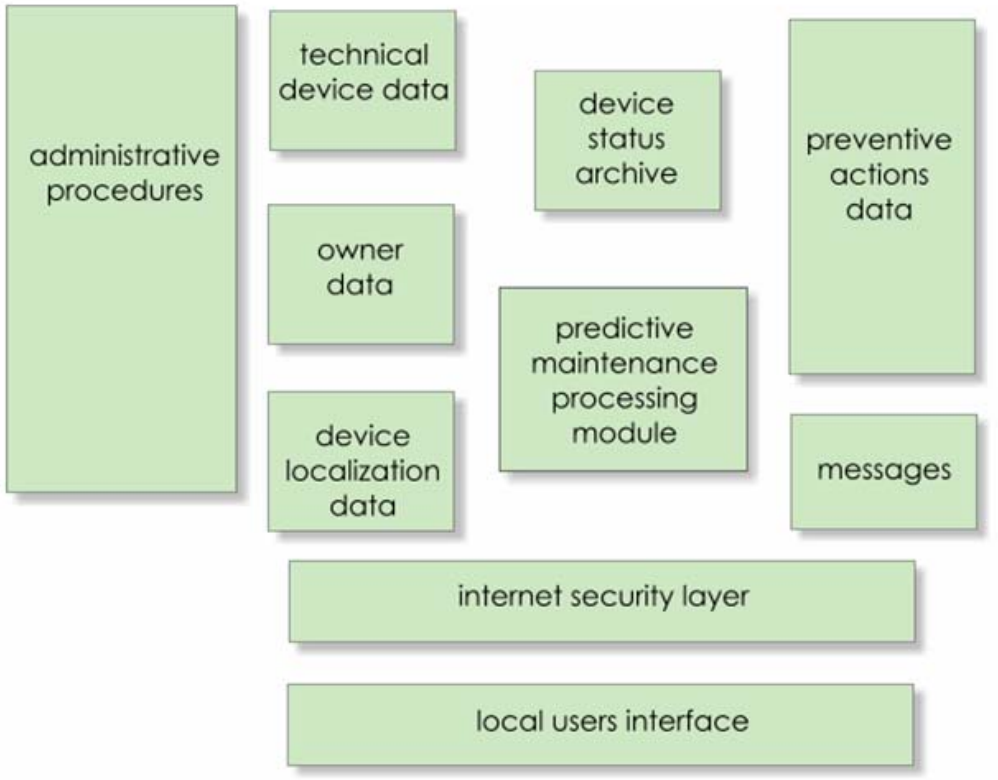


Fig. 3. Components of predictive maintenance database.

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.

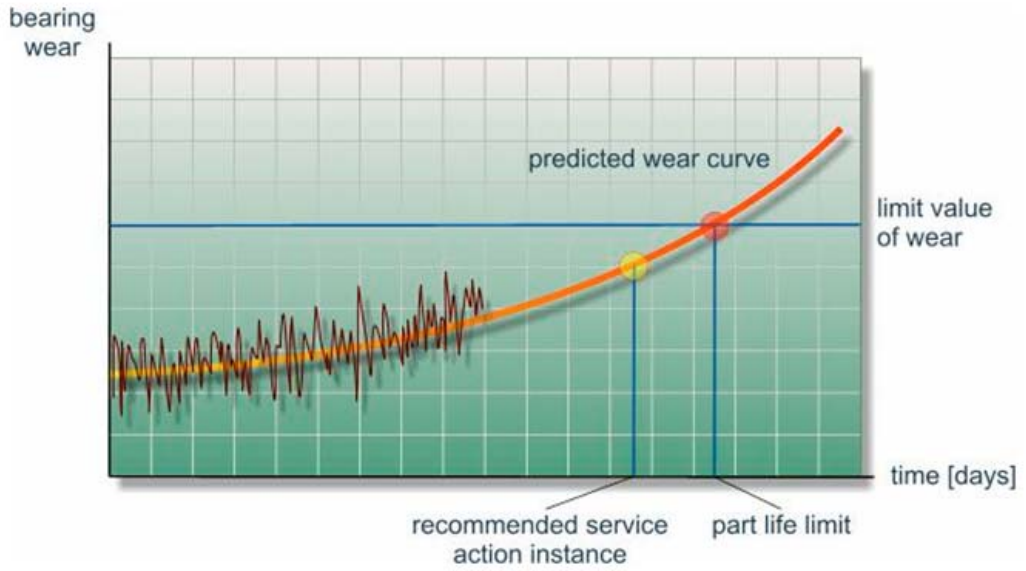


Fig. 4. Predictive maintenance curve.

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.

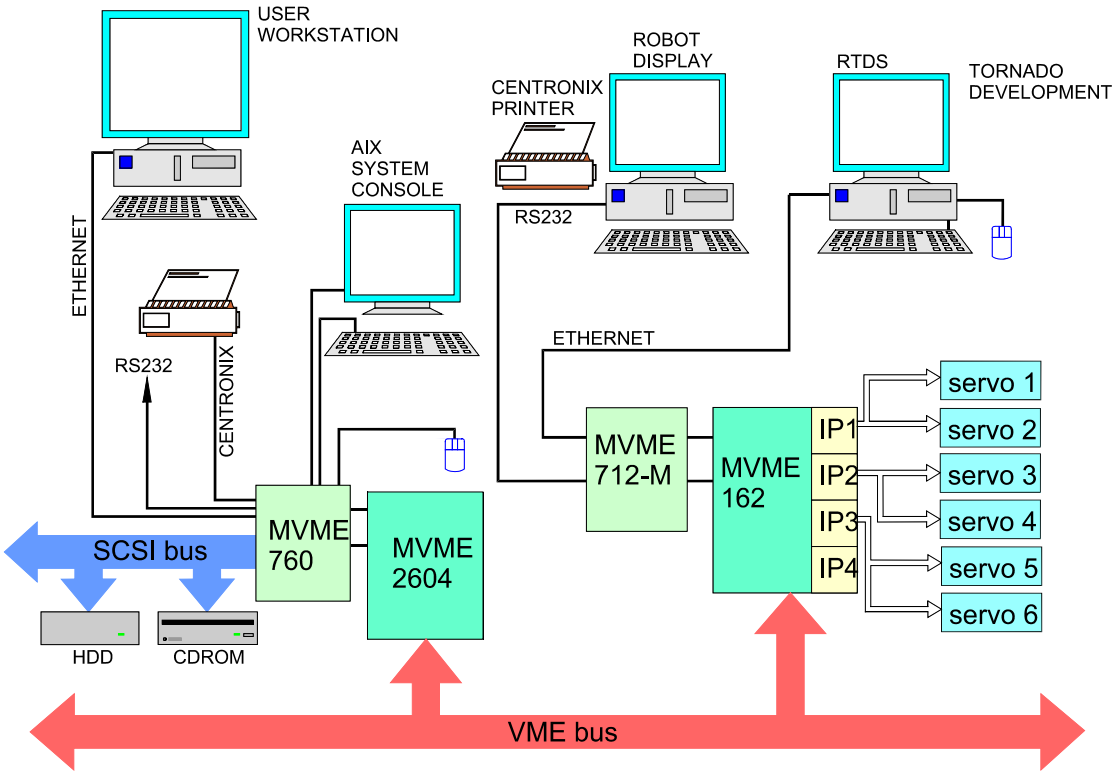


Fig.1. Hardware structure of robot control system.

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.

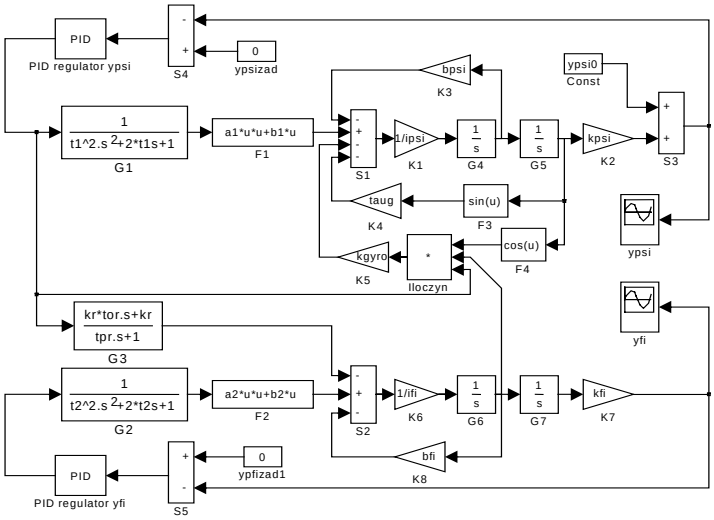
LABORATORY AND RESEARCH EQUIPMENT

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

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 Unit is shown adjacent to a CE122 Controller and an IBM compatible PC.

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.

Magnetic levitation system

Magnetic levitation system (MLS) is a complex system manufactured by Feedback Corporation. It contains Magnetic Levitation Unit 33-210 (electromagnet, photo-sensor axis, analog controller and power adapter), analog interface, I/O pc-card and software: procedures and main control program implemented in Matlab environment. MLS contains module: Real Task Kernel which collect data in real-time. Full access to the sensors actuators is available. It has real and safe facility for students of control theory and practice engineering.

The main purpose of MLS is to control the vertical position of iron ball in electromagnetic field. The mathematical model of phenomena magnetic levitation is based on the basics equations of physics and mechanics. The dynamic behavior of MLS is modeled by differential equations. It presents non-linearity and it is naturally unstable. It is possible to change all the parameters of mathematical model for the research purpose MLS permits different type of control algorithms to be investigated. The possible tasks approach such problems as state feedback control, mathematics model identification, linearization, simplification, 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). Its configuration enables control by an IBM PC computer.

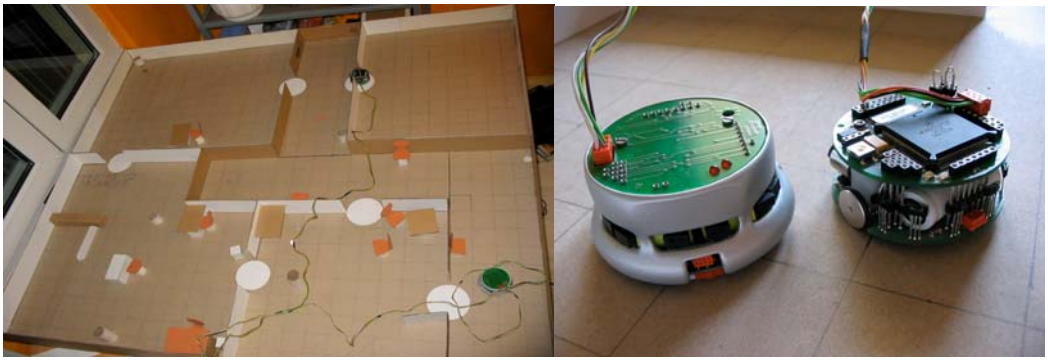
A wealth of control system design and analysis features that the plant provides, make it very useful for education and research problems. The cart - pendulum model shows the natural nonlinearity and instability that make it very difficult for control. It also provides wide range of possible investigations such as derivation of the mathematical model, linearization, simplification, identification, dynamic system analysis and design. Included external DLL library interface makes the system architecture open and allows a user to modify and change implemented control algorithms.

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

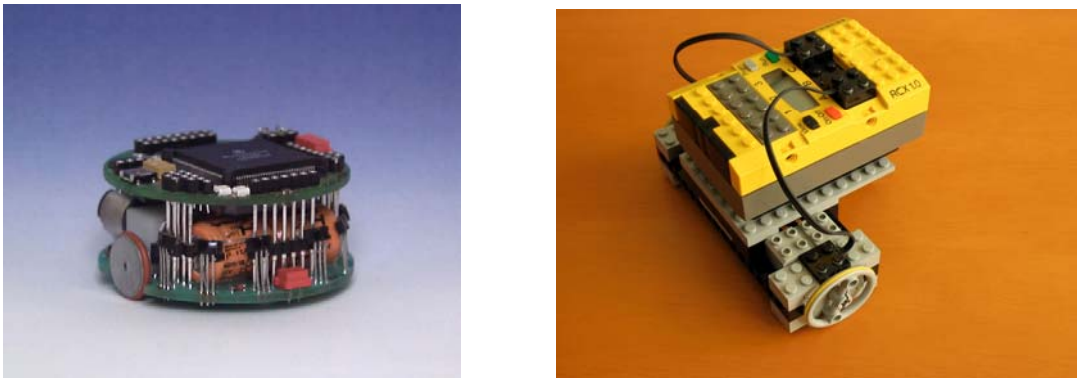
The laboratory is equipped with two *Khepera* robots, two sets of *LEGO MindStorms - Robotic Invention System*, two colour CCD cameras, ultrasound and IR sensors, six soccer robots. We also have special development tools like MPLAB ICE 2000, MPLAB ICD 2 Debugger and dsPIC Development Board.

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.

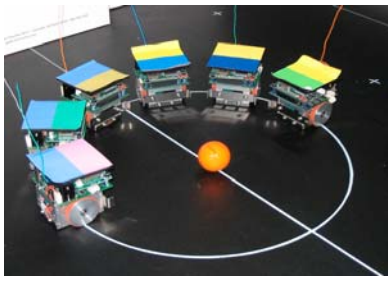
MPLAB ICD 2 is a low cost, real-time debugger and programmer for selected PICmicro® MCUs. Using Microchip Technology's proprietary In-Circuit Debug functions, programs can be downloaded, executed in real time and examined in detail using the debug functions of MPLAB. Watch variables and breakpoints can 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

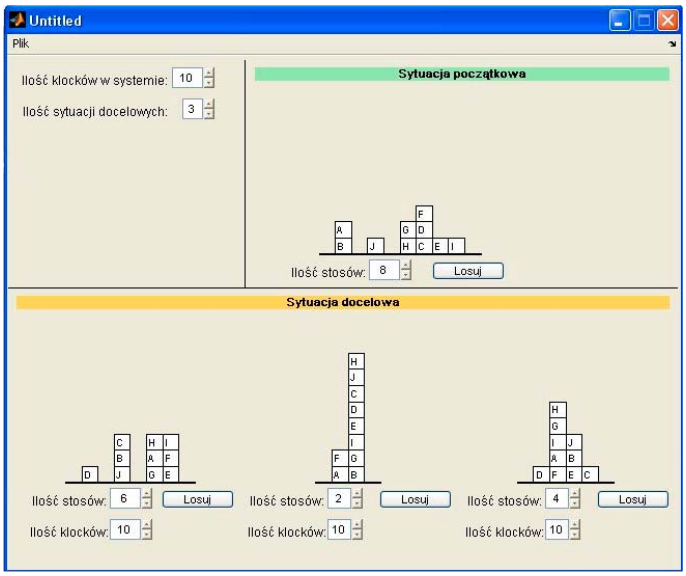


QTeam soccer robots and dsPIC (Microchip) development tool

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.

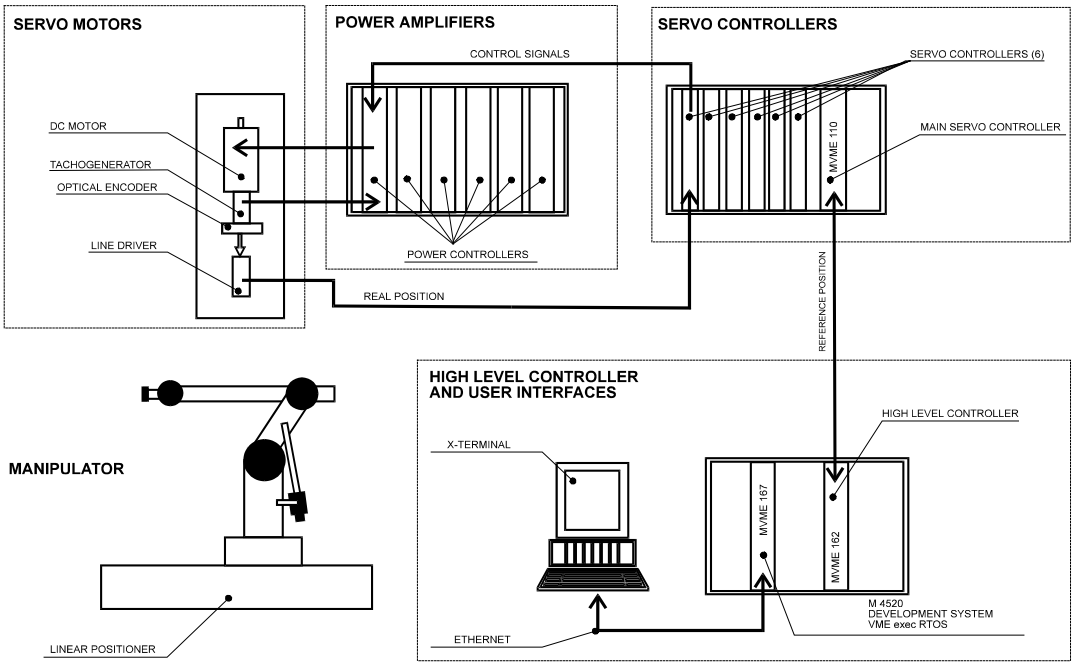
The advanced robot control system for robotic research has been entirely designed and implemented of the RDEA Group. The sensorial part of IRb-6 system has been modified according to the design.

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.

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.



RESEARCH STATION

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.

COMPUTER CONTROL GROUP

The research activities focus on:

- control theory,
- system identification,
- active noise and vibration control,
- signal processing,
- modern education technologies,
- microelectronics in control,
- process control,
- artificial intelligence and constraint programming.

CONTROL THEORY

Controllability and observability of infinite-dimensional systems

J. Klamka, J. Wyrwał

Controllability and observability are fundamental concepts in modern mathematical control theory. They are qualitative properties of control systems of great importance in control theory. Moreover, it should be pointed out that there exists a formal duality between the concepts of controllability and observability. Roughly speaking, controllability generally means that it is possible to steer dynamical system from an arbitrary initial state to an arbitrary final state using admissible controls. On the other hand, dynamical system is said to be observable in a time interval if the initial state of the system can be uniquely determined from the output over this time interval.

Controllability and observability are also strongly related to the theory of minimal realisation of linear time-invariant control systems, optimal control and pole-assignment. In addition, there are important relationships between controllability, observability and stabilizability of linear control systems. 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 stabilised. It is impossible on the one hand when the control does not affect the complete state of the dynamical system but

only a part of it, and on the other hand when only a certain part of the complete state of the dynamical system may be observed at the output. Therefore it is very important in practice to determine whether or not control and observation of the complete state of the dynamical system are possible. In other words, controllability and observability of the dynamic system have to be verified.

In recent decades a systematic study of controllability and observability for infinite dimensional systems could be observed. It has been motivated, on the one hand, by the wide range of applications of such systems in various areas of science and engineering, and, on the other hand, by the difficult and stimulating theoretical problems posed by such research. It should be emphasised that – contrary to finite dimensional systems – in case of infinite dimensional systems two basic concepts of controllability and observability can be distinguished:

- exact and approximate controllability,
- continuous and initial observability.

The research reported here concentrates on investigation of controllability and observability for

- continuous time linear, semi-linear and nonlinear dynamical systems defined in infinite dimensional function spaces,
- continuous time linear hereditary dynamical systems defined in infinite dimensional function systems,
- discrete time linear and nonlinear dynamical systems with two independent variables – so called 2-D systems.

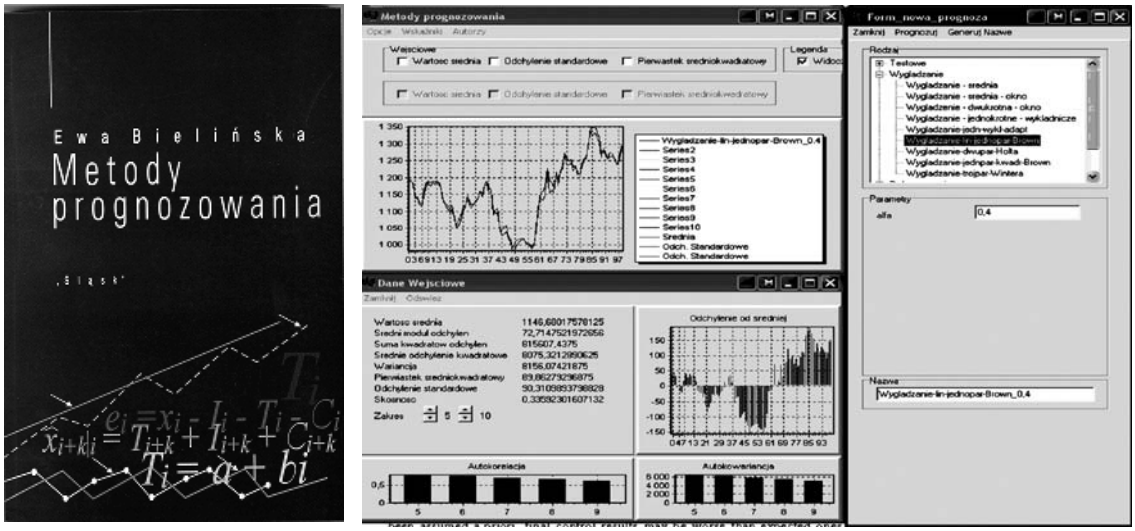
For the stated dynamic systems unconstrained and constrained controllability were investigated. Using methods of functional analysis, and especially the approach based on the spectral theory of linear operators, necessary and sufficient conditions for different types of controllability were formulated and proved. Conditions formulated for infinite dimensional continuous time systems can be applied to the investigation of controllability and observability of distributed parameter systems (PDS) described by partial differential equations. In the case of PDS the following two types of controllability were investigated:

- distributed controllability – with control being distributed over the domain in which PDS is defined,
- boundary controllability - with controls appearing only in boundary conditions of different types.

Prediction methods

E. Bielińska

A key issue is a development, testing and comparison of different prediction methods. The advanced methods using, e.g., neural networks, minimum variance prediction, Kalman filtering, are compared with the classical ones, like naive prediction of different types, smoothing or decomposition. The methods of a'priori estimation of prediction efficiency are developed and compared with an ex post prediction efficiency obtained with the use of a particular prediction algorithm. A set of new computer programs dedicated for testing the different prediction methods has been designed and developed. The programs written Matlab or C++ are user friendly and make possible testing the properties of the prediction methods in dependence on the assumed parameters.



Development and analysis of optimal and adaptive systems for generating zones of quiet at desired locations

M. Pawełczyk

The purpose of this research has been to design and verify feedback control algorithms capable of attenuating acoustic noise at desired locations in a group of electro-acoustic plants.

In the first of the proposed Virtual Microphone Control (VMC) systems, a real path model is used to reduce contribution of the control signal to the system output, thus allowing for estimation of the primary noise at the real microphone. Since for the considered group of plants it can be assumed that the primary noise at the real and virtual microphones is the same, it was added to an estimate of the secondary sound at the virtual microphone found by filtering the control signal by the virtual path model. Obtained estimate of the residual signal at the virtual microphone has been minimised. It constituted also the control filter input in this structure [II-85]. The second structure was similar to the first one with the exception that an estimate of the primary noise was the control filter input [II-83]. The third algorithm is composed of two stages [II-82]. In the tuning stage the signal at the virtual microphone is directly minimised. At the same time knowledge about the residual signal at the real microphone is used in an additional filter. This filter is then used during the actual operation (when the virtual microphone cannot be used) to produce a command signal to that measured by the real microphone. These three VMC systems have been designed as fixed and adaptive using all considered methodologies.

Design of the optimal H_2 control filter has been performed using the polynomial, frequency-domain and correlation-based approaches [II-6]. In case of the polynomial-based approach two alternative design methodologies have been used. The first one requires modification of the basic cost function, i.e. variance of the system output, to respond to non-minimum phase character of the plant. In the second methodology, an inner-outer factorisation of a non-minimum phase model is required [II-84]. Also, the

causal part of the optimal filter should be extracted or a Diophantine equation should be solved. These operations are simpler when performed in the discrete-frequency domain. However, the latter approach involves finally designing a time-domain control filter, which matches the obtained frequency response sufficiently well. The alternative correlation-based approach requires calculating an autocorrelation matrix and a vector of cross correlation, which is more computationally efficient when performed in the frequency domain. Other forms of the cost functions have also been analysed [II-84]. Adaptive control has been considered next. The Filtered-Reference LMS algorithm has been chosen for updating parameters of the control filter of Finite Impulse Response structure. Different representations and modifications of this algorithm have also been referred to. Sufficient conditions for convergence defined in different sense have been derived. The disturbance-to-output path has been linearised over trajectory allowing for obtaining a phase convergence condition convenient for analysis [II-87]. It has been shown that there exists a significant coupling between stability of the structural feedback loop and convergence of the parameter-update algorithm [II-25]. Simulation experiments demonstrated that influence of the feedback loop on convergence of the adaptive algorithm cannot be strictly adjudicated. For some plants and disturbances the feedback loop may support the adaptation and for others it may restrict the convergence condition. Stability, convergence, convergence time (and rate), tracking and noise attenuation are crucially influenced by the convergence coefficient [II-88].

All the VMC systems have also been designed for multi-channel plants. The design methodology similar to that for single-channel systems has been applied. Both optimal and adaptive solutions have been developed [II-6].

The feedback systems have been verified in terms of generating zones of quiet in a prototype of the active headrest system. Both simulation and laboratory experiments demonstrated that the multi-channel VMC systems efficiently shift the zones of quiet to desired locations. An exemplary distribution of the zones of quiet is presented in the figure below.

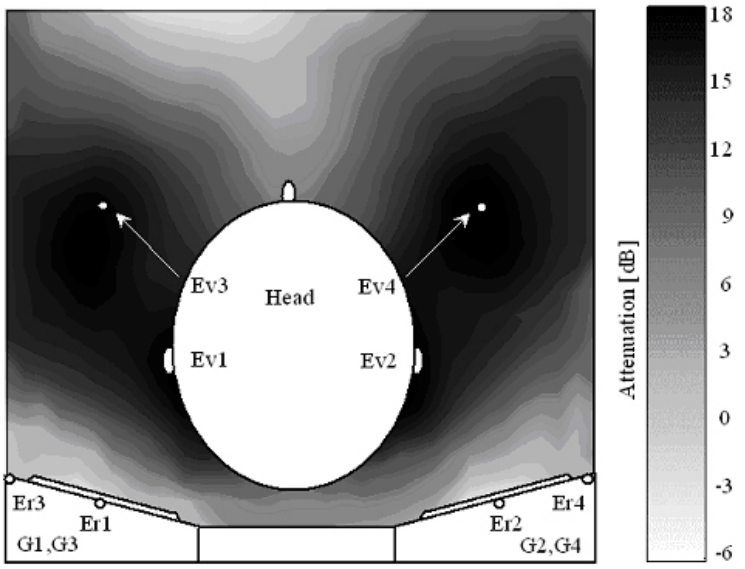


Fig. 1. Distribution of zones of quiet for a 250 Hz tone and a VMC system of four inputs and four outputs.

Predictive control

Z. Ogonowski

Research on predictive control concerns mainly nonlinear suboptimal predictive control algorithms [II-23, II-76]. The only advanced control methodology that had a significant impact on industrial control engineering was predictive control. It poses a control problem as a constrained optimisation and can be effectively solved only for relatively slow plants. To make on-line optimization implementable, heuristic or sub-optimal approach is necessary. One of the idea behind this would be prof. Grimble's Limited Authority Adaptive Control. By separation of the control law into two part and making only one tunable, a limited structure model predictive control has been proposed [II-78].

Suboptimality can be hardly generalized. Thus applications have been devoted to the special topic. One of the most interesting examples is magnetic levitation system – magnetic bearings in rotating machines, e.g., turbo-generators. Specially designed predictive control algorithm has been tested based on laboratory set-up MBC500 of the Magnetic Moments. The results of the shaft stabilization against displacement caused by the eccentric forces was surprisingly good. It has been proven that feasibility of the local optimization problem assured stability of the closed-loop system.

SYSTEM IDENTIFICATION

Computer aided process identification

J. Kasprzyk

Practical application of process identification involves access to suitable software, but also some skills resulting from experience and knowledge about principles of inference are needed. The main goal of this work is to analyse prospects in computer aided identification, especially discussion on tasks and opportunities in implementation of such systems, as well as constraints that can be faced [II-5].

The essence of process identification is in inference from data, following the methodology of experimental scientific method and general procedure of hypotheses refinement and falsification. Thus the following steps can be distinguished: carrying out an experiment and collecting data, settling a model structure, estimating parameters according to chosen approximation criterion, and testing the obtained model. If the result of this procedure does not fulfil the requirements then it is necessary to improve the model structure and repeat the procedure from the second step, until adequate results are obtained. This iterative identification procedure is presented in a formal form, and the part of the procedure that can be automatically carried out in a computer is recognized. Nevertheless, this procedure does not guarantee that correct model will be obtained in every situation. There are cases in which identification ends with the erroneous model, but this can not be predicted when the procedure is to be applied. The potential causes of such errors are considered and other useful sources of information are regarded. Subsequently, the procedure for linear time-invariant model identification is discussed in details, like model selection criterion, algorithm to find the best

structure, testing and analysis of the obtained model. Procedure for automatic structure determination for MISO models is proposed. It minimizes the chosen criterion together with parameter estimation. This problem is especially important when the structure of the process is not known or hard to establish *a priori*. In addition, some tests that may help the user in model validation and falsification are presented, especially numerical analysis of the results.

A system for computer aided identification, particularly its user interface, should be implemented in such a way, that the user may easily obtain a necessary help. Some skills needed for carrying out the procedure are connected with pure mathematical tasks and can be programmed in such a way, that the user could be intelligently supported. The proposed algorithm for searching a model structure is a typical example. In those parts of the procedure that are difficult (or impossible) to execute automatically, the aid may consist in displaying *prompts* based on the knowledge and experience of the designer, leaving the final decision to the user that takes the responsibility following the specific application. After the requirements for software of the computer aided identification system are presented, different solutions are considered and necessity for some kind of trade-off between flexibility and simplicity is emphasized. Many years' experience and efforts resulted in a software package *MULTI-EDIP* that intelligently aids the user in process identification.

Designing the system for computer aided identification creates new opportunities, but it may also lead to some pitfalls – with respect to designers as well as users of such systems. Therefore, some conclusions are drawn on prospects and potential risks during evolving and using computer aided identification.

Software for process identification

J. Kasprzyk, J. Figwer, A. Niederliński

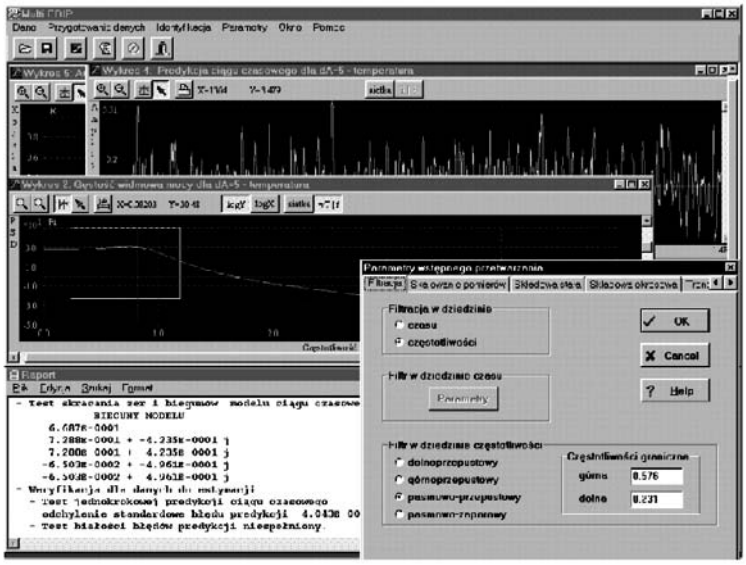
Part of the staff of the Computer Controlled Systems Group is traditionally engaged in research on various aspects of process identification and its applications, particularly to adaptive control problems. As a result of these activities a software package for process identification called Multi-EDIP was developed and its scope is continuously enlarged [II-5]. It is used in education and research and commercialised on a small scale.

Multi-EDIP is a user-friendly application for Windows 9x/NT/XP that may be used to identify and validate the following models for scalar or vector time-series:

- parametric, stochastic, stationary as well as non-stationary 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, stationary as well as non-stationary models (ARX, ARMAX, control channel transfer function, FIR, output error model, etc.),
- nonparametric models – correlation and frequency-domain models (cross power spectral density, coherence, frequency transfer 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.).



Multi-EDIP frees the user from doing any computer programming by providing full control of all functions and services through a system of windows and pull-down menus and by taking advantage of graphical capabilities provided by 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,
- 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.

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

Nonlinear system identification

J. Figwer

In the last two decades fast development of microprocessor control systems and necessity to control plants in which nonlinearities have substantial influence on the quality of control contributed to development of nonlinear dynamic model identification methods. Identification methods based on signal processing in the time- and frequency-

domain were developed. Special interest has been given to identification of simple nonlinear models, in which nonlinearity of plant is modeled by a static nonlinearity connected in series with a linear dynamic at input (Hammerstein model), at output (Wiener model) or at input and output (Hammerstein-Wiener model).

In this research a new approach to Wiener model identification is presented. The proposed approach is based on a multisine random excitation. The identification experiment with the random multisine excitation is designed in a special way. The excitation is repeated after all transients have decayed. Properties of this excitation and specially designed identification experiment allows to decompose overall Wiener model identification problem into linear dynamic part and static nonlinearity identification problems. To identify model of the linear dynamic part the corresponding static nonlinearity is interpreted as a random disturbance with specific statistical properties. This interpretation allows to identify model of the linear dynamic part using classical methods, e.g., instrumental variable identification method. In the next step estimates of linear dynamic part parameters are used to calculate the corresponding estimates of the output of this part. These values together with measured values of the Wiener system output can be used to identify the model of static nonlinearity. A feature of the proposed Wiener model identification method that differs it from the literature methods is an easy detection of the nonlinearity and its model identification as well as low computational complexity and high accuracy of obtained estimates.

Continuous-time system identification

J. Figwer, K. Czyż

This research concentrates on methods of nonparametric and parametric model identification for continuous-time systems based on continuous-time band-limited multisine excitation. This continuous-time excitation is generated with a high-order analog low-pass reconstruction filter driven by D/A converter with zero-order hold filter, which converts the corresponding discrete-time multisine time-series.

The identification experiment with the continuous-time band-limited multisine excitation is designed in a classical way for multisine excitations, i.e. the excitation is repeated after all transients have decayed. In order to estimate models, continuous-time system input and output signals are represented by sets of their samples taken at nonuniformly spaced discrete-time instants that are random variables with statistical properties chosen a special way. In the proposed approach to continuous-time system identification the obtained sets of nonuniformly sampled values are transformed into the sets of values that corresponds to samples of input and output signals taken with a constant deterministic sampling interval. The obtained sets of samples are used to estimate models of continuous-time systems directly without identification of auxiliary discrete-time models. It implies that continuous-time model identification with continuous-time band-limited multisine excitation based on finite data sequences can be made more accurately due to elimination of analog antialiasing filters from measurement system and processing data characterizing steady state system output signal for the multisine excitation.

Frequency response identification

J. Figwer, T. Główka

Nonparametric identification method based on estimation of second-order spectrum (known as power spectral density, PSD), i.e. classical spectral analysis, has a long tradition in system identification. Recently similar algorithms based on higher-order spectra (HOS) have been proposed. In some cases use of the HOS-based methods allows to obtain unbiased estimates in contrary to the classical methods. Such situation occurs in errors-in-variables systems, because the classical spectral analysis gives biased estimates when input signal measurement is noisy, and in all systems where the disturbance is correlated simultaneously with input and output of identified plant (all feedforward and feedback control systems belong to this group).

A part of our work in the field of frequency response (FR) identification is oriented on reduction of FR estimates variance. The simplest way of variance reduction is smoothing in the frequency domain. But if the true FR of identified system is strongly varying, the smoothing window cannot be too wide. For flat FR the window can be wider than for FR having a lot of peaks and notches (because smoothing flattens the FR). We propose an alternative way of the estimates smoothing (and variance reduction), that doesn't cause the flattening of FR estimates. The proposed method is based on the iterative identification algorithm, in which single identification procedure (using second- or higher-order spectra) is repeated several times. In each iteration the current FR model is identified on the basis of the input and the estimate of output (obtained with the use of previous FR model). The output estimate in the first iteration is equal to the system output. The proposed iterative algorithm doesn't require any additional data nor extra information about the system.

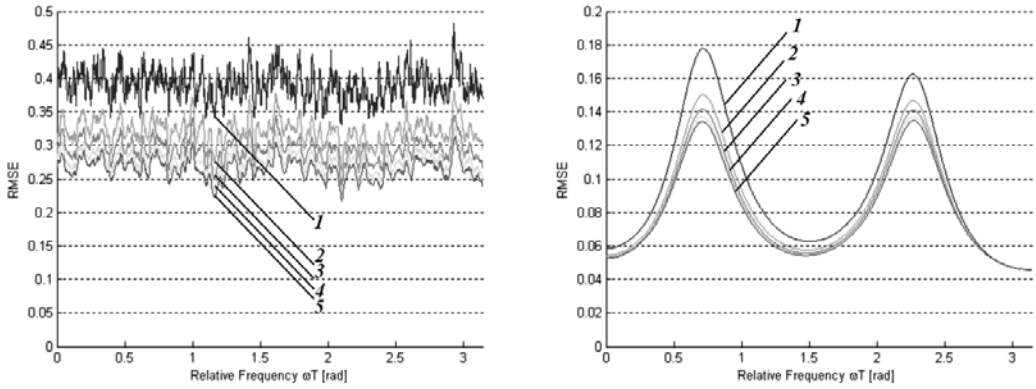


Fig. 1. Exemplary results of identification for simulated 4-th order system: root-mean-square error of FR estimates (obtained in 100 Monte Carlo experiments) in consecutive m = 1, 2, 3, 4, 5 iteration for nonparametric (left) and parametric (right) results.

Model identification using higher-order spectra

T. Główka

This research concentrates on model identification with higher-order spectra. 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 some

processes, including Gaussian processes. Thus, if the additive disturbance is Gaussian, it theoretically does not influence the identification results, and in practice this influence is significantly reduced. Such situation occurs in errors-in-variables systems, because the classical spectral analysis gives biased estimates when input signal measurement is noisy; and in all systems where the disturbance is correlated simultaneously with input and output of identified plant (all feedforward and feedback control systems belong to this group). The proposed approach requires a special non-Gaussian excitation signal, the properties of which were tested in previous work [II-46]. The main drawback of HOS is their computational complexity (important in the on-line applications), therefore we focus mostly on methods based on integrated HOS, particularly of 3rd and 4th order (i.e. integrated bispectrum (IB) and integrated trispectrum (IT), respectively). In our approach frequency response (FR) of identified system is calculated as the ratio of input-output cross-IB (or IT) to IB (or IT) of the input – similarly to the classical spectral analysis (the difference is in the type of used spectrum). The profits in obtained models accuracy for identification methods based on IB (or IT) in comparison with the classical methods was extensively studied [II-45,47,48,49].

A problem of identification in the presence of non-Gaussian disturbances was also considered. A special way of data acquisition and pre-processing, in which the excitation sequence is repeated several times and the measured data are averaged, was proposed. By employing averaging we get improvement of signal-to-noise ratio and reduction of non-Gaussianity of disturbances (according to the Central Limit Theorem). This approach let us to use HOS-based identification methods successfully, even if the disturbances do not satisfy the Gaussianity assumption. The convergence of non-Gaussian distribution to Gaussian distribution in the function of averaged sequences number was tested in [II-48]. The simulation experiments showed that in practice we need far less averaged sequences to obtain the same identification results for Gaussian and non-Gaussian disturbances, than it arises from commonly used statistical goodness-of-fit tests.

A modification of HOS-based methods that helps to reduce the variance of obtained models especially if the disturbance is concentrated only in some frequency ranges, has been also proposed. 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 more important [II-47,49].

ECG signal processing

M. I. Michalczyk

The aim of the research conducted in cooperation with Dr A. Sielańczyk (Medical University of Silesia, Katowice) is the development of system for automatic detection of specific electrical heart activity in classical and transesophageal ECG data. Different techniques of ECG signals preprocessing were evaluated and new methods of signal processing had to be applied for transesophageal ECG data processing. The preliminary developed system is based on neural networks trained on the basis of information prepared by the expert. The database of exemplary ECG signals was developed in

cooperation with the cardiology expert. It contains both signals and information about the electrical heart activity as well as about its classification. Basing on the database information different neural networks were trained. After verification of the results, the system will be able to automatically detect and classify the electrical heart activity.

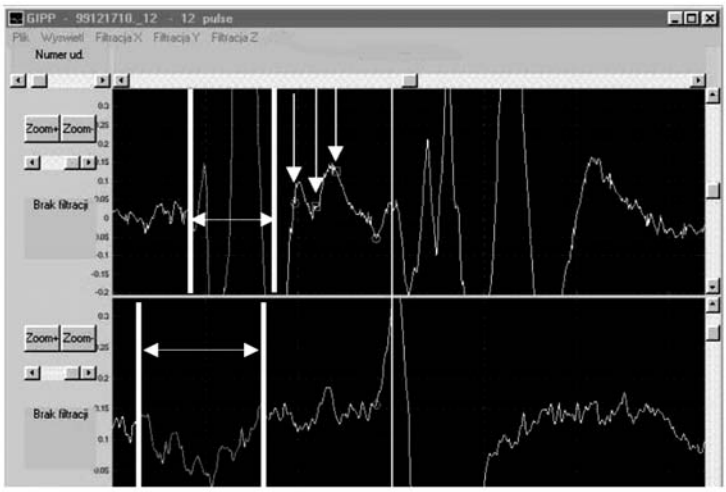


Fig. 1. ECG data analysis.

ACTIVE NOISE AND VIBRATION CONTROL

Development of new algorithms for electro-acoustic plants identification

T. Główka, J. Figwer, J. Kasprzyk

Adaptive ANC systems are parameterized 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, what 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, then 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 (RTF) are calculated to approximate the obtained frequency responses. These RTFs are used to design suitable filters for ANC systems.

The proposed method is based on direct estimation of integrated bispectrum (IB). Then FR is calculated as the ratio of input-output cross-IB to IB of the input. Regardless of loops existing in the system, the method allows to obtain strongly consistent estimates [II-45]. Also, a modification of this method has been proposed, in which 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 [II-49]. The idea of this approach is described in “System Identification | Model identification using higher-order spectra” section. It helps to reduce the variance of obtained models especially if the disturbance is concentrated only in some frequency ranges.

After the frequency response is calculated, the next step is to retrieve the RTF from it. This parametric model can be obtained via, e.g. the least squares approximation of frequency response by a fixed model structure or weighted least squares, as it was proposed in [II-52]. If the model structure is unknown it can be estimated using trial and error method based on testing different structures and selecting the model that has the lowest information criterion. To omit an "exhaustive search", which means that models for all structures within the assumed range ought to be estimated, the appropriate strategy of searches has been proposed . The travel path through the space of structure indices is driven by a set of heuristic rules that attempt to reach a (sub)optimal point (the best structure according to the assumed criterion) in a small number of steps.

Extension of the proposed techniques for the multi-channel case is in process. We focus on solving a MIMO system identification problem by decomposing it into independent SISO problems using orthogonal excitation signals.

We present an example of on-line secondary path identification in a feedforward ANC system creating a local spatial zone of quiet (see [II-47] for details). During the experiment a disturbance (real pump noise) was concentrated in the frequency band from 70 to 110 Hz. This example demonstrates that the classical second-order estimates give greater errors than the higher-order and mixed-order ones. However, outside the most disturbed frequency band (70÷110 Hz), the second-order estimates are a little better than higher-order estimates – this defect is eliminated by using the mixed-order estimator that is a linear combination of two estimators: higher- and second order one. The first counts more within the range where the noise occurs, while the second – outside.

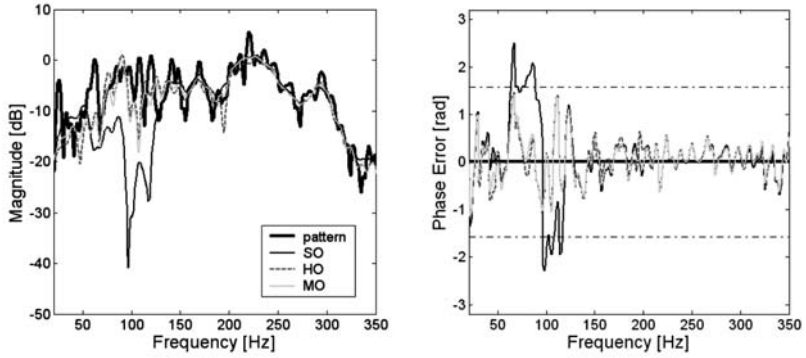


Fig. 1. Frequency response magnitude and frequency response phase error of second-order (SO), higher-order (HO) and mixed-order (MO) estimates.

Enhancement of ANC system efficiency

K. Czyż

In the classical approach to ANC system design high order analogue filters are required to avoid aliasing effects. The main drawback is that the analogue filters deteriorate dynamics of the controlled plant. Then, the performance of ANC system is highly dependent on dynamic properties of the signal processing path especially for random disturbances. A nonuniform additive random sampling gets around this limitation. It

omits analogue filters in the system design and uses special signal sampling technique to disperse aliasing. This technique occurred to be very effective for ANC systems. However, sophisticated signal processing algorithms should be employed for processing of nonuniformly sampled signal [II-39]. A possible approach is to resample nonuniformly sampled signal values into a corresponding periodically sampled data set and then to employ well established signal processing algorithms for periodically sampled signals. If considerable level of random errors is acceptable this approach can be simplified by omitting the signal resampling and directly supplying signal processing algorithms with nonuniformly sampled signal values [II-41].

On the basis of proposed approaches new ANC system structures were designed. The first structure includes the resampling of the nonuniformly sampled signal values from the reference and error microphones so that the further signal processing with well-established adaptive control algorithms can be applied. In the second ANC structure the nonuniformly sampled signal values from microphones are directly processed by the adaptive control algorithms. Both proposed system structures employ the same signal reconstruction method with oversampling to avoid inter-sample effects during control signal reconstruction [II-42].

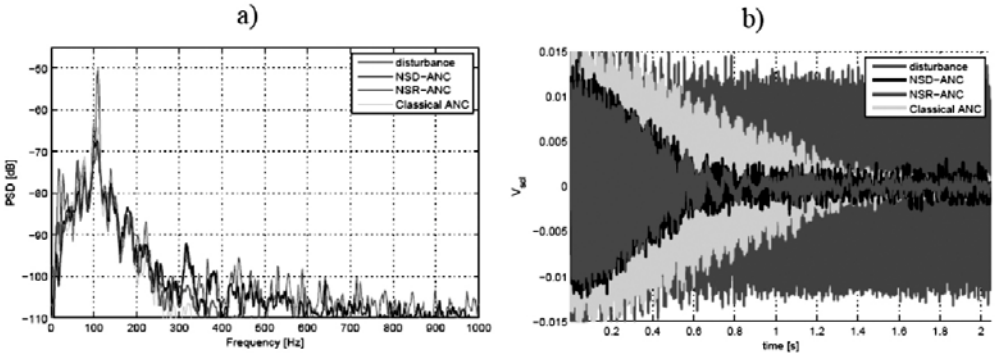


Fig. 1. Performance of ANC structures with nonuniform signal sampling: a) PSD of error signal during semi-random disturbance attenuation, b) error signal plot during single tone disturbance attenuation.

The proposed ANC structures with nonuniform signal sampling and control signal reconstruction with oversampling have satisfactory disturbance attenuation and fast convergence of adaptive control algorithm for the single tone signals as well as broadband disturbances (Fig. 1) [II-40]. For difficult, nonperiodic disturbances (random and semi-random) the new structures outperform classical ANC system.

The proposed approach to ANC system design includes efficient hardware implementation in which the function of analogue filters is taken over by the software solution that is responsible for dispersion of aliasing and inter-sample effects. The ANC system designed in such way is characterized by: simplified analogue front-end, cheaper implementation, smaller dimensions and possibility of changing the sampling frequency on-fly.

Chaotic behaviour of active noise control systems

M. I. Michalczyk, J. Figwer

In real-world applications of adaptive active noise control (ANC) systems their unexpected behaviour implied by parameterisation of adaptation algorithms can be

observed. The ANC system can be stable, however, its performance can be unsatisfactory, e.g., it can generate the noise instead of attenuating it. The ANC systems may generate additional unwanted sound waves even though they are not present in the attenuated noise as well as the error signal may pulsate. The number of additional frequency components and the pulsation intensity are functions of adaptation algorithm parameter value. To explain such behaviour adaptation in ANC systems can be interpreted as a nonlinear feedback. It is well known that such feedback is an essential prerequisite for chaos. The properties of adaptive feedforward and internal model control ANC systems used to create a local zone of quiet in a laboratory reverberant enclosure were analysed from the chaos theory point of view as a function of adaptive algorithm parameter. Results of real-word experiments these ANC systems showed complex periodic and chaotic behaviour (Figs 1-2).

Basing on the results of real-world experiments, the simplified system models were built to explain how the chaos is generated [II-71]. It was shown that due to the nonlinearity introduced by an adaptive algorithm along with particular dynamic properties of the controlled plant the chaos appears in an adaptive ANC system with non-acoustic reference sensor. A parasitic acoustic feedback that is insufficiently neutralised in adaptive ANC system with a reference microphone can be also the reason of the chaos generation.

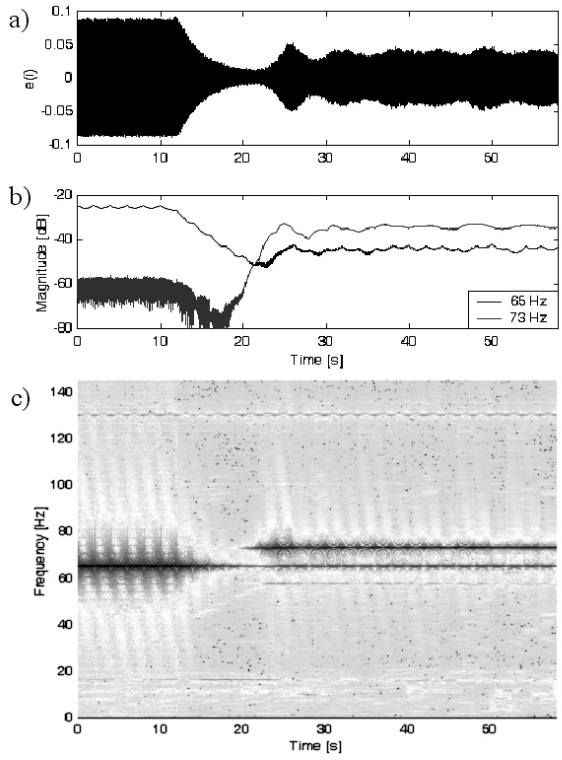


Fig. 1. a) Error signal $e(i)$, b) magnitudes of chosen frequency components and c) spectra for a chosen frequency range – feedforward ANC system with the reference microphone, adaptation: normalised FX-LMS algorithm, attenuation of pure tone of 65 Hz frequency.

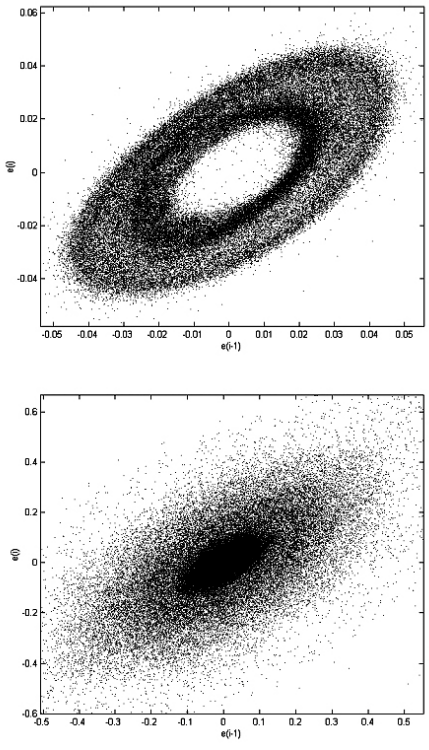


Fig. 2. Plots of the error signal $e(i)$ versus $e(i\text{-}1)$ for different μ values (smaller and larger) showing chaotic behaviour of ANC system.

Active noise control for time-varying plants

M. I. Michalczyk

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 large, inevitable 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 [II-21], which cause strong nonstationarities of the acoustic feedback path can also serve as examples. The FX-LMS algorithm is robust with respect to such changes of the secondary path [II-21];
- severe changes, caused by movements of the error microphone around the created zone of quiet. Such movements cause huge changes in the plant dynamics, especially changes of the phase shift. The increase of the phase estimation error can result in divergence of the adaptive control algorithm (if it exceeds $\pm\pi/2$).

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, then such case can be dealt with the use of standard adaptive control algorithm, as it was shown in [II-21,69].

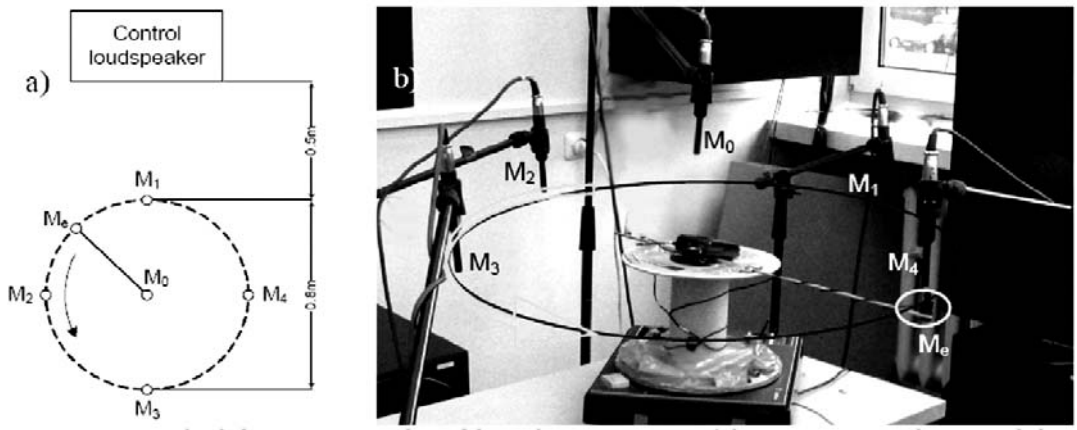


Fig. 1. The laboratory stand enabling the movement of the error microphone and the observation microphones positions: a) scheme and b) photo (error microphone trajectory denoted with blue circle).

The real-world experiments were conducted on specially designed laboratory stand that allows introducing severe changes of electro-acoustic plant properties in time, by the movement of the error microphone (Fig. 1). 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.

The laboratory stand is used for testing different modifications of adaptive control algorithms in order to compare their speed of convergence for time-varying properties of controlled electro-acoustic plant.

Development of algorithms for generating local zones of quiet

M. I. Michalczyk

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 initialization 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-21,67,68]. The observation conclusions allowed to formulate the rules of the ANC system parameterisation that were applied in further research.

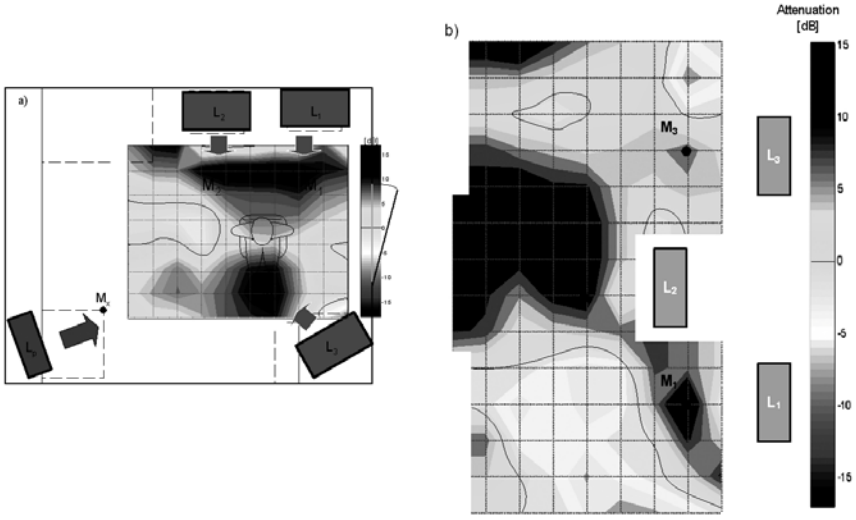


Fig. 1. Maps of attenuation distribution show shapes of zones of quiet created in the small (a) and large (b) enclosures using 3-channel ANC system based on FX-LMS algorithm during random disturbance attenuation. The spatial configuration of microphones and loudspeakers determines number and size of zones of quiet.

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-70]. 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.

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. 1). Attenuation obtained when using full and diagonal feed-forward controllers was similar.

Attenuation in the IMC ANC system was slightly worse for random disturbances, however, it showed the possibility of implementation of decentralized ANC systems for creating local zones of quiet in enclosures.

Virtual unidirectional source of sound

D. Bismor

One of the problems concerned with active noise control is the existence of acoustical feedback between control value ("active" loudspeaker output) and reference signal. This phenomenon, rather unusual for "classical" feedback control systems, can seriously decrease effects of attenuation or even make the whole system unstable.

In acoustic duct applications there are several methods for avoiding acoustic feedback. The modern approach to acoustic feedback cancellation is called virtual unidirectional source of sound (VUSS). This method, although requiring additional loudspeaker, allows also for successful attenuation in frequency bands in which acoustic environment constitutes limitations for attenuation by means of one loudspeaker.

The idea of virtual unidirectional source of sound (VUSS) is to use digital signal processing algorithm to drive *two* loudspeakers in such way that the sound produced by them virtually propagates only downstream the duct. Virtually means that although the sound generated by each loudspeaker propagates in both directions, the processing algorithm tries to assure the sound waves propagating upstream the duct are actively cancelled by themselves while those propagating downstream the duct are amplified. The advantage of this approach is that it is sometimes possible to equalize the amplitude spectrum of so called secondary path transfer function that plays very important role in active control of sound. Schematic diagram of VUSS has been shown on Fig. 1.

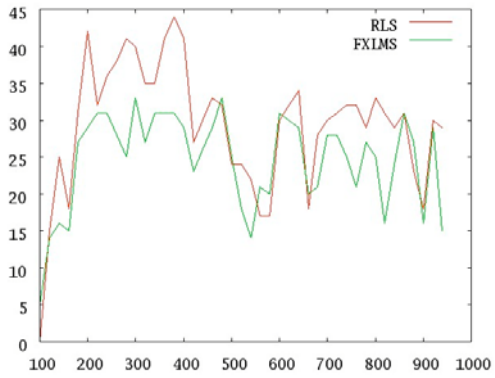


Fig. 1. Virtual Unidirectional Source of Sound Schematic Diagram

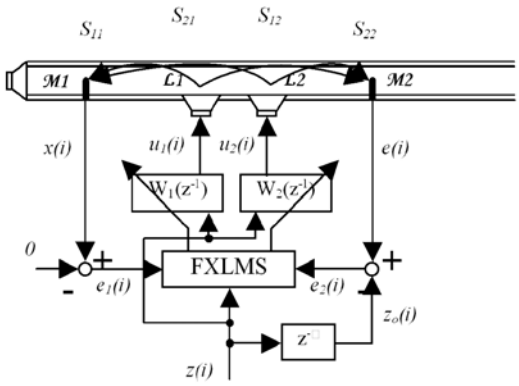


Fig. 2. Acoustic Duct Active Noise Control Station Block Diagram

The goal of the research was to show that effectiveness of VUSS is better than effectiveness of other control structures. This goal was attained by implementing VUSS algorithm on DSP board and performing active noise control experiments with it. Some results of such experiments are shown in Fig. 2. The results proved that VUSS is very effective solution for active noise control in an acoustic duct.

Control of semi-active systems

K. Plaza, Z. Ogonowski

Recently the semi-active systems and components are becoming very popular. The magneto-rheological (MR) damper is the most famous one among such systems. Several famous applications have been equipped with an MR damper suspension system. The most recent and spectacular is the Audi R8 car. The interest in MR dampers has grown significantly because they offer similar performance as the active systems, but much less energy is needed to damp the vibrations. However, because of the fact that the vibrations are damped through damper characteristics change, the semi-active systems are significantly more difficult to control. The following features of the semi-active components and systems can be pointed out:

- small control signal energy comparing to active systems,
- strong inherent nonlinearity,
- possibility of energy dissipation only,
- inherent stability,
- controllability problem.

A semi-active system utilizing an MR damper (RD-1005-03) supplied by the Lord Corporation has been developed. The system consists of a full suspension mountain bike, in which the rear suspension has been substituted with the mentioned MR damper and a dedicated spring (see figure below).

A crucial element of the semi-active systems control is the semi-active components modeling. In cooperation with Tenneco Automotive Gliwice several identification experiments were carried out to give a chance of MR damper model identification. Several structures have been chosen, of which some are given in literature. New structures have been proposed, which allow for model use for controller synthesis [II-90].

For control purpose the inverse model has been created, which is needed for one of the most popular versions of the semi-active control algorithms, which is the skyhook

algorithm. The skyhook algorithm has been tested in simulation and enhanced by an adaptive scheme of controller gain selection based upon the dominant disturbance frequency. Other control algorithms are also tested to be reported in future.

The control algorithms will be tested on the assembled system with the use of an MTB-MRS control unit, which includes accelerometers, battery, and microcontroller with memory to store the measurements. Most of the above work has been reported in publications and is a part of the PhD dissertation.

Active vibration control of rotating machines

Z. Ogonowski, K. Plaza

Magnetic bearings systems for high-speed rotating machinery became one of the most challenging control problem. 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. 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.

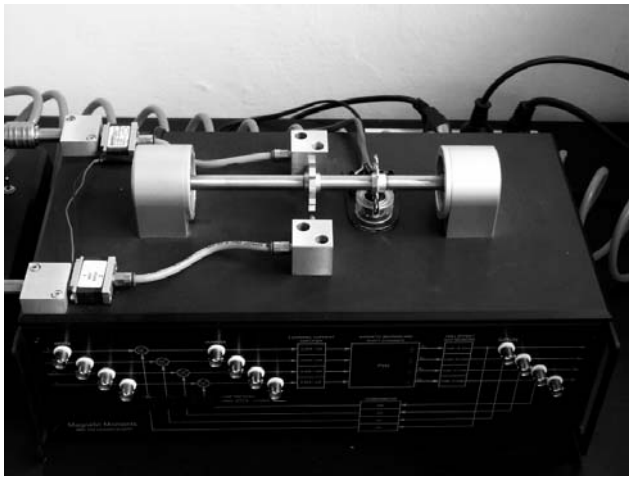


Fig1. MBC500 magnetic bearing system

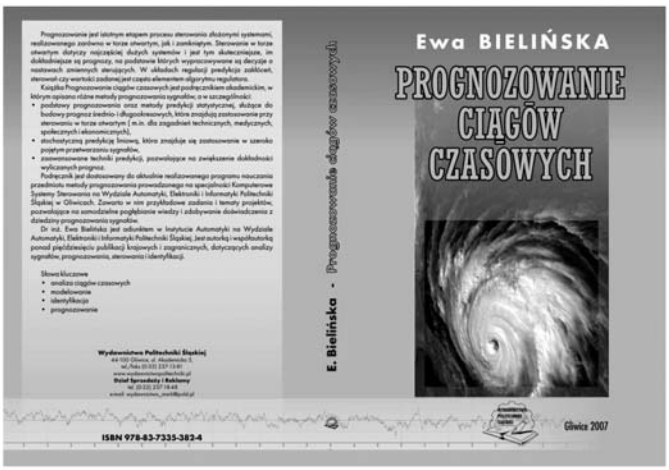
In [II-81] internal model approach and pole assignment method is applied to control magnetic bearing system. The idea is to include a model of deterministic disturbances of the shaft's end position into controller design procedure to damp vibration in a steady state. The speed of convergence depends on the closed-loop poles thus additional problem of pole assignment is solved. This approach is compared with weighted minimum-variance (WMV) control. The improvement was evident, however, both control systems used single-input and single output (SISO) controllers. In [II-80] further improvement of WMV control is presented, namely inclusion of cross-channel influence and imposing corresponding multi-input and multi-output upper control layer. The algorithms were experimentally tested on the laboratory model of magnetic bearing

system MBC 500 of Magnetic Moments LLC. (Goleta, USA) – see Fig. 1. This unit consists of two active radial magnetic bearings and a supported rotor mounted on a specially designed case. The shaft is actively positioned in the radial directions at the shaft ends providing 4 degrees of freedom. Four linear current amplifiers and four linear lead-lag compensators are included in the system, which control the radial bearing axes. The unit has been extended with pneumatic push-pull driver and speed measurement. The above pointed control algorithms has been tested using the MBC500 unit.

SIGNAL PROCESSING

Time series analysis

E. Bielińska



Time series analysis covers wide area of data processing, and can be described as a set of the following procedures:

- checking the data correctness,
- data transformation,
- data scaling,
- series decomposition,
- descriptive statistics,
- series modelling,
- model identification,
- series prediction.

The research on time series analysis refers to all stages mentioned above. The variety of the real time series causes that only a general methodology, and not a unique technique or concluding one, 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.

Bilinear time series models in signal processing

E. Bielińska

Research concerns elementary bilinear time series and their application in signal analysis. Stochastic properties of elementary bilinear time series models are discussed from the viewpoint of modelling in simulation studies, prediction and control. Bilinear time series models have been mentioned in control engineering since early seventieth. Though they may be considered as a part of Volterra series, their general structure is complex enough to make their analysis very difficult.

$$A(z^{-1})y_i = C(z^{-1})e_i + \sum_{k=1}^{K}\sum_{l=1}^{L}\beta_{kl}e_{i-k}y_{i-l}$$

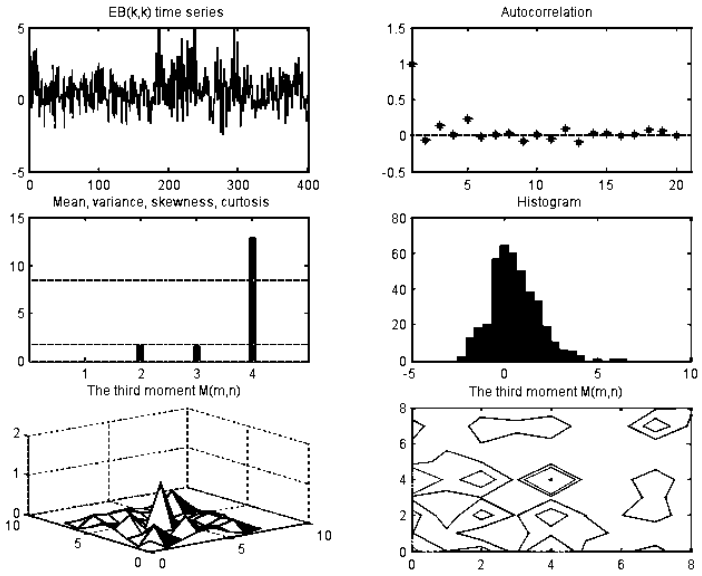
In 1976 Granger and Andersen derived some interesting properties of the bilinear model with the simplest structure

$$y_i = e_i + \beta_{11}e_{i-1}y_{i-1}$$

where e_i is an independent white noise sequence with zero mean and the variance λ^2. Elementary bilinear series EB(k,l), that is the topic of the research, has the structure:

$$y_i = e_i + \beta_{kl}e_{i-k}y_{i-l}$$

An example of a single realisation of EB*(5,5)* series as well as its characteristics calculated for this realisation is shown in the figure below.



EB(5,5) sequence and its characteristics

Elementary bilinear time series model may be applied to simulation studies as a model of disturbances. Dynamic effects, such as rapid peaks, may be obtained choosing the value $\beta_{kl}^2\lambda^2$ close to 1. Not every invertible *EB(k,l)* model may be applied in time series prediction and control, though for linear models invertibility is the only requirement. The serious restriction is identifiability of elementary bilinear time series. In practice the small subset of all invertible processes only is identifiable.

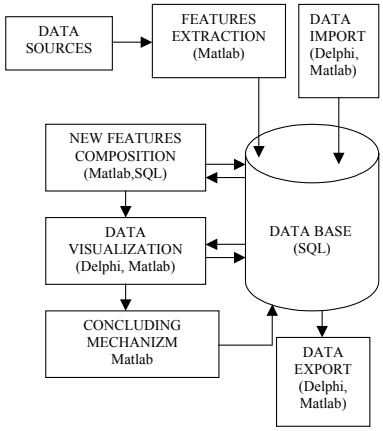
Research are focused on defining identifiability conditions for elementary bilinear time series and methods of bilinear models application in prediction and control tasks.

Speaker identification

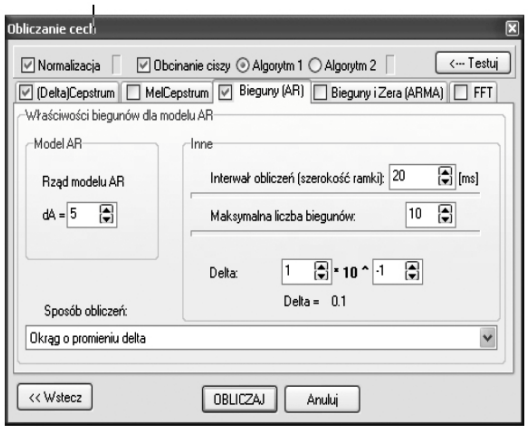
E. Bielińska

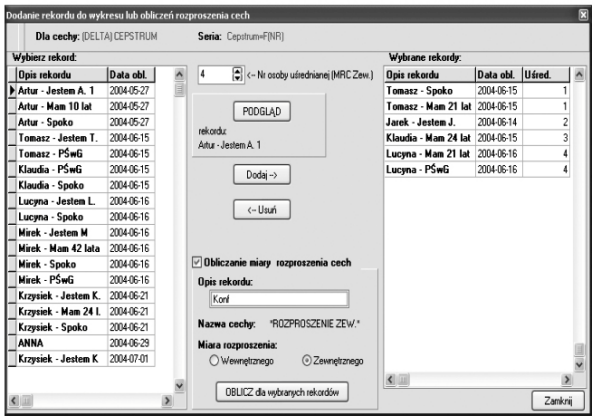
The aim of speaker identification is to recognise an actual speaker among set of possible speakers, on the basis of an individual utterance. At the stage of trials and experiments speaker identification is an iterative and multi-stage process of speech signal pre-processing.

Research on speech signal processing, designed for speaker recognition, needs 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. The proposed structure of the system of data operating is presented in the figure above. The figures below present example windows coming from the designed data operating system.





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 is an application of the multisine

transformation to uniformly distributed random number generation. This transformation allows to synthesise and simulate finite sample multisine time-series recursively.

The presented algorithm of random number generation is based on a synthesis and simulation procedure of multisine time-series. In the presented approach N-sample multisine time-series from the (r-1)-th iteration is used as phase shifts and amplitudes to synthesise 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 synthesised 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 random number generator are analysed 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 implementation 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 with 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 approach.

Controllers based on logarithmic number system

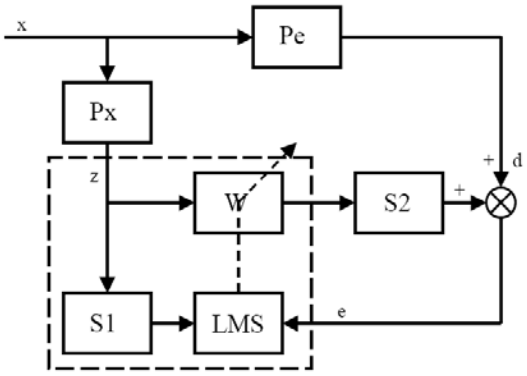
M. Latos

Computational problems in digital signal processing are usually the most challen-ging. The computations often has to be performed in real-time thus lot of numbers in dynamic range format need to be processed. These restrictions are handled if floating point number system (FP) or logarithmic number system (LNS) are used. LNS has some advantages in specific situations over the FP arithmetic. Main advantage is simplicity of implementation and faster realisation of multiplication and division operations. However, more complex are addition and subtraction operations. Applications of LNS algorithms in Active Noise controller (ANC) systems (fig. below, left) brings surprisingly good results.

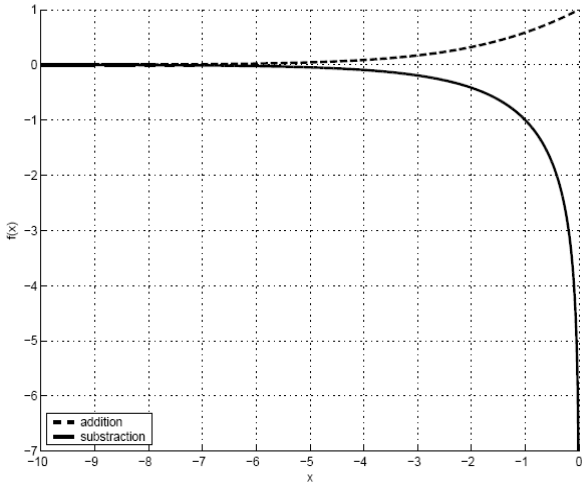
The most important task is efficient implementation of all arithmetic operations and conversions between LNS and FP number formats. The multiplication/division operations are the easiest to implement, it is simply addiction/subtraction of two numbers in LNS form. After simple mathematical calculations both conversions reduce to a sum of constant component and different nonlinear functions (fig. below, right). That functions must be tabulated and stored in a memory in the chosen ranges.

Similar situation occurs during implementation of addition and subtraction operations. Accuracy of arithmetical operations depends strongly on interpolation accuracy of the tabulated functions. Proper experiments let evaluation of the influence

of LNS arithmetic on the ANC controller performance. This was compared with the corresponding FP arithmetic.



Block diagram of ANC system.



Nonlinear function for addiction and subtraction.

Research on random process synthesis and simulation

J. Figwer

Multisine time-series are sums of discrete-time sines with amplitudes and phase shifts determined by a variety of methods, depending upon the purpose for which the multisine time-series will serve. One of the most recent applications of multisine time-series is synthesis and simulation of various deterministic signals and random processes with predetermined spectral or correlation properties.

This research concentrates on applications of multisine time-series for synthesis and simulation of wide-sense stationary scalar and multivariate one- and multi-dimensional random processes given by diagrams of their power spectral densities, where:

- synthesis means the process of establishing the discrete Fourier transform vector of multivariate multisine random time-series (1-D random process) or multidimensional (M-D) random process based on the corresponding power spectral density matrix of random process to be simulated,
- simulation means the process of numerically generating the corresponding time-series by performing an inverse FFT on the synthesised discrete Fourier transform vector.

In the presented approach to the problem of numerically synthesising and simulating wide-sense stationary time-series for which only a non-parametric power spectral density representation is known. In the presented approach the non-parametric power spectral density is approximated by a periodogram of multisine time-series with deterministic amplitudes chosen so that for a given number of equally spaced frequencies from the range $[0,2\pi)$, the periodogram of multisine random time-series is equal to the original power spectral density. The periodogram may be used in turn to construct the corresponding discrete Fourier transform provided the phase shifts for each sine component are chosen. It is well known, that any periodogram corresponds to infinitely many different time-series, which differ by choices of phase shifts. It is demonstrated, that in order to get stationary ergodic random processes, the phase shifts

should be chosen with some well defined random properties - they should be uniformly distributed in the range [0,2 π). This concludes the synthesis part of the procedure. To simulate the synthesised time-series, the discrete Fourier spectrum with such chosen phase shifts is transformed into the time-domain using the inverse discrete Fourier transform. Using this approach a broad range of scalar and multivariate random processes may be synthesised and simulated provided their power spectral density matrices are known. Realisations of the random phase shifts needed to synthesise and simulate realisations of the multisine approximation may be obtained using classical uniformly distributed random number generators. An interpretation of multisine time-series definition as a non-linear transformation of the corresponding phase shifts allowed proposing a new approach to generation of these realisations. This transformation is called a multisine transformation. It exhibits chaotic behaviour. Using the multisine transformation realisations of multisine time-series are calculated recursively: the phase shifts needed to synthesise and simulate N-sample multisine time-series are constructed using N/2-sample multisine time-series simulated in the previous iteration.

Multidimensional random processes given also by power spectral densities may be synthesised and simulated in the same way as 1-D random processes. The main building block is an M-D multisine random process consisting of a sum of M-D sine components with deterministic amplitudes and random phase shifts chosen as previously in a special way.

MODERN EDUCATION TECHNOLOGIES

e-learning

J. Mościński

The CCS Group 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 2005, the group was involved in the final stage of realization of Socrates programme based Thematic Network dissemination project called THEIERE-DISS (Thematic Harmonisation in Electrical and Information Engineering in Europe, approx. 80 partners). The project aimed at disseminating information and publications developed on the basis of comparing and analysing modern education curricula in electrical and information engineering field. The main components of the projects were related to modern teaching methodologies and tools – especially e-learning, as well as possibilities of curricula harmonisation that could make the mobility of electrical and information engineering students easier and more natural. The curricula harmonisation tasks can be ideally accompanied by means of modules sharing between universities from various countries, especially on the basis of e-learning infrastructure that would enable students to attend lectures and laboratory exercises from other building, from their home, and from their home in other country.

The curricula harmonisation dissemination project is continued in the form of even larger Thematic Network project called EIE-Surveyor (Reference Point for Electrical and Information Engineering in Europe), started in October, 2005, with strong participation of CCS Group staff. 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 CCS Group 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. CCS Group was involved in preparing and editing two special volumes of iNEER Innovations in 2005 and one in 2006.

The CCS Group 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 CCS Group are mentioned in the next section.

Internet technologies in education

J. Mościński

Internet technologies are useful in increasingly many areas of human activities and education – especially engineering education – is no exception with respect to this trend. Several specific examples of internet technologies utilization are subject to current research and education interest of CCS Group. Most of them resulted from developing concepts concerning computer networks based education methods, but nowadays the focus is on internetwork based services, which of course are built on computer network based connection grid.

One example of internet technologies based system developed in CCS group concerns building customised communication platform for students and teachers, in order to enhance the learning process and make it more efficient. The typical and widely used concept includes the facilities for providing students with additional, possibly multimedia teaching materials that can be used by the lecturer for exemplifying complex ideas presented during lectures and also downloaded individually by students for self-work. With respect to laboratory exercises such additional materials typically include introductory and extended source of information necessary for mastering before specific exercise. On the other hand, the students are typically equipped with the possibilities of uploading reports and related work after laboratory exercise and obtain feedback information on it from the teacher and final grade. Such systems typically

include other extensive communication facilities for e-mail communication, chatting, bulletin boards and similar.

Other systems developed in CCS group for enhancing laboratory exercises organisation concern so called electronic laboratory register. Such systems enable the administrator to set up students groups and teams for working on specific laboratory exercises, whereas every laboratory supervisor is responsible for setting up lab exercises topics and time-table. Every teacher is responsible for putting grades concerning student's work and report value and every student is capable of getting information concerning all his/her grades and any additional work that has to be done in order to pass the specific course. The system is accessed by means of Internet and browser and therefore is extremely flexible and easy to use. Definitely measures concerning the system security have to be taken into serious consideration.

Other systems based on internet technologies and built for enhancing education at CCS Group 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 CCS Group staff was also involved in developing more general event registration systems that could include substantially more complex organisation 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 CCS Group 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.

International Conference on Engineering Education, Gliwice, 2005

J. Mościński

An important international engineering education event – International conference on Engineering Education ICEE 2005 – was held at Silesian University of Technology, Gliwice, 25-29.07.2005. Dr Jerzy Mościński from Institute of Automatic Control worked as ICEE 2005 Organising Committee Chairman, the ICEE 2005 General Chairman position was held by Rector of Silesian University of Technology, Professor Wojciech Zieliński. Dr Mościński prepared and presented in 2001 the proposal concerning ICEE 0205 organisation in Gliwice and from 2004 he coordinated the work of approximately 60 people directly involved in the organisation of conference.

There were 317 presenting authors and 72 accompanying persons from 42 countries at ICEE 2005 in Gliwice, 326 presentations were delivered within 4 plenary sessions and 44 topical parallel sessions. All conference materials were published in two volumes printed form as well as in the form of conference CD. Organisation of

conference included an important task of setting up the system of abstracts and papers acquisition and peer review process, conference planning with respect to the plenary and topical sessions profile and contents, editing of conference materials and organisation of Internet based participants' registration system.

Dr Mościński was also involved as one of editors of book entitled „Innovations 2005 – Special Edition. World Innovations in Engineering Education and Research", which was published on the occasions of ICEE 2005 organisation in Gliwice and 60th Anniversary of Silesian University of Technology.

The conference presentations concentrated on several important topics from engineering education and research field. One of the most important topic concerned new teaching methods and tools and the role of universities in promoting education development with this respect. Conference participants were also especially interested in presentations concerning competence driven education schemes, multimedia based teaching, open and distance learning paradigms and internet technologies in education. Important part of ICEE 2005 discussion concerned the organisation of international cooperation between universities and mobility schemes, as well as universities accreditation issues and quality of teaching.

ICEE 2005 conference served as important element of maintaining and developing international cooperation in the field of engineering education and research between Silesian University of Technology and other universities from all over the world. The conference preparation and organisation were thoroughly evaluated by representatives of iNEER – International Network for Engineering Education and Research, the organiser of the whole ICEE and ICEER conferences sequence, and regarded as exceptionally successful, both from the organisation and scientific level points of view.

Programmable Logic Controllers

J. Kasprzyk, J. Wyrwał

Programmable 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, engineering 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 the control system design, like, e.g., communication with SCADA systems, reliability of the system etc..

Part of the staff of the Computer Controlled Systems Group is engaged in development of control systems using PLCs. They are authors of the book "Programming PLCs" (the first one in Poland) and the book on programming according to IEC 61131-3 standard [II-4]. The Laboratory of Programmable Controllers created by the group has been equipped with the following PLC families: *GE Fanuc 90-30* and *VersaMax*, *Schneider's Modicon TSX Compact* and *Momentum*, *Allen Bradley's SLC 500*, *Simatic S7-300* and industrial computers *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 can create and test their own projects in situations resembling practical applications. Thus, the laboratory has been fitted with didactic

panels to simulate real installations. There have been simulators of simple binary objects to enable training on-off control with time conditionings as well as continuous objects to make students possible to test sophisticated control strategies. The emphasis is put on typical tasks met in the industry, like sequential relay control (e.g. drive control), motion control, process control, distributed control systems and networking.

PLCs may have to interact with operator for the purpose of modifying parameters and configuration, displaying messages, variables and alarm reporting, recording operating incidents or everyday interactive control. To meet these requirements PLC installations are equipped with Human Machine Interface (HMI) devices. Thus students are also trained in designing and programming various HMI applications, using textual and graphical operator panels.

Contemporary control applications are often designed as distributed systems. Therefore, some of the equipment in the laboratory is connected with industrial networks like Profibus DP, Genius, Modbus and Modbus+ to make acquaintance with typical solutions in this area.

The concept of the laboratory corresponds to 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 available industrial networks mentioned above. Moreover, to guarantee fast communication between PLC and SCADA systems, laboratory equipment is fitted up with modules providing Ethernet interface. Consequently, software and hardware that are available in the laboratory enable students to create modern distributed control systems providing advanced diagnostics and redundant configurations.

Identification, modelling, optimization and control for energy systems

Z. Ogonowski, T. Szczygieł

Economical issues motivates application of modern control methods in energy systems. Specially prepared laboratory set up are subject of current research and education interest of CCS Group in this area. The first part of the set up models HVAC system and consists of 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 can simulate disturbances. The second part of the set up is portable system for measurement, monitoring, data collection and control of HVAC units. 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. The third part of the set up is the PLC stand for application of Constraint Logic Programming (CLP) to control harmonic disturbances in the energy generation network. All these elements of the set up are used in advanced education concerning identification, modelling, optimization and control for energy systems.

Educational suite 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 with ARM7 were additionally designed and manufactured in Institute of Automatic Control. New courses were prepared to let students learn the microprocessor systems, based on the possessed hardware. The students can also work with microprocessors and digital signal processors while taking part in research and engineering tasks as part of their Master of Science theses preparation.

Educational Starter Kits with ARM7

The starter kits for Atmel AT91SAM7S256 microcontroller (Fig. 1) have full functionality necessary to setup first projects by students and enable them to get acquainted with ARM architecture. Starter kits include evaluation board, JTAG emulator, GNU C compiler, on-chip debugger (OpenOCD), Eclipse IDE, eCOS real-time operating system and examples. The Atmel starter kits contain all the necessary hardware to design, develop and test applications with following peripherals: GPIO connected to 8 LED's and 4 buttons, Timer Counter, PWM's, Watchdog Timer, Real Time Clock, Interrupt Controller, AD and DA converters, I2C, SPI, UART and USB interfaces.

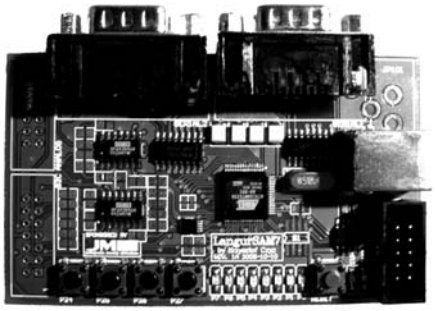


Fig. 1. Evaluation board of educational starter kit for Atmel AT91SAM7S256 microcontroller.

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 commonly 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 include the implementation of simple digital signal processing algorithms firstly using C language and, next, using assembler language. By means of code optimization the experience concerning 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 trade-off 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 with signal processing on FPGA. Digital signal processing algorithms usually have very strong computational requirements. Substituting 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 can 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 DSP boards 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 concerns the fundamental concepts of ARM architecture and internal hardware structure of Atmel SAM7 series microcontrollers. Nowadays the ARM processor is the processor of 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 with dedicated educational starter kit based on Atmel AT91SAM7S256 microcontroller.

MICROELECTRONICS IN CONTROL

Portable ANC platform

K. Czyż

In order to implement adaptive ANC algorithms developed at the Computer Control Systems Group, a portable multi-channel active noise control (PANC) platform was designed. The PANC is an efficient programmable DSP platform that is destined for generation of spatial local zones of quiet in enclosures [II-38]. It consists of two modules: signal processing core (Fig. 1) and additional analogue frontend board. The signal processing core module is based on high-performance 32-bit RISC processor unit SH4 (SH7750R). The integrated FPU unit includes specialized high performance integrated vector floating point achieving 1.7 GFLOPS peak floating-point performance.

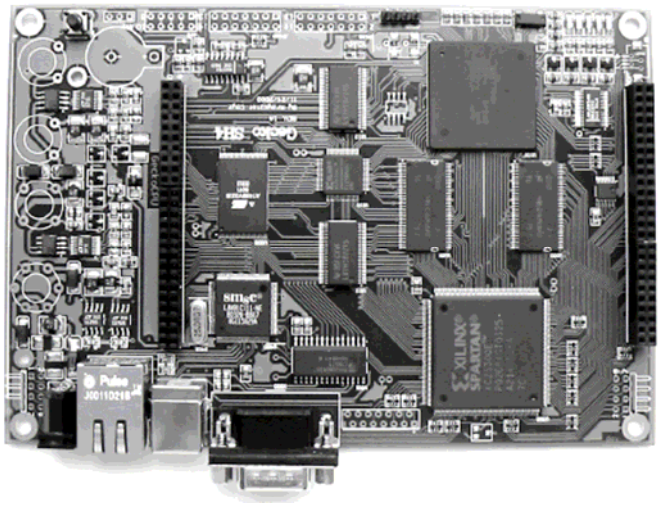


Fig. 1. PANC – the portable multi-channel active noise control platform core module

Digital signal processing algorithms used in ANC systems usually have very strong computational requirements. Substituting some parts of processing algorithms by hardware operations using FPGA may radically increase signal processing performance. In PANC platform Xilinx Spartan-IIE FPGA enables hardware realization of application-specific accelerators assisting the CPU in nonuniform signal sampling, control signal interpolation and reconstruction, data preprocessing and post processing. The FPGA is also used as glue logic tying various system functions together and acting as programmable high-speed interface to analogue converters enabling to offload the CPU and reduce data transfer rates. Analogue frontend board contains 8 analogue input channels for reference and error microphones and 8 analogue output channels for control loudspeakers.

One of the most important innovations, that have made the design of portable ANC platform practical, was nonuniform sampling technique which enabled to replace analog anti-aliasing filters by digital signal processing algorithm [II-39]. Additionally, control signal reconstruction with oversampling was used to replace analog low-frequency forming filters with software oversampling algorithm.

The PANC system includes efficient hardware implementation and simple analog frontend. The most of hardware was replaced with software or programmable logic enabling shorter development time and possibility of fast reconfiguration of PANC platform according to application needs. An important advantage of the presented PANC system is its flexibility – it can be successfully applied in different applications, not only in ANC.

DSP technology

K. Czyż, M. I. Michalczyk

Digital Signal Processing Laboratory in the 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 with dSPACE board, TMS320C6713 and TMS320C6416 with Spectrum Digital DSK,

Renesas SH4) and other processors (Motorola/Freescale PowerPC MPC8240 with dSPACE board). These processors are used both for educational purposes (especially for Master of Science theses preparation) and as tools in research activities.

DSP algorithms have to be implemented in hardware to carry out real-world experiments, e.g., for use in active noise control systems. This requires a careful hardware choice and often also low-level code optimisation. Independent benchmarks of the possessed processors in DSP tasks are being developed in order to evaluate the hardware and gain reliable knowledge about its capabilities.

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 manufactured in the Institute of Automatic Control. One of them is a 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 optimized for high performance applications including VoIP.

For more sophisticated problems new processor boards with expanded functionality were designed and manufactured: low-cost, educational starter kits with ARM7 and efficient Portable ANC platform (Fig. 1) 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 analog input channels for reference and error microphones, and 8 analog output channels for control loudspeakers.

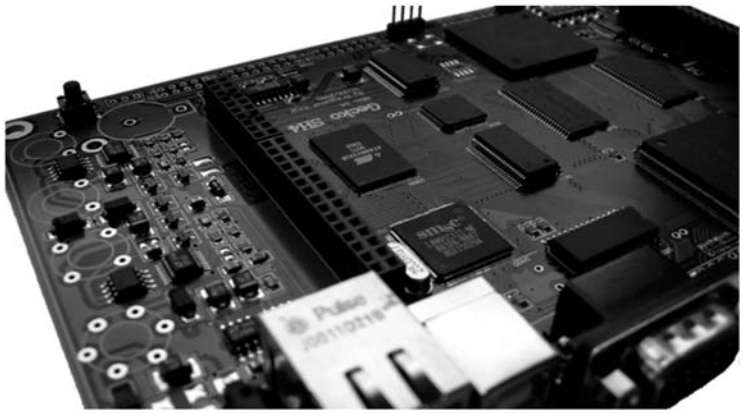


Fig. 1. One of the DSP platforms designed and realised in Computer Controlled Systems Group in Institute of Automatic Control.

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.

The most complex and challenging system in Digital Signal Processing Laboratory is MMatrix system employing large microphones matrix for measurements of sound level over an enclosure and estimation dimensions of zones of quiet created by ANC systems. MMatrix is massive multi-channel acquisition and signal processing system being developed on the basis of multiprocessor system with NI PCI-6289 data acquisition board. The system enables to pre-process and record up to 16 continuous analogue signals at 32 KHz sampling rate. The analogue channel count is dependent

upon the acquisition speed. Decreasing the acquisition speed to 4 KHz increases the channel count up to 128 channels.

PROCESS CONTROL

Industrial networks

J. Hajda

Industrial networks are a very important part of the modern control systems. Sensor buses, device buses, field buses and data buses connect PLCs to the meters, sensors, remote input/output modules, other controllers, PLCs and SCADA systems.

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

The next issue concerns possibilities and constraints with respect to Ethernet TCP/IP network with various protocols and media, to be used in fast and slow, as well as small and big industrial control systems.

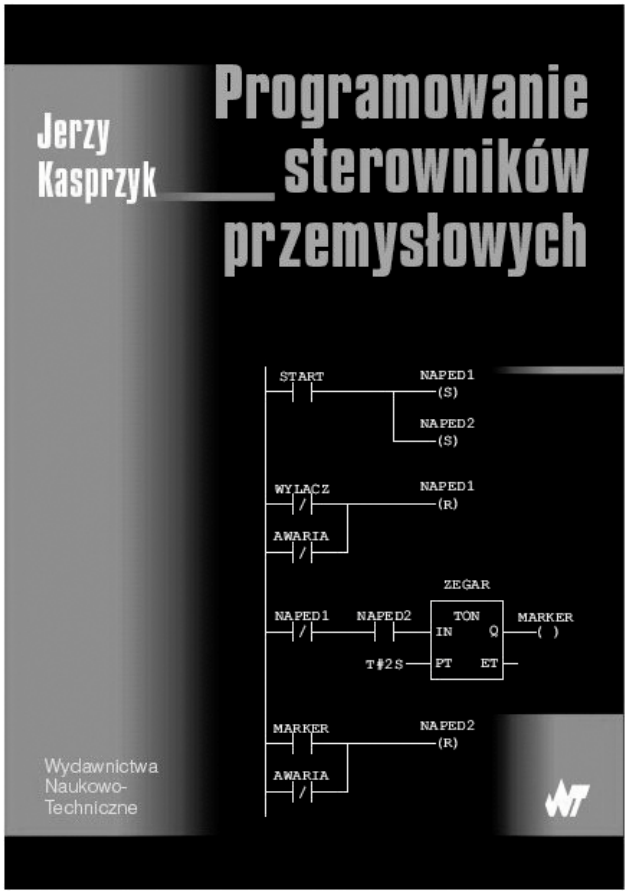
The networks concerned are Modbus, Interbus, Uni-Telway, Profibus-DP, Modbus Plus, ControlNet, CAN, DeviceNet, ASi, FIPIO and Ethernet TCP/IP. Also LonWorks, BACnet and EIB networks for building automation and M-bus and HART-bus for meters are tested and assessed.

PLC Programming

J. Kasprzyk

Since programmable controllers (PLCs) have become the basic equipment in control systems and there are a lot of different solutions proposed by manufacturers, there is a need for standardization in this area, especially with respect to programming languages and methods. The main goal of this research is to work out basics, principles and examples of PLC programming following from the international standard IEC 61131, especially in the context of automation and industrial control systems.

The result of this work is a textbook [II-4] which presents uniform, complete and coherent concept of PLC programming. The approach is based on modern solutions introduced in the third part of IEC 61131, which is the first endeavour to standardize programming languages for industrial automation. This standard specifies the syntax and semantics of a unified suite of programming languages for PLCs. However, it will not restrict itself to the conventional PLC market. Nowadays, it is adopted in softlogic/ PC based control systems as well, including SCADA packages.



To explain the basic high-level elements and their interrelationships, the study concerns with the software model proposed in IEC 61131-3. In this concept configuration is treated as an element of the programming language that corresponds to a PLC system as a whole. Configuration defines arrangement of the hardware, like processing resources or memory addresses for I/O channels. Within a resource one can define one or more tasks to control the execution of a set of programs. Such approach makes it open to the future, as it is expected that multi-processing and event driven programs will have to be included. The configuration concept is explained by means of practical examples.

The book presents in a bottom-up manner all elements of the standard, i.e., from common elements, like, e.g., data types and variable declarations, up to the detailed description of four programming languages – two textual languages (Instruction List, IL, and Structured Text, ST) and two graphical languages (Ladder Diagram, LD, and Function Block Diagram, FBD). Using these languages the user can define Program Organization Units (POUs), i.e., Functions, Function Blocks (FFBs) and Programs. Besides, standard FFBs defined in IEC 61131-3 are described together with examples of their usage. Further, a way for structuring the internal organization of POUs using SFC (Sequential Function Chart) is explained. SFC describes graphically the sequential behaviour of a control program with the aid of steps, actions associated with steps, and linked by transitions.

Requirements for modern programming and debugging tools are discussed and programming environment CONCEPT is presented together with examples of its usage. This package allows the user to write control programs according to IEC 61131-3 standard and test them by means of the simulator (virtual PLC) being a part of the package.

Additionally, to be more familiar for beginners in the field, the textbook contains also an introduction to PLC functioning and programming.

The book is ended with a glossary of the most important terms associated with industrial controllers programming.

Real-time control and real-time operating systems

D. Bismor, J. Wyrwał

Computer Controlled Systems Group has developed a real-time approach to process control focusing on both a theoretical and practical issues related to this increasingly important approach.

Research has spanned such issues as control algorithms that are suitable for real-time use: algorithms for real-time identification, real-time filtering algorithms, control algorithms, adaptive and self-tuning control. In addition, real-time control applications, computer architectures that are suitable for real-time control algorithms and applications for real-time control issues have been investigated. Real-time computer systems that enable control system to keep up with the external process that is to be controlled have been developed as well.

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 not satisfactory 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 times. 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 emphasised 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 of real-time control strategies.

A QNX® operating system based on the microkernel architecture has been included to the research. It is the RTOS offering advanced memory protection, distributed processing and dynamically upgradable architecture. Because of its large scalability, it can be also successfully used to manage real-time embedded systems. It has been introduced into education programme to show the students important issues related to operating RTOS and implementing real-time applications.

For applications with soft real-time requirements (i.e. systems in which exceeding real-time requirements does not lead to irreversible or danger effects) real-time kernels for Linux has also been considered. Solutions such as KURT (Kansas University Real-Time Linux Kernel) or QLinux (QoS Enhanced Linux Kernel) have been studied. This introductory work appears to be promising.

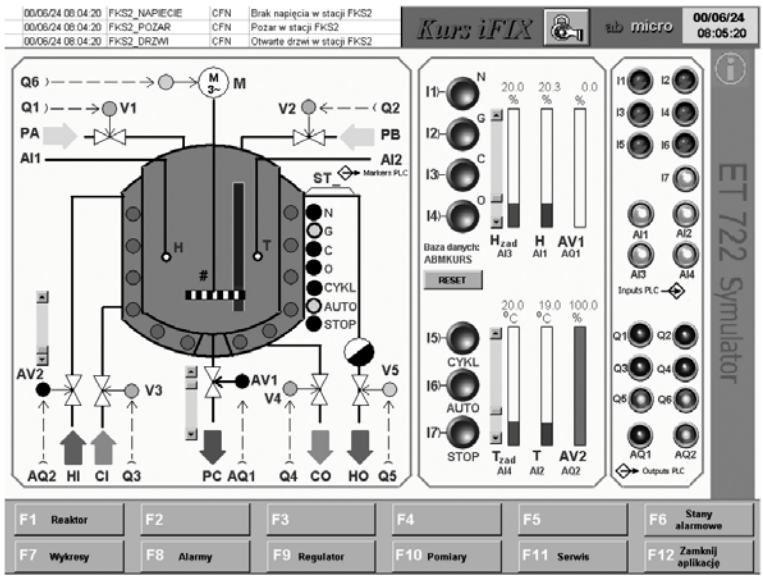
Last, modular structure of Linux kernel has been recognized in order to prepare modules for connection with DSP board. This will allow to use ordinary PC as soft real-time system with dedicated DSP board containing time-critical part and service routines.

Polish Version of Professional Computer Programmes Packet Used to Supervisory Control and Data Acquisition with Technical Documentation

R. Jakuszewski, M. Pawełczyk

Polish version (translation, verification and supplement) of the Proficy HMI/SCADA - iFIX v4.0 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:

- 147 programmes of the iFIX system – total 26.2 MB,
- contextual help of the iFIX system and VBA (*Visual Basic for Applications)* programming language,
- technical documentation in the form of textbooks (22 textbooks – total 4280 pages) and compact disk.



Proficy iFIX made by GE Fanuc is a leading SCADA software all over the world. It fulfills 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 in 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.

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 2000 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.

Simulation of gas carburising

J. Wyrwał

Carburisation as a process of thermo-chemical treatment is known since many years. It is defined as a process that imparts by diffusion carbon into the surface of carburised component. As a result of carburising process on the top surface a layer from 0.5 to 1.5 mm thick with carbon concentration from 0.7 to 1.2% is achieved. It is used for surface hardening to achieve improved fatigue and wear resistance. Accurate control of carburisation remains still a complex task because of many parameters influencing process. That is why, it is important both from practical and theoretical point of view to develop model, which makes it possible to simulate the entire process.

Depending on the source of active carbon atoms, carburising is carried out in industrial practice according to one of the following methods:

- carburising in solid environment,
- carburising in liquid environment,
- carburising in gas environment.

Endothermic gas carburisation is most widely used method in the industry.

The purpose of the research was to develop mathematical model of gas carburising process and efficient method of numerical solution of this model. The final result was the development of the unit simulating in real-time carburising process that was incorporated into control system of batch furnace.

The analysis performed within the work reported has comprised:

- phenomena occurring in the gas phase,
- phenomena occurring at the gas-solid interface,
- phenomena occurring in the solid phase.

The model worked out has taken into account that carbon transfer and the creation of carburised layer is possible under the following basic conditions:

- carbon activity in atmosphere is higher then in austenite,
- the amount of carbon educing from atmosphere is adequate for creation of carburised layer.

Three main elements influencing the course of carburising process in endothermic atmospheres have been taken into account in the development of the model:

- mechanism of carbon transfer comprising generation of active carbon atoms in the endothermic atmosphere, adsorption of educed carbon atoms on the surface of components and diffusion of carbon to the interior of carburised steel,
- thermodynamics of carburising process determining the progress in tending to achieve conditions of carbon equilibrium,
- kinetics of carburising process determining the speed of carbon transfer from endothermic atmosphere to steel surface and speed of carbon diffusion in steel.

Within the framework of the research mathematical model of gas carburising process in endothermic atmospheres was developed. Numerical method of solving the model was worked out. Consequently, carbon concentration profiles for the carburised components can be predicted.

Heating control system

S. Ogonowski, J. Figwer, Z. Ogonowski

Optimizing of heating, ventilation and air conditioning systems (HVAC) has reached great interest especially if industrial applications and domestic climate conditions are concerned. This follows form economical reasons. Commercially available environment of heating systems have reached their maturity while the control units are usually simple on-off type.

This control systems are robust against disturbances and variety of environmental thermal properties of the HVAC systems, however, they are significantly inefficient if fuel consumption is concerned.

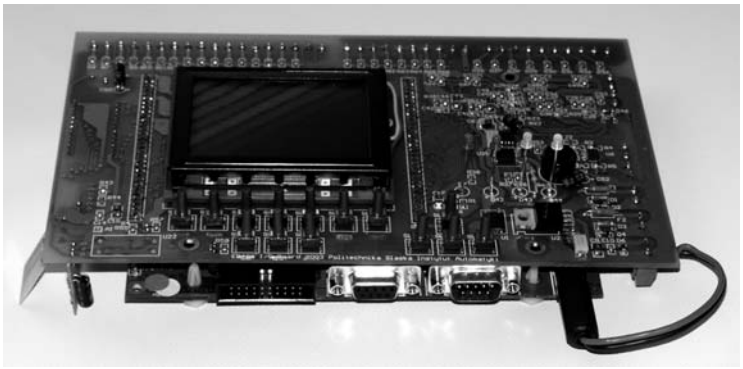


Fig. 1 The central unit (CU)

Heating processes are slow, thus HVAC systems need long-time observation to collect representative data in order to identify respect models. Specially designed wire-less system for monitoring and control of HVAC system has been created in CCG. The

central unit (Fig. 1) communicates with PC directly through the serial interface or indirectly via the modem and the internet facility. CU collects data from heating system and transfer them out (e.g. to the PC). The wireless communicator allows the connection of the CU with radio-module (Fig. 2) which serves as measurement pods.

CU is based on standard Atmel product EB40A with AT91R40008 microprocessor and is equipped with number of ports (A/D and D/A converters, serial ports, bus of digital thermo-elements, digital inputs or outputs, wire-less 433MHz communicator) and other facilities.

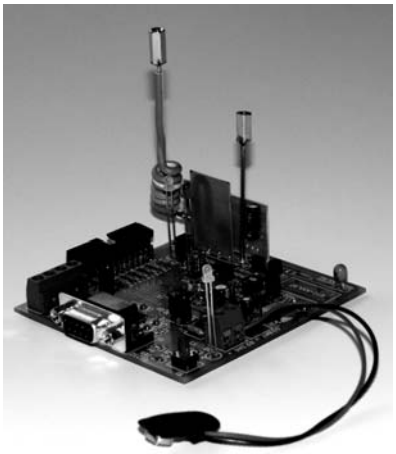


Fig. 4 Radio-module (RM) unit

Basic role of RMs is collecting and transferring data obtained directly from the HVAC system. Data can be transferred through the CU, but RM can also perform as the server.

This system has been used for monitoring of HVA system in small buildings (2005 and 2006 winter) and industrial spray booths Module-Master USI ITALIA in winter 2006. Models obtained in the first case serve to conduct real-time simulation of the heating system (PC coupled with the above CU). The second case allowed for building a set-up (Fig.3) which serves for laboratory experimenting with number of control strategies to be applied in HVAC technology.

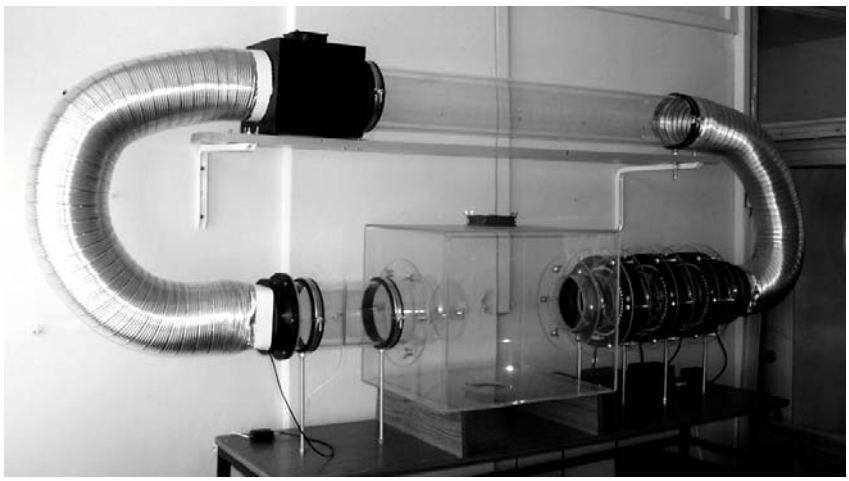


Fig. 1 Laboratory set-up

HVAC laboratory has been equipped also with weather transmitter (WXT 510) and indoor humidity transmitter (HMW60) assembled by Vaisala (Finland). These units allow for precise analysis of the weather conditions influence on performance of HVAC systems

Bilinear PID controller

E. Bielińska

PID controllers are widely applied in many industries and provide acceptable performance without specific mathematical knowledge of the plant. However, the controllers that are tuned for one operating point, are based on the assumption, that the plant to be controlled is locally linear. The assumption may become invalid when an operation over a range is considered. Research concerns application of bilinear control strategy, proposed by Martineau, and presented in Fig. 1.

Fig. 2 presents a controlled output runs for two different methods of bilinear compensation. The respective control indices are given in the table and show that the effects of the bilinear control may be worse than simple PID and depend significantly on the way of bilinear compensation.

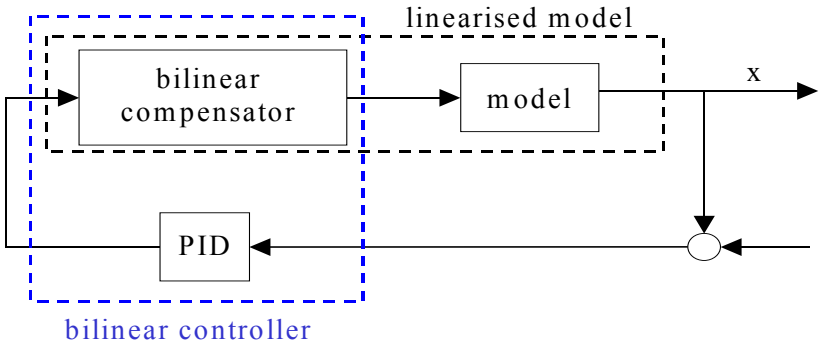


Fig.1. Research concerns application

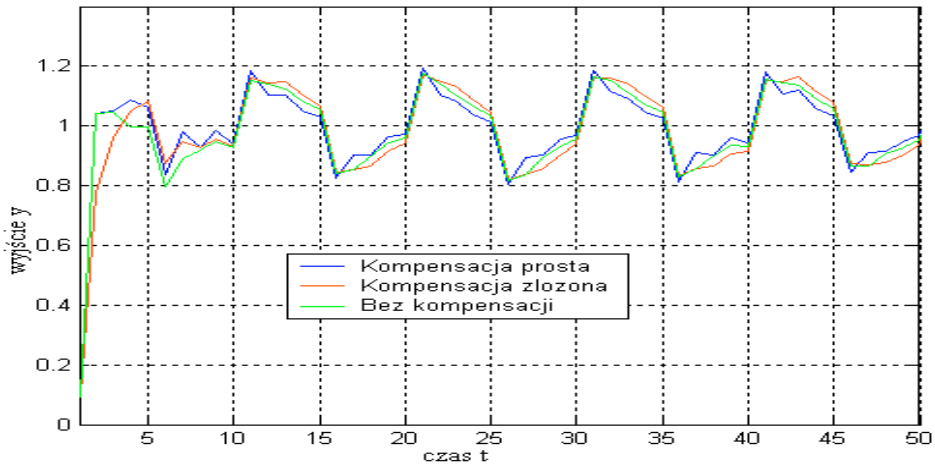


Fig. 2. Controlled output

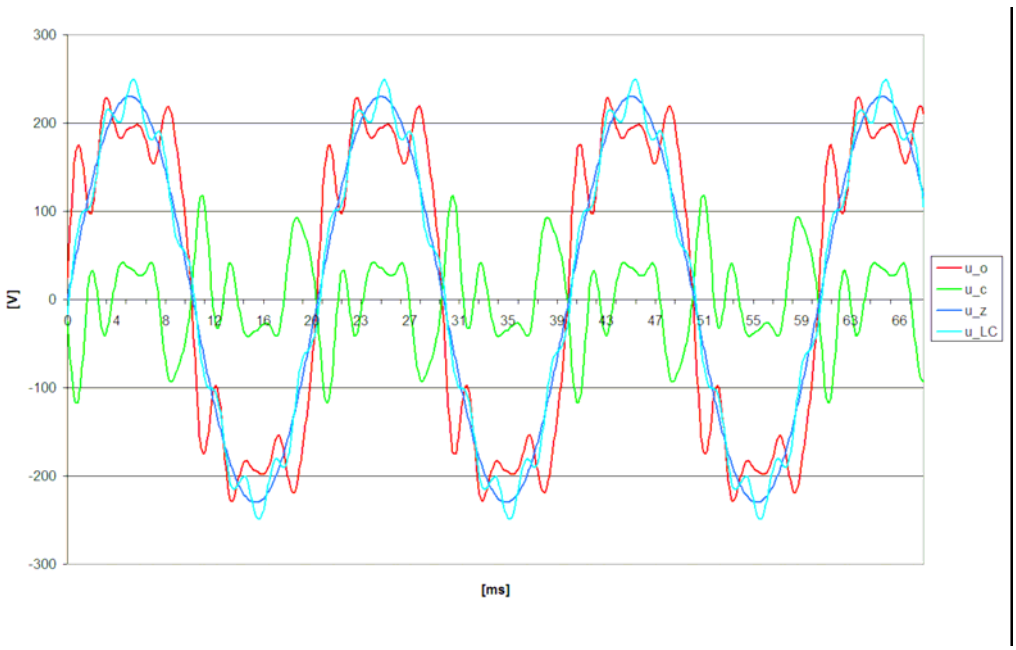
	Simple compensation	Complex compensation	No compensation
Time	2	3	2
Maximum	1.2068	1.1844	1.1883
Variance	0.0196	0.0244	0.0218

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.

The system diagrams, obtained during the simulation and experimental tests, are presented below.



ARTIFICIAL INTELLIGENCE AND CONSTRAINT PROGRAMMING

Research on rule- and model base expert systems

A. Niederliński

Prof. A. Niederliński completed an important phase in his work on rule- and model based expert systems (*rmse*) by publishing a *reference–cum-textbook* about those systems. The rule- and model-based expert system shells have been developed and matured in the years 1984-2006 as tools supporting lectures and laboratory sessions for subjects like "Automated inference systems", "Expert systems" and "Computer-aided decision making". All those tutorial activities had - at their background - the aim to provide students with a chance of "making something that functions", starting with small Prolog programs up to relatively large knowledge bases presenting complicated technical, financial and legal documents. The experience of "making something that functions" is basic for anybody studying engineering; it cannot be replaced by any amount of likewise important analytical activities ("explain why..." problems), computational activities (this can be done much better by a computer) nor theoretical activities ("prove that...for all.."). In a rapidly developing and still fluctuating technology, academic teachers have problems in deciding what constitutes the basic and *sine qua non* items of a course and what is just outdated or of secondary importance academic superfluousness . It seems that while trying to make something that functions, both sides of the tutorial process acquire the right sort and amount of analytical, computational and theoretical skills useful in practice.

The hybrid (rule- and model-based) nature of *rmse* means the shells synergetically combine rule-based logical inference with testing of relational models having arguments determined by arithmetical models.

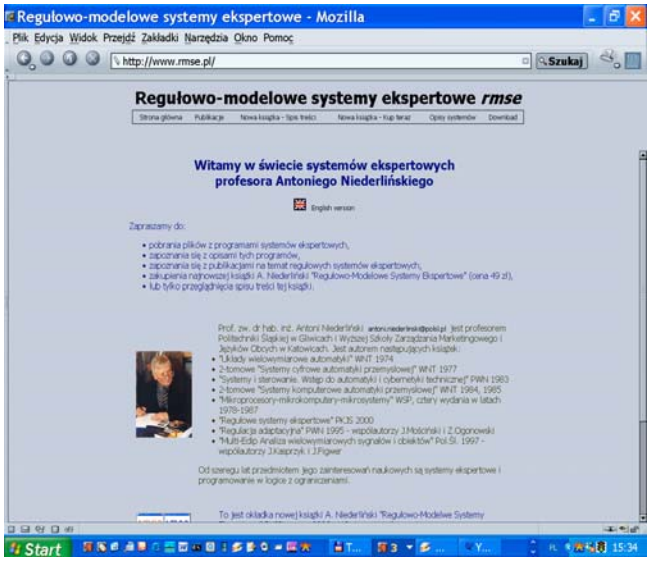
This is a *sine qua non* for the majority of technological and business applications, which cannot be designed using rule-based systems only.

The shells may be used for knowledge bases containing following bases:

a) rule base (exact or uncertain) consisting of "IF...THEN..." rules (exact or uncertain),
b) constraint base (exact or uncertain), containing lists of askable conditions. which are mutually exclusive in an exact or uncertain way,
c) model base (exact or uncertain), containing exact arithmetical models and exact or uncertain relational models. Models may be nested to practically any depth. Nesting of rules and models as well as nesting of models and rules is feasible,
d) advice base, being a set of advice file names corresponding to rules or relational models,
e) advice text files, containing text of advices listed in the advice base,
f) graphics base, being a set of graphic file names corresponding to rules or relational models,
g) graphic files of the type \verb"*.bmp" with graphics listed in the graphics base,
h) sound base, being a set of sound file names corresponding to rules or relational models,
i) sound files of the type \verb"*.wav" with sounds listed in the sound base,
j) abstract files containing summaries of domain knowledge used for the knowledge bases.

The book „Rule- and Model-Based Expert Systems rmse" by Antoni Niederliński (WPKJS, Gliwice, 2006, pp. 450) is intended to give readers an understanding of the key concepts in *rmse* expert systems and to provide some hand-on experience in applying those concepts to a number of practical cases using user-friendly software. It will identify decision support tasks that are amenable to Knowledge Based (KB) solutions, and categorize the various types of KB solutions that may be developed.

The Polish Website http://www.rmse.pl on rule- and model base expert systems *rmse* (more than 42300 visits up to May 2007).



The English Website http://www.rmes.pl on rule- and model base expert systems *rmes* (more than 1070 visits up to May 2007).

The essence of the proposed modification of the Stanford Certainty Factor Algebra is to postulate that rules with the same conclusion belong to one of two mutually exclusive group of rules:

- cumulative rules with independent lists of conditions,
- disjunctive rules with dependent lists of conditions.

For the original Stanford Certainty Factor Algebra (Buchanan, B. and E. Shortliffe 1984) such a distinction was – perhaps because of the nature of application involved – not needed: all rules with same conclusions have been considered as cumulative.

Computer support of credit validation decisions

A. Niederliński

This subject was extensively elaborated in the Ph.D. Thesis "Komputerowe wspomaganie procesu podejmowania decyzji kredytowych" (*Computer support of credit validation decisions*) by Tomasz Żurek (PKJS, Gliwice 2005, pp.1-245). Validation of credit applications is in any market economy one oft he most important and often made decision. This is the main reason it deserves to be automated. The thesis demonstrates that:

- Credit validation procedures may be expressed as knowledge bases (rule bases, model bases, constraint bases and advice bases) having semantics compatible with the *rmes* family of rule- and model based expert system shells. This has been demonstrated by two knowledge base benchmarks created on the basis of a synthetic credit validation procedure for small businesses: an elementary exact benchmark and an elementary uncertain benchmark. The benefits of this approach have been discussed.
- The elementary uncertain approach resulted in a more detailed and more precise model of the credit validation process as compared with the elementary exact approach. This seemingly paradox is due to the fact, that – because of the presence of certainty factors – the elementary uncertain knowledge base may be equipped with more knowledge regarding the credit applicant as compared with the elementary exact knowledge base.
- The thesis contains a methodological contribution concerned with determining the certainty factor for elementary uncertain rules.

Legal applications of expert systems

A. Niederliński

Law seems to be one of the very few domains of human activity, the form and practice of which has not changed substantially from its beginnings, i.e. from the 283 laws contained in Hammurabi's law code, the first written code of laws in human history (c. 1700 years BC), Tora and Ten Commandments (Moses, c. 1300 years BC) and Solon's code of laws (c. 621 BC) to the present times. Both in ancient times and nowadays, laws were formulated as text files (in the broadest sense of the term) and its practice then and now amounts to reasoning from those text files, performed by excellent minds of highly qualified specialists like lawyers and judges The structural similarities between expert systems knowledge bases and various legal regulations are overwhelming and have

been notice quite early. The issue has been the subject of many research projects, monographs and technical solutions.

A few words are due regarding the domains of legal discourse, for which expert systems technology will be discussed. In the sequel a distinction is made between:

1. *Deterministic legal domains*, for which no matter who does the reasoning, the same conclusions follow. This is mainly due to its un-ambiguity, its un-equivocalness. There seems to be a large number of such legal domains, e.g. in corporate finance, in banking. Statutory laws regulating social insurances and old-age pensions belong to deterministic domains as well. For deterministic legal domains expert systems are becoming more and more a viable alternative compared to the prevailing *status quo*.
2. *Non-deterministic legal domains*, for which the outcome of reasoning depends to some non-negligible extent on who does the reasoning. Nondeterministic domains, as in civil law and tort, contain usually uncertain variables like "low social harmfulness", "ill will", evaluated differently by different lawyers and leading to different conclusions. The application of expert system to non-deterministic legal domains may safely be considered to be still in its infancy stage.

The research aims at investigating the suitability of the *rmes* rule- and model based expert system shells for deterministic legal domains.

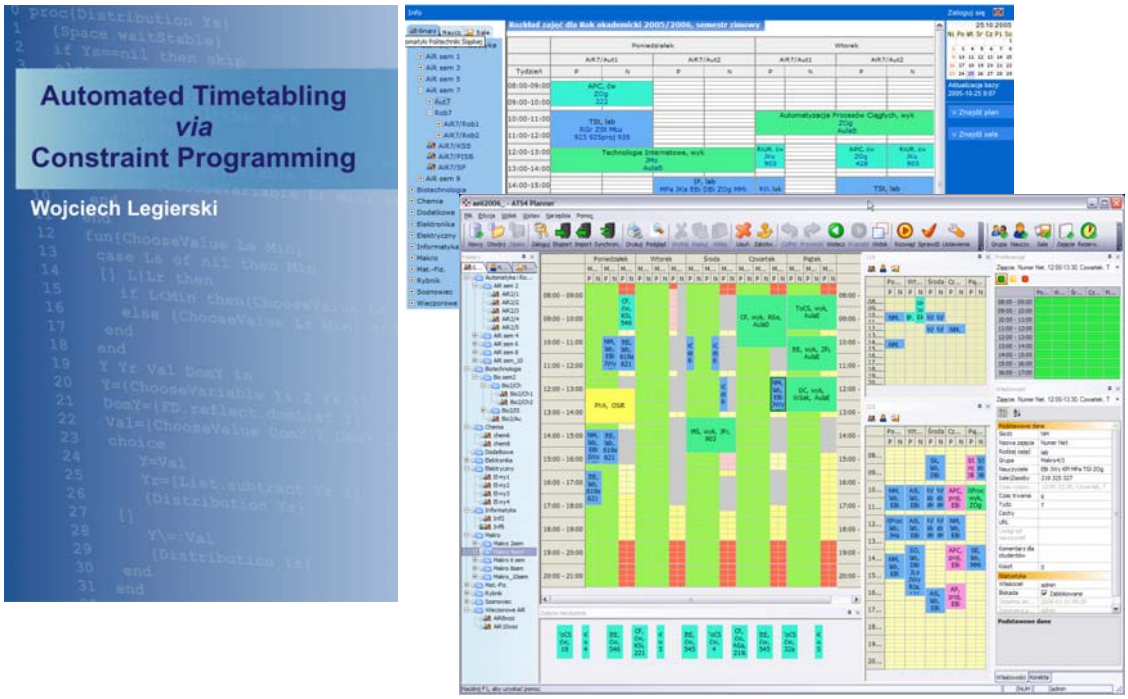
Automated timetabling via constraint programming

W. Legierski

Ph.D. thesis “Automated Timetabling via Constraint Programming” by Wojciech Legierski tries to prove that Constraint Programming may be used as a powerful tool to solve Timetabling Problems for two most popular categories - Class-Teacher Timetabling Problems and University Course Timetabling Problems. To attain this goal the following tasks were performed:

- Soft constraining was presented in a unified way, effective search methods were presented for taking them into account. The methods were implemented using the Constraint Programming paradigm.
- Original and effective custom-tailored distribution strategies were developed. They rely upon the proposed idea of constraining while distributing, which allowed to effectively handle constraints and search for ’good’ timetables straight away.
- Original and effective custom-tailored search methods were developed to enhanced search effectiveness of timetabling solutions.
- Integration of Local Search techniques into the Constraint Programming paradigm with use of space-based search enhanced search effectiveness of timetabling solutions.
- Two real-world timetabling problems were solved using a custom-tailored distribution strategy and a custom-tailored search method.
- Small instances of University Course Timetabling Problem (UCTP) benchmarks were effectively solved and the results were much better than results using random search methods as reported in literature. Proposals for using Constraint Programming for larger instances were formulated.

The developed automated timetabling system was successfully launched at the Department of Automation, Electronics and Computer Science.



Global Constraints Library to ECL^{i}PS^e

T. Szczygieł

Constraint programming is the field of research, ranging from theoretical area in mathematical logic to practical applications area such as job-shop scheduling. Constraint programming is concerned with solving instances of the Constraint Satisfaction Problem (CSP). The difficult practical problems can be expressed declaratively in terms of variables and constraints. The variables range over a (finite) set of values and typically denote alternative decisions to be taken. The constraints are expressed as relations over subsets of variables and restrict feasible value combinations for the variables. Constraints can be given: explicitly, by listing all possible rules or implicitly, by describing a relation in some (mathematical) form. A feasible solution is an assignment of variables to value which satisfies all constraints. The classical scheduling problems include the following problems: job-shop scheduling, open shop scheduling, cycle shop scheduling, online scheduling.

The problem of scheduling activities is a discrete optimization problem and therefore very hard to solve in practice (most of the scheduling problems are NP-Hard). To find good solutions or even solutions that meet all constraints, one has to explore a gigantic search space, most often exponential with the size of the problem. As a brutal exploration of the search space is not possible, several techniques have been proposed in the past forty years, including Mixed Integer Linear Programming, Branch-and-Bound or more recently Constraint Programming.

Generally, the global constraint library is focused on constraint programming techniques for various problems. The efficiency of constraint based scheduling applications could be drastically improved by using dedicated heuristic techniques: on

the one hand operations research offers efficient algorithms to solve problems that however might not be well suited to be used in practice, on the other hand constraint programming offers algorithms that are more generally applicable, but that might suffer from somewhat poor performance.

Workshop on Constraint Programming for Decision and Control

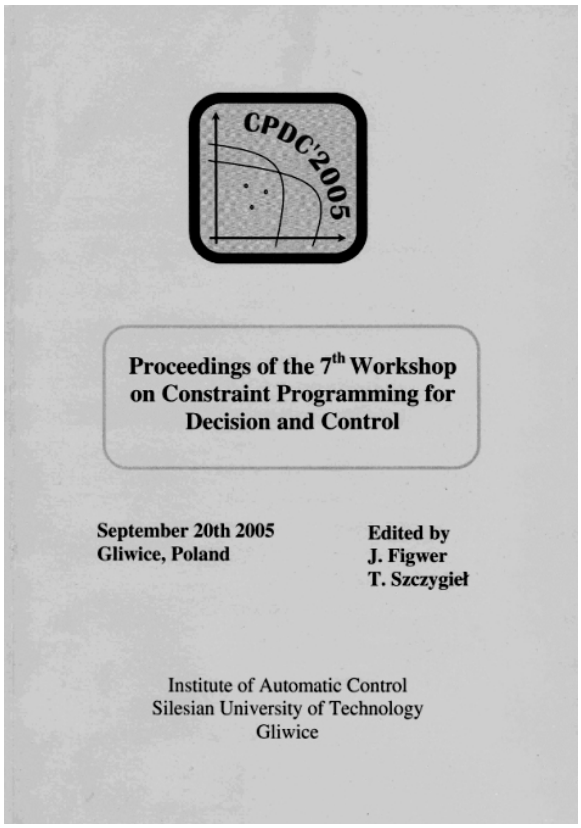
Niederliński, J. Figwer, T. Szczygieł

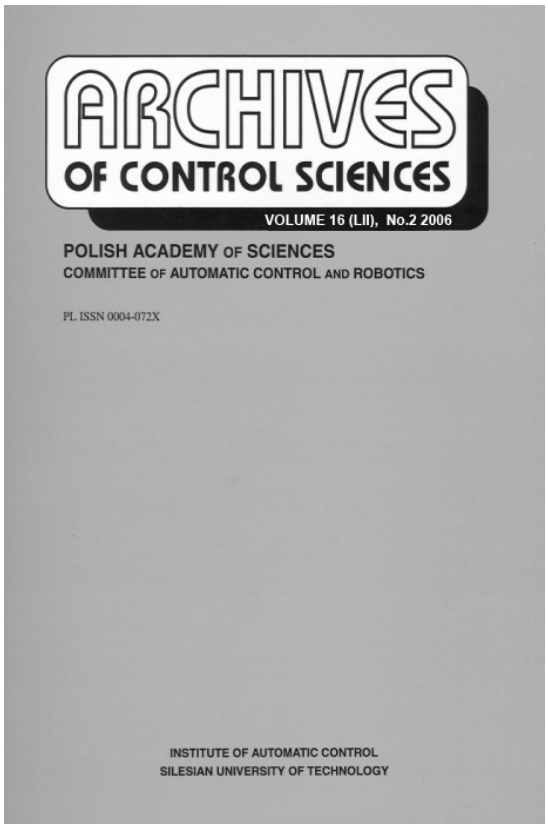
Professor Niederliński is acting as Chairman of Scientific Committee and Dr. Figwer as Chairman of the Organising Committee of the Workshop on Constraint Programming for Decision and Control. The 7th Workshops (CPDC'2005) was organised by the Computer Control Group and took place at Gliwice 2005. The homepage of the Workshop is http://kss.ia.polsl.gliwice.pl/kss/.

The CPDC Workshops are an attempt to bring together people from Polish Universities interested in using Constraint Programming (CP) or Constraint Logic Programming (CLP) for decision or control problem solving. To provide a better perspective on what others are doing, avoid being hampered by language barriers and create for all participants the opportunity to merge into the large international CP/CLP community, the Workshop was envisaged to be run in English. It addressed first of all the needs of graduate students working on theses using CP or CLP tools.

Papers presented during the CPDC'2005 Workshops were devoted to combinatorial decision and control problems like time-tabling, production planning, scheduling and resource allocation as well as combinatorial and mixed optimisation problems.

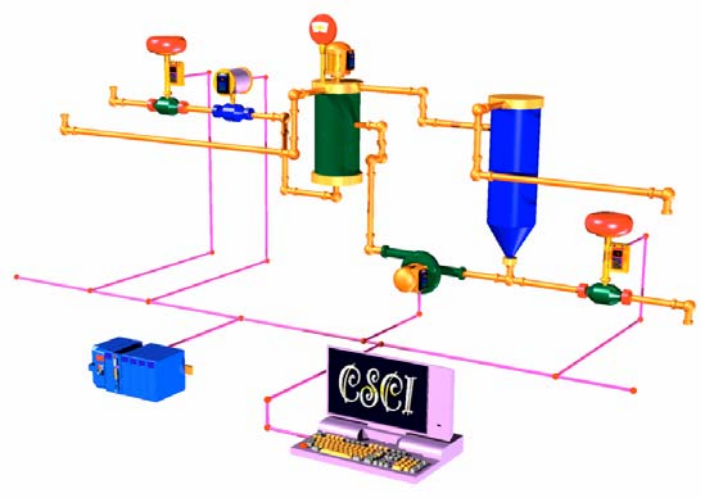
The Proceedings of the Workshop have been published, see below (left).





Editing the Archives of Control Sciences quarterly

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 – see above, right). Dr Z. Ogonowski is Assistant Editor of the quarterly. There was 8 issues published in 2005 and 2006 year including special issues devoted to: "Human Language Technologies as a Challenge for Computer Science and Linguistics" and "Constraint Programming". Total 80 papers have been published in the last 8 issues with 47 papers from abroad. See the ACS homepage http://ia.polsl.gliwice.pl/acs for abstracts of the papers.



CONTROL SYSTEMS AND CONTROL INSTRUMENTATION GROUP

GENERAL INFORMATIONS

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

- Modelling, simulation and control of continuous industrial processes,
- Theory and practice of modelling and simulation,
- Real-time simulation and training systems,
- Modelling, simulation and control of biotechnological processes in the environment protection - aspects: activated sludge processes, sequencing batch reactors, biofilm processes, biofilters,
- Modelling, simulation and control of biotechnological fermentation processes - aspects: anaerobic processes, yeast fermentation, enzymatic processes,
- Intelligent equipment for automation: transmitters, actuators, regulators and controllers,
- Distributed control systems – industrial networks, agent-based control, holonic systems,
- Programming of digital regulators, controllers, monitoring and SCADA systems,
- Low-cost PC-based control systems,
- Development and design of control systems in chemical, power and environmental protection industry,
- TCP/IP-based virtual plants, controllers and control systems, OPC.
- Microrobotics, microfluidics, microprocessing

The CSCI group consists of twelve researchers (including two titular professors 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 and the faculty of Chemical Engineering. 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 model" supported by the Polish Ministry of Scientific Research and Information Technology under Grant No N514 006 31/1739 (2006-2008).

Moreover together with System Engineering Group two important educational enterprises are undertaken. The first one started in the fall 2003 initiated new courses in Information Processing and Control in Biotechnology for students in Automatic Control and Robotics. The second one are interdepartmental studies in Biotechnology initiated by three Faculties. Our Faculty is responsible for specialization Bioinformatics and the study will start in the fall 2005.

RESEARCH ACTIVITY

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 TCP/IP and OPC connection; as well as for distribution of real-world control data from control plants by the Internet. The newest research activity deals with agent-based and holonic technology applied for intelligent and mobile control and monitoring as well as microrobotics and microprocess technology.

The following notes present chosen 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.

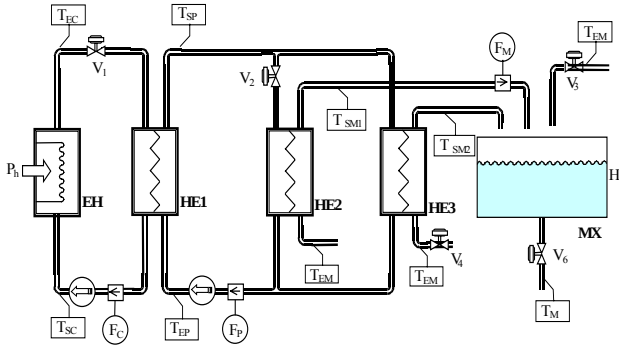


Fig. 1. Heat distribution pilot plant.

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

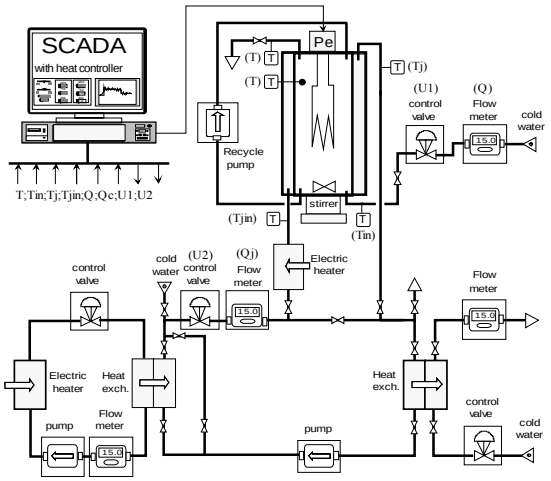
Both the continuous and the batch stirred tank reactors, considered as the control plants, are ones of the most frequently investigated processes. The classical irreversible $A \rightarrow B$ exothermic reaction, taking place in the reactor, is a great challenge faced by the automatic control engineers 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

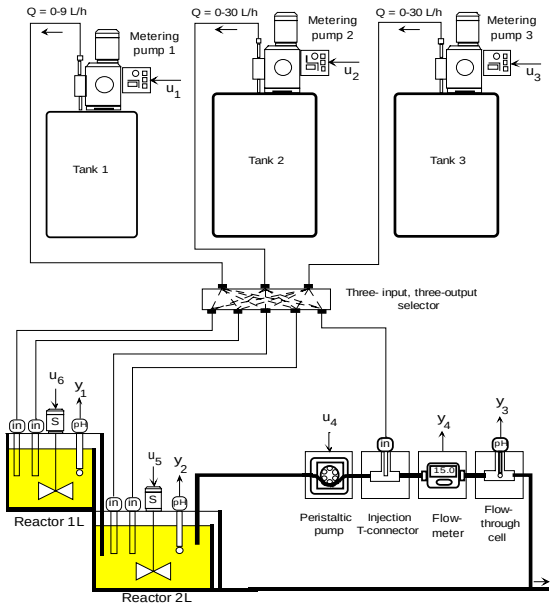
M. Metzger, D. Choiński

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.

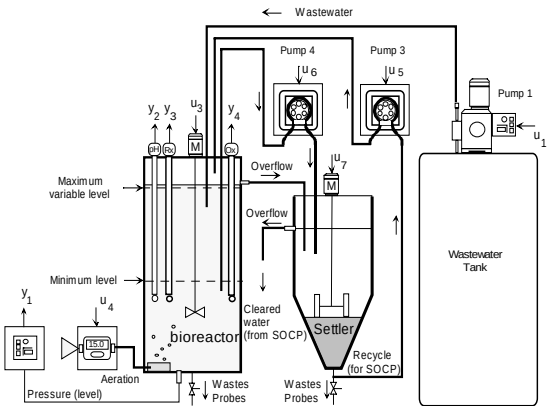
In comparison to classical continuous biological processes when the process can be carried out without any control system, the sequences of the periodically operated process must be controlled and thus the development of the SBR (or SOCP) as a real-world pilot plant can be very interesting for the real-world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

During 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 with a possibility of the biomass concentration control.

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.

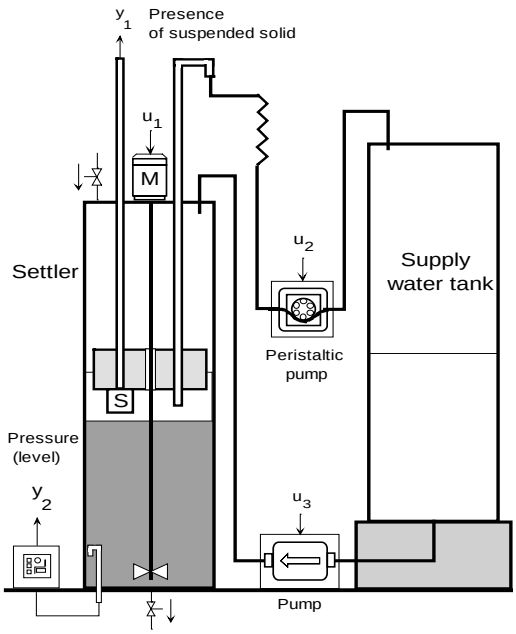
Batch sedimentation pilot-plant

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.

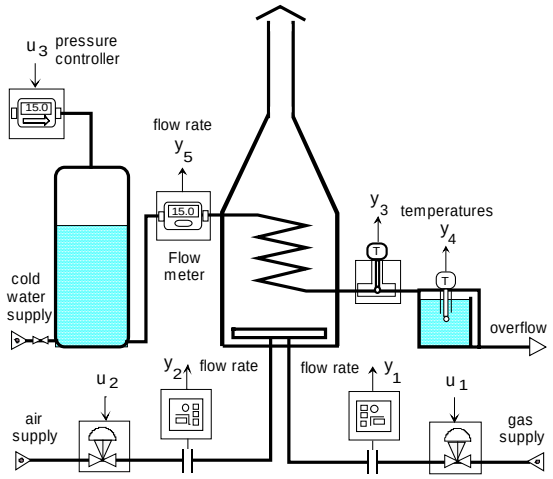
This pilot plant is used to design and test different methods and algorithms for control of the clearing processes in batch settlers (including identification of sedimentation process parameters from the simple measurements, calibration of simple sensors and optimisation of the clearing processes). Moreover, 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

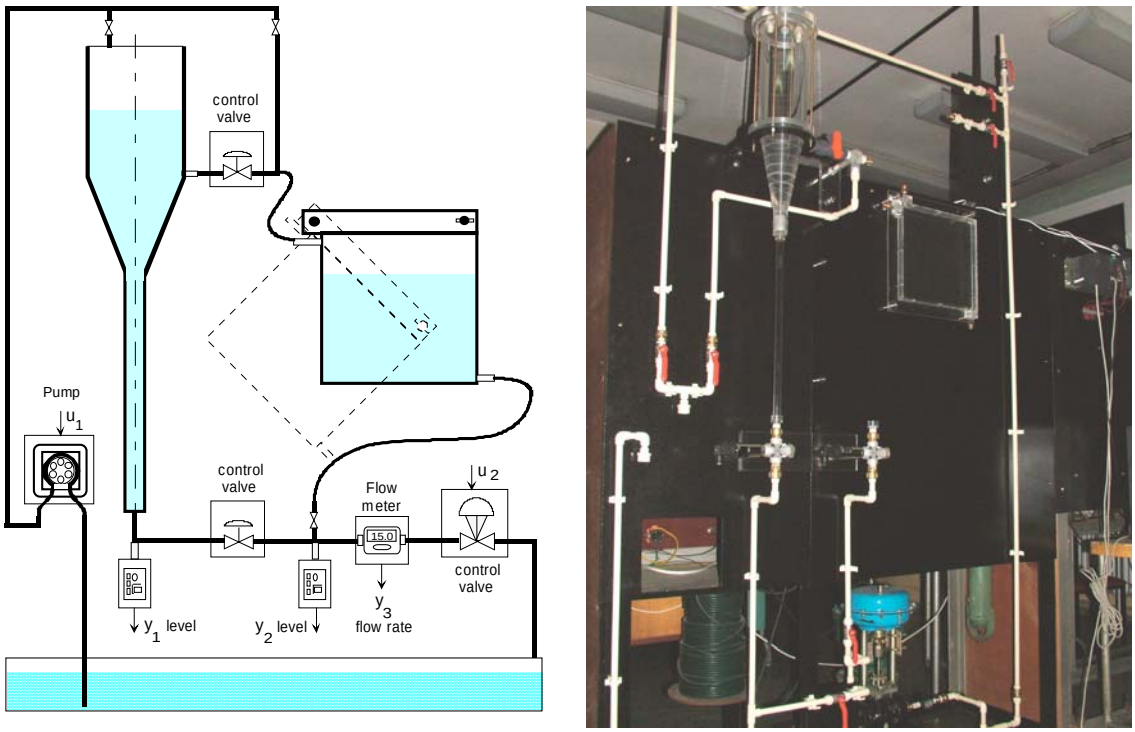


Fig. 1. Hydraulic pilot-plant with flexible two-tank architecture.

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.

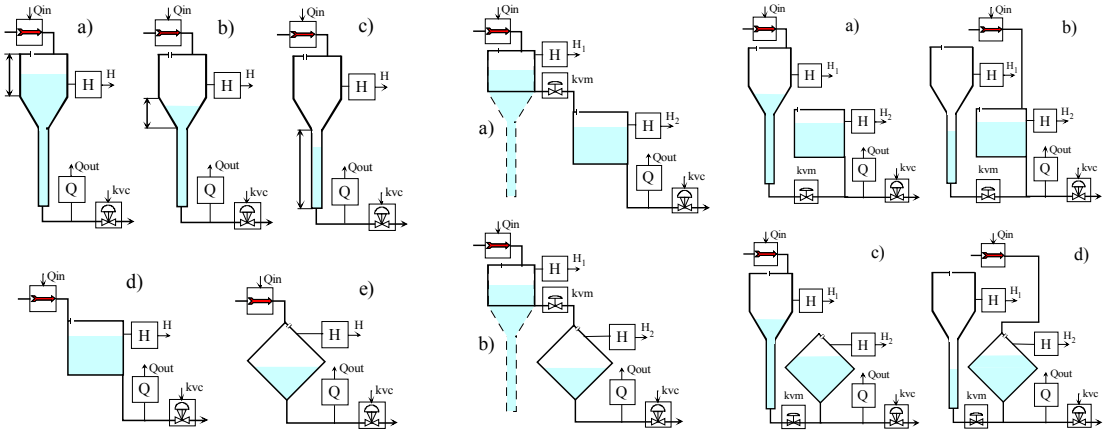


Fig. 2. Possibilities one/two tank and linear/nonlinear dynamic systems.

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.

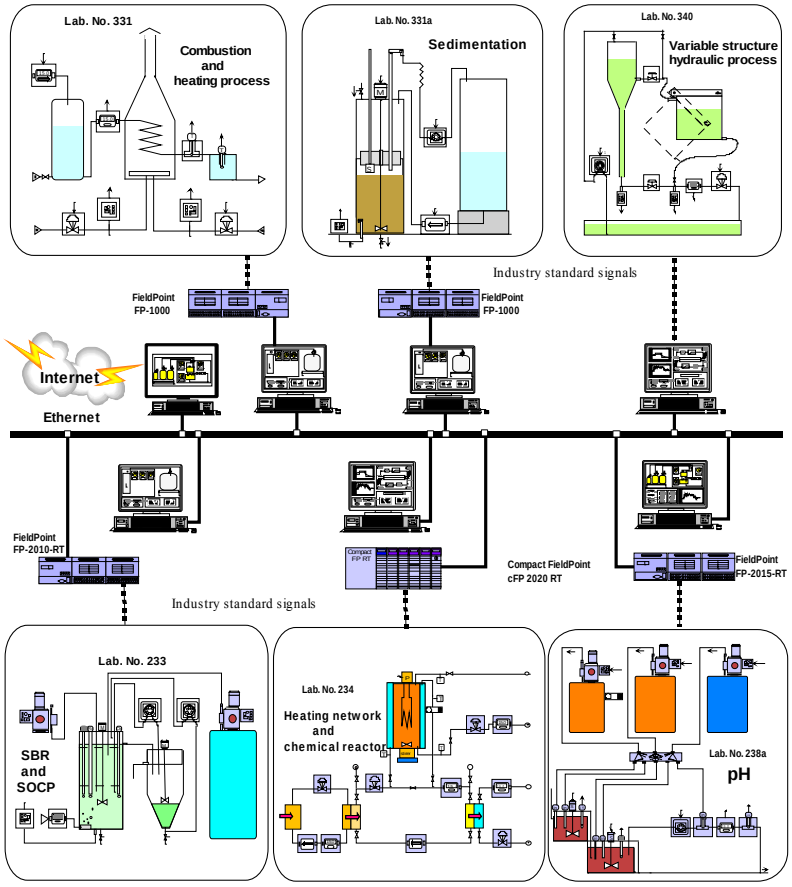


Fig. 1. Architecture of the DCS based on the FieldPoint instrumentation.

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.

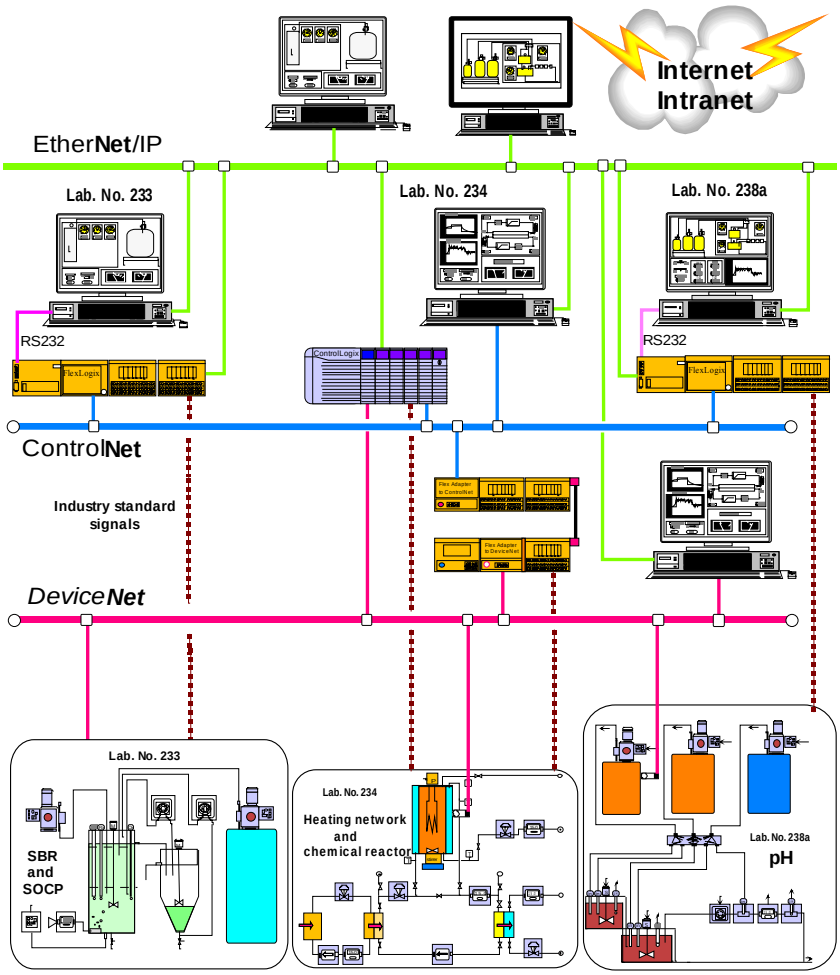


Fig. 2. Architecture of the distributed control system based on the Logix system.

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).

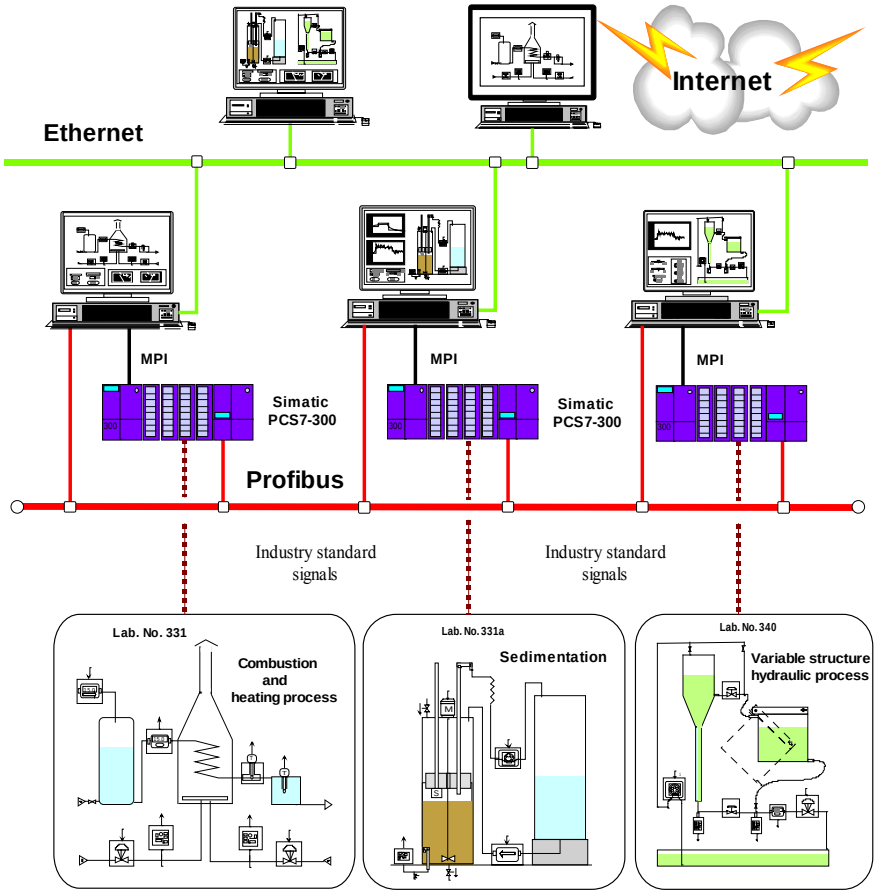


Fig. 3. Architecture of the distributed control system based on the Simatic system.

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

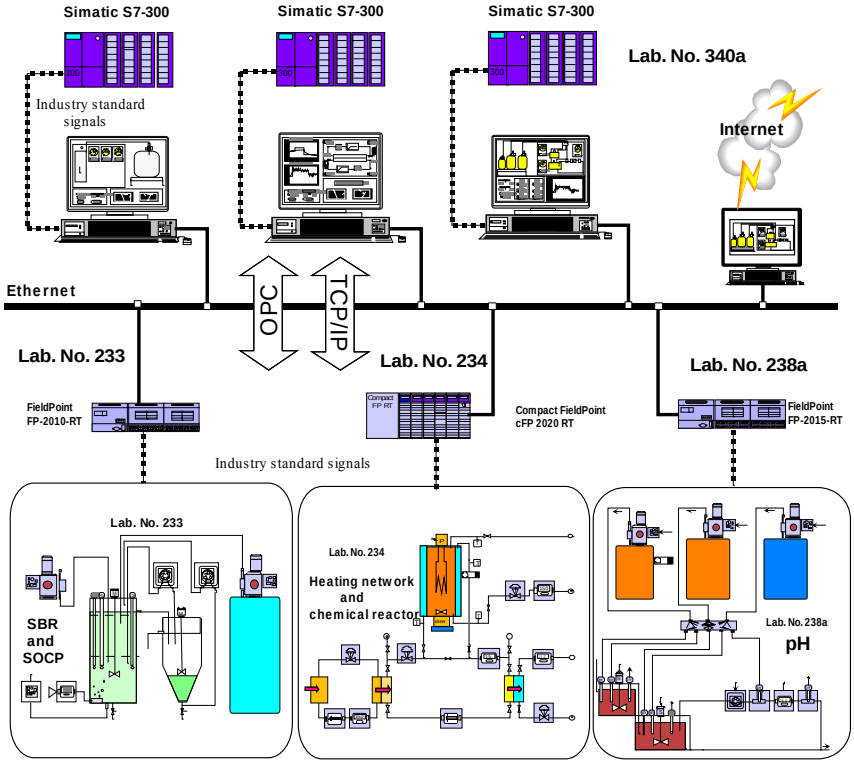


Fig. 4. Architecture of the nonstandard Simatic plus FieldPoint system.

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.

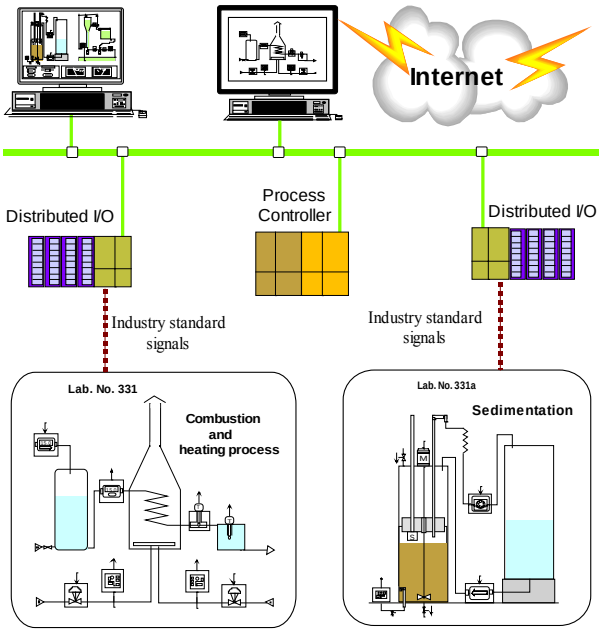


Fig. 5. Architecture of the distributed control system from metsoDNA

Real-time control strategies for sequentially operated continuous wastewater treatment process

D. Choiński, W. Nocoń, M. Metzger

The substrate reduction depends on many factors characterising biological growth rate. The simulation studies show that substrate reduction strongly depends of the initial biomass concentration. Hence, a possibility of changing the biomass concentration in the bioreactor can be very attractive for enhancing flexibility of the wastewater treatment processes especially in the presence of large fluctuations of the inflow loads. A real-time sequential control strategy based on such idea has been developed and realised for an enhanced sequentially operated continuous process. Real-world experiments were performed on semi-industrial pilot plant presented above. This application is presented in this note based on [III.20], [III.21, [III.22].

The principle of controlling the biomass concentration in the bioreactor is based on the recognition that microorganisms satisfy their maintenance energy requirements in preference to producing additional biomass. In a substrate limited environment it is reasonable to expect that microorganisms' allocation of carbon source will preferentially be oriented towards satisfying their maintenance energy requirements and not towards their anabolic functions (biomass generation). The consequence is that the biomass production decreases proportionally to the biomass concentration. A method for reducing the generation of excess biomass during wastewater treatment has been presented and was based mainly on control of the recycle of biomass from the settler back into the reactor.

In a steady-state operation of the wastewater treatment plant it is assumed that the load variations are relatively low. The dissolved oxygen set point level is selected so that the nitrification process is assured, and the recycle flow is selected so that the appropriate sludge age is maintained. For this reason, using the recycle flow as a manipulated variable for the biomass concentration control is not advised.

In this note an alternative method for controlling the biomass concentration is presented. It is based on the fact, that during steady state operations, the biomass concentration is maintained at a constant level. If however a need to alter the biomass concentration arises, a certain operation will be performed that will sequentially change this concentration.

In a classical approach, the continuous wastewater treatment plant is configured as presented in Fig. 1.

The plant consists of two separate tanks: bioreactor in which all the biochemical reactions are taking place, and the settler in which the separation of activated sludge flocs from water occurs. The wastewater reaching the plant is fed directly into the reactor. The volume of the bioreactor is assumed constant, which is usually realized by an overflow linked to the settler. The thickened sludge from the bottom of the settler is fed back into the reactor using a recycle pump, while the clarified water is removed by an overflow are directed out of the wastewater treatment system. In the pilot-plant used in the experiments, the recycle flow and the settler mixer are operated quasi-continuously using, the pulse-width modulation (PWM) control.

The proposed control scheme implies the following requirements:

- the bioreactor must possess the capability to operate with different volumes and a possibility to operate in a batch mode,
- the settler, being a constant volume tank, must possess the capability to operate with a varying solid retention time.

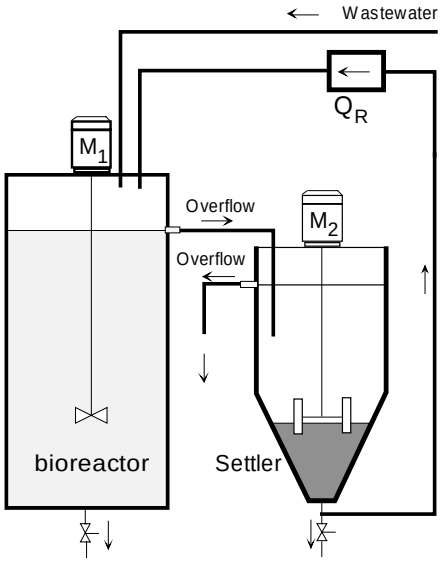


Fig. 1. Working point in classical architecture.

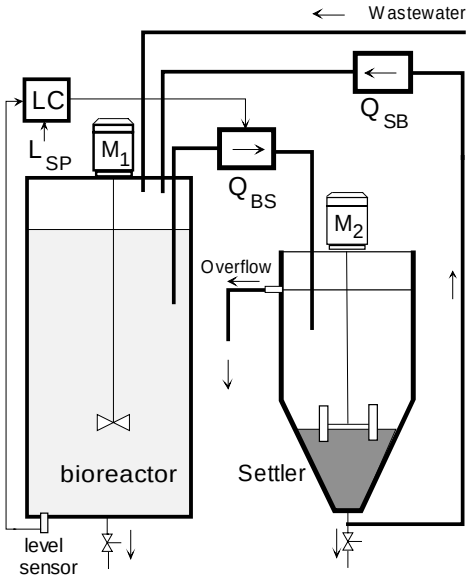


Fig. 2. The same working point in enhanced structure.

The first requirement is fulfilled by using an explicitly controlled pump instead of an overflow (Fig. 2). Level in the reactor is measured and a simple control algorithm (LC) is applied to maintain a constant level inside the bioreactor. Therefore, in a steady-state operation, the reactor works with a constant volume, but the set point level (L_{SP}) may be changed if needed. The batch mode may be realized for example by setting the Q_{SB} and Q_{BS} flows to zero (switching the pumps off) and by stopping the mixer (M1) in the bioreactor in order to commence the settling phase.
The second requirement (a settler with a varying solid retention time) may be fulfilled by applying a gentle mixing at the bottom of the settler. The mixer (M2) is usually used to maintain a unified thickening process. However, it may also be used to change the solid retention time by changing the mixing speed (for a longer solid retention time, the mixing speed must be increased).

When the mentioned requirements are fulfilled the appropriete sequences for changing biomass concentration (X) inside the reactor may be applied.

For example, when a need to condense the biomass in the reactor arises, the following sequence of operation is carried out (Fig. 3):

1. The overflow pump (Q_{BS}) is switched off.
2. Mixing in the bioreactor (M_1) is stopped.
3. Mixing inside the settler is also stopped to perform a rapid thickening of the biomass at the bottom of the setter.
4. When the thickening process in the settler reaches a satisfying level, the recycle pump (Q_{SB} flow) is used to move the biomass into the reactor.
5. Because the mixer (M_1) in the bioreactor is switched off, the sedimentation process occurs and a clarified zone at the top part of the reactor is created enabling the reduction of reactor volume without reducing the amount of biomass.
6. After a certain period of time that is required for the whole biomass to settle (including the biomass pumped from the settler), a new level set point is generated and the overflow pump (Q_{BS}) is switched back to it's normal

operation. The new set point may either be the same as the previous one or, if higher concentration of biomass is needed, the new set point may be lower.

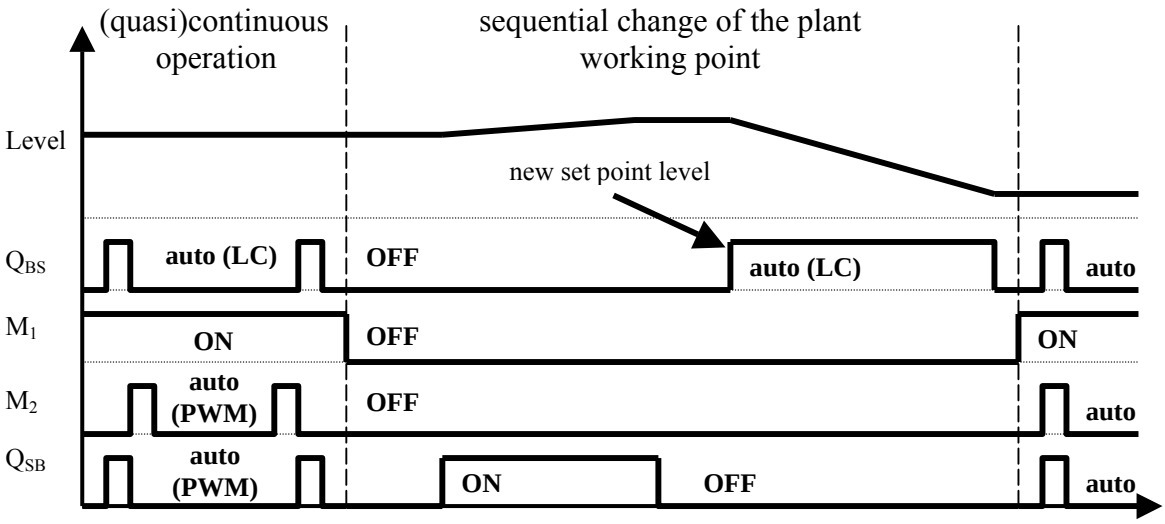


Fig. 3. Sequence for increasing biomass concentration.

The control system for the pilot-plant is realized using the distributed control system build and operated at the CSCI group (see precedings note). At present, the FieldPoint 2010 controller, programmed using LabVIEW, is used. Utilization of Alan-Bradley Flex-Logix controller is also possible. The HMI panel of the SCADA application is presented in Fig. 4. In addition to realizing the control logic, this application allows manual control, data recording and an Internet-based remote access to the pilot-plant.

The purpose of the first experiments was to prove that activated sludge process performance control by changing the biomass concentration in the bioreactor is possible. The standard operation of the plant requires the dissolved oxygen in the reactor to be controlled at different set points. A set point of 1,5 [mg O_2/l] is applied to maintain aerobic conditions in the reactor while a set point of 0,1 [mg O_2/l] is applied to maintain anoxic conditions. The aerobic phase lasts for 100 [min] while the anoxic phase lasts for 90 [min].

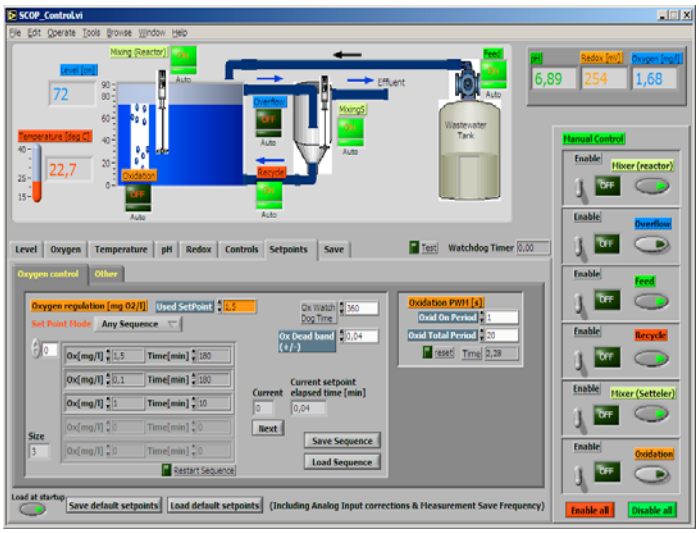


Fig. 4. HMI of the SCADA application used to supervise and control.

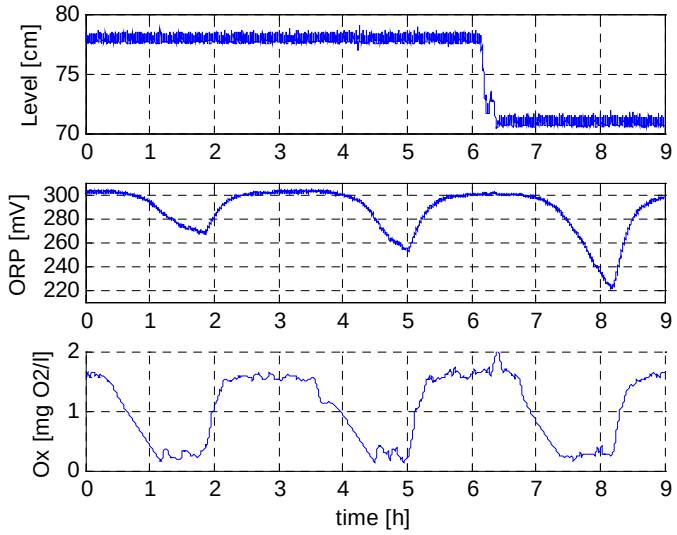


Fig. 5. Influence of the biomass concentration on the denitrification process.

In order to examine the influence of biomass concentration on the denitrification process, a sequence for increasing biomass concentration has been applied during the aerobic phase (Fig. 5). First, at about 3,5 [h], the sequence has been performed without changing the set point level in the reactor. It resulted in the biomass accumulated in the settler to be moved into the reactor. Such operation decreased the minimum ORP (oxidation-reduction potential) value attained during the anoxic phase by 16 [mV] (from 268 [mV] to 252 [mV]), thus intensifying the denitrification process. Secondly, at about 6,3 [h] another sequence has been applied, but this time, with a lower set point level and the biomass in the reactor has been condensed.

Fig.6. Presentation of the biomass manipulations. After the thickened sludge is pumped from the settler into the reactor, which results in a drop of level in the setter (right image) and a corresponding rise of level in the reactor, a new set point level is determined and reached by the controller. Mixing in the reactor starts (left image) and the system restarts it's normal continuous operation with a changed biomass concentration.

This resulted in a drop of the minimum ORP value attained during the anoxic phase by an additional 30 [mV] (from 252 [mV] to 222 [mV]). Obviously, it must be stated, that in the experiment, substrate was not the limiting factor in the reactions. Example of the sequence performed is pictured in Fig. 6.

Based on real-world experiments a methodology for a sequential change of the continuous wastewater treatment plant has been presented. It modifies the operation of the WWTP in such a way, that when a need to change the biomass concentration in the bioreactor arises, a certain sequence of events may be applied. Hence, a possibility of using the biomass concentration as a control variable is provided. In addition, the presented methodology, does not interfere with the sludge age control by leaving the recycle flow as an independent control variable. In other words, the presented methodology posses a potential for increasing the controllability of the wastewater treatment plant. These results are very interesting for teaching purposes taking into consideration participation of the CSCI group in the biotechnology field of education.

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], [III.3], [III.14], and [III.25]. Moreover, the properties of the estimation procedure are investigated both analytically (proof of convergence) [III.4] and by simulation [III.24]. 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.5].

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.1]. The controller synthesis and its simulation verification can be found in [III.14]. The experiments were carried out on the part 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.

Figure 1 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.

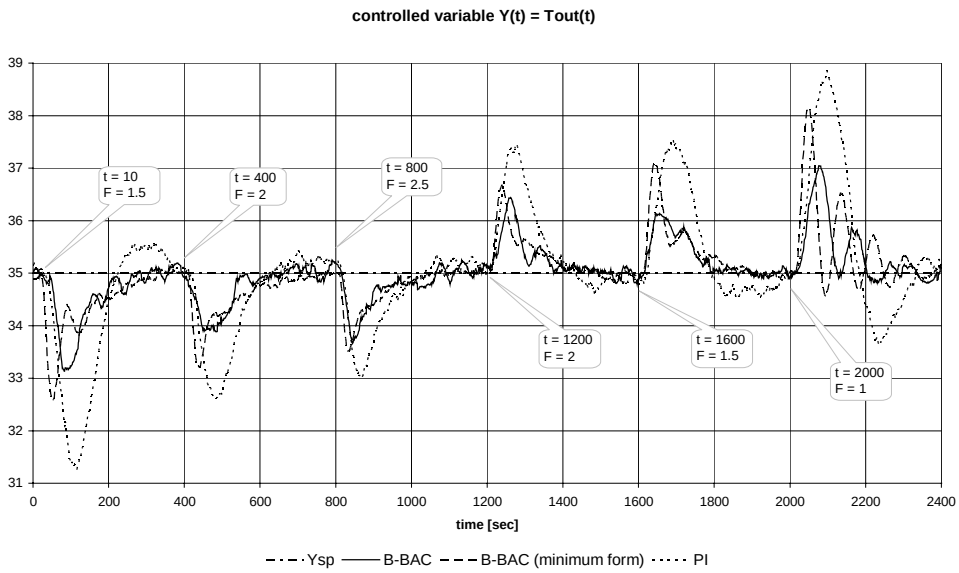


Fig. 1. Closed-loop responses for the electric flow heater in the presence of the step changes of the disturbing flow rate.

Agent 007

M. 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. 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 information science. One can found some propositions for manufacturing control and mobile multirobot systems.

A big effort was made over the years 2006/2007 in the CSCI group for adaptation the agent and holonic systems for process control. Five following notes present the most interesting results published in 2007 in the Springer Lecture Notes serie [III.8-III.11] and [III.13].

Multi-agent System for Hierarchical Control with Self-organising Database

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 paper [III. 8] presents 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 multiagent system is presented in Fig.1, while Fig.2 shows an example of object states transition in hybrid hierarchical and multi-agent control system.

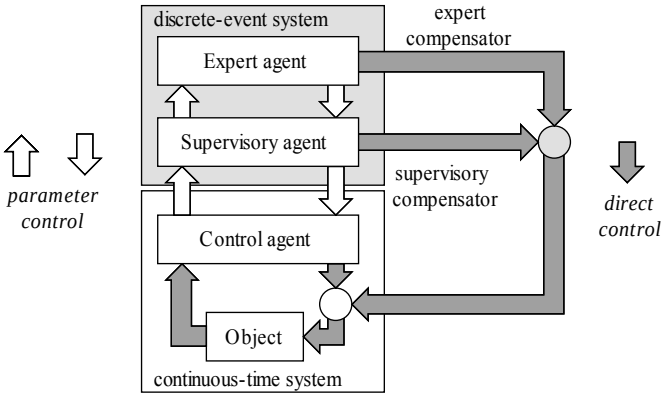


Fig. 1. Architecture of the multi-agent system.

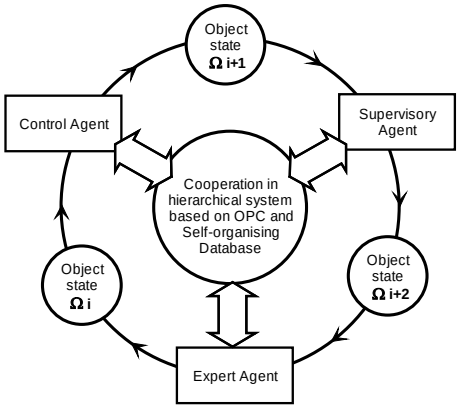


Fig. 2. An example of object states transition in hybrid hierarchical and multi-agent control system.

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 nonconventional biotechnological process control in the pilot plant. In the proposed multiagent heterogeneous system the OPC plays an important role as powerful communication technology especially dedicated for real-time distributed control systems. This technology consists of OPC standard and specialized software architectures offered by most of Distributed Control System (DCS) vendors.

Application of the Holonic Approach in Distributed Control Systems Designing

D. Choiński, W. Nocoń, M. Metzger

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. Those requirements address a reliable operation of the particular elements of the technological system and of the control system, realization of the supervisory control goals and adaptation of the plant to the changing

technological or marketing requirements. Therefore, every entity of this structure may be a subject of research and design of a new solution, and usually, this solution has a complex structure that takes into account many technological or control algorithm aspects. Those actions are usually grouped into stages: selection, modification: upgrade/reduction and validation. Selection requires such a projection of the structure so that the selected subsystem fully realizes those functions. Modification requires mutual bindings between particular subsystems to be projected. 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.9] proposes a holonic approach to validation of distributed control systems considering also its hybrid architecture. The proposed holarchy (Fig. 1) includes a multi-agent system (MAS), connected with a self-organization database and ontology-based technology rules decomposition.

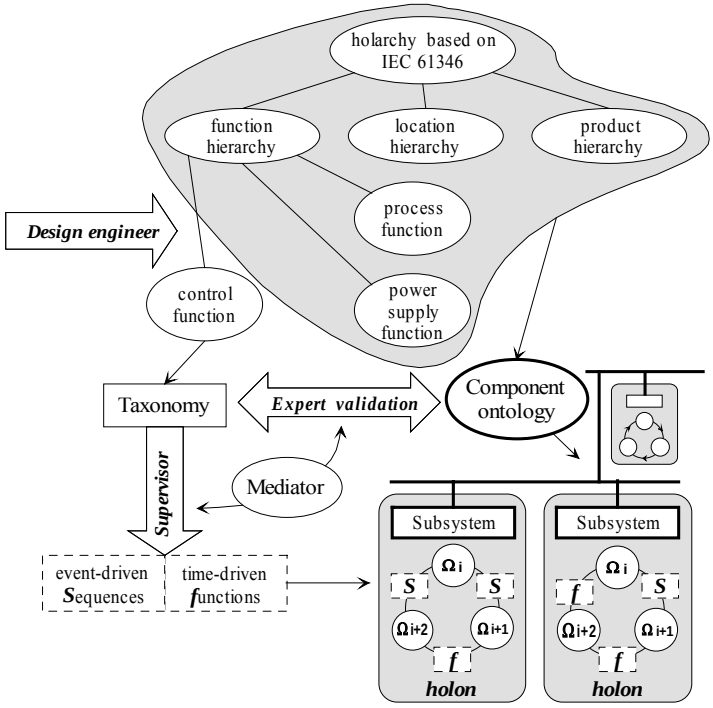


Fig.1. Holons composition for MAS.

Cooperative Validation in Distributed Control Systems Design

D. Choiński, M. Metzger, W. Nocoń, G. Polaków

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.10] is presented in Fig. 1.

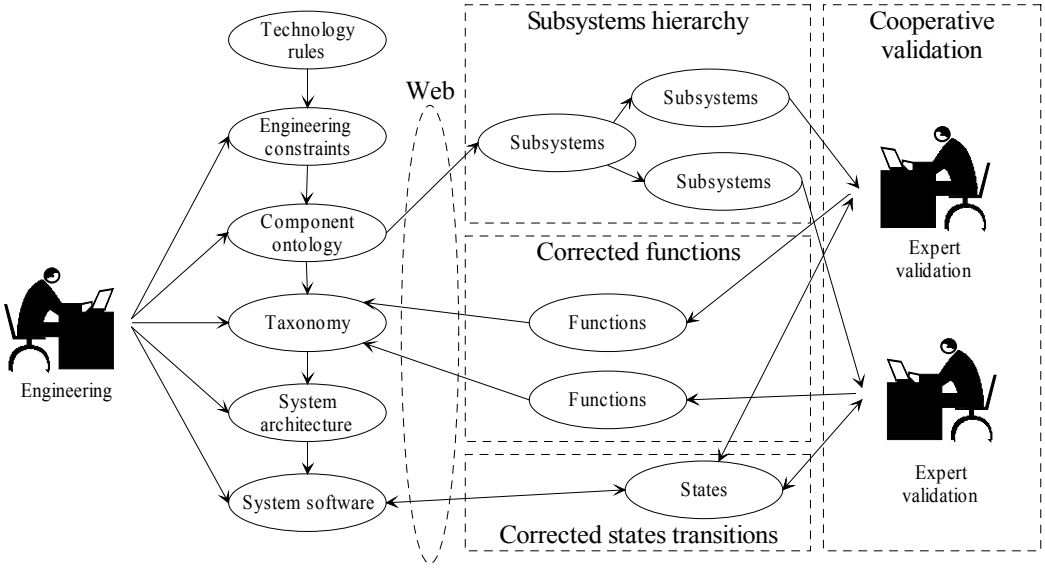


Fig. 3. Concept of the hybrid system.

Agent–Based Approach for LabVIEW Developed Distributed Control Systems

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.13] 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.

It is difficult to assign an agent to non–discrete continuous physical phenomenon. Therefore, it is assumed that each LabVIEW developed agent, is tied to one of the clearly defined tasks of control system itself. Such tasks include:

- control: agent receives values of process variables and answers with values of control variables;
- simulation: agent receives values of inputs of mathematical model and answers with outputs of the model;
- data acquisition: on request agent sends value gathered from plant;
- visualisation: agent receives some values and presents them in human readable form to system operator.

Described agents were communicating by means of TCP/IP protocol and they proved to be especially useful in the field of learning and education as their modular composition allowed for quick reconfiguration. The proposed architecture is shown in Fig.1, whereas Fig. 2 shows external environment and internal structure of typical agent.

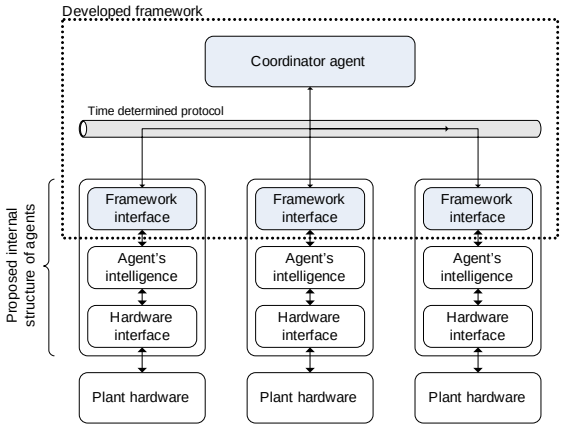


Fig. 1. Proposed architecture for agent–based control system.

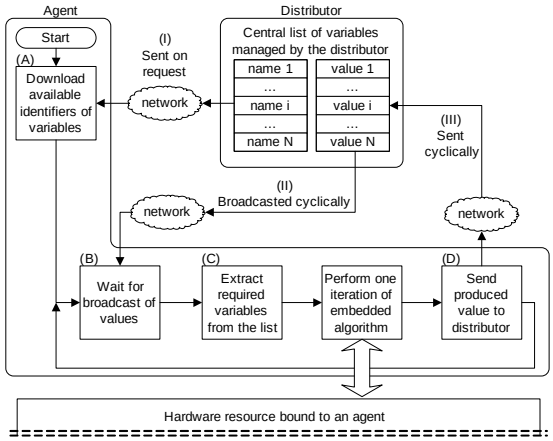


Fig. 2. External environment and internal structure of typical agent working with the protocol.

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

M. Metzger, G. Polaków

Semi-industrial pilot plants [III.16] 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.11], 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.

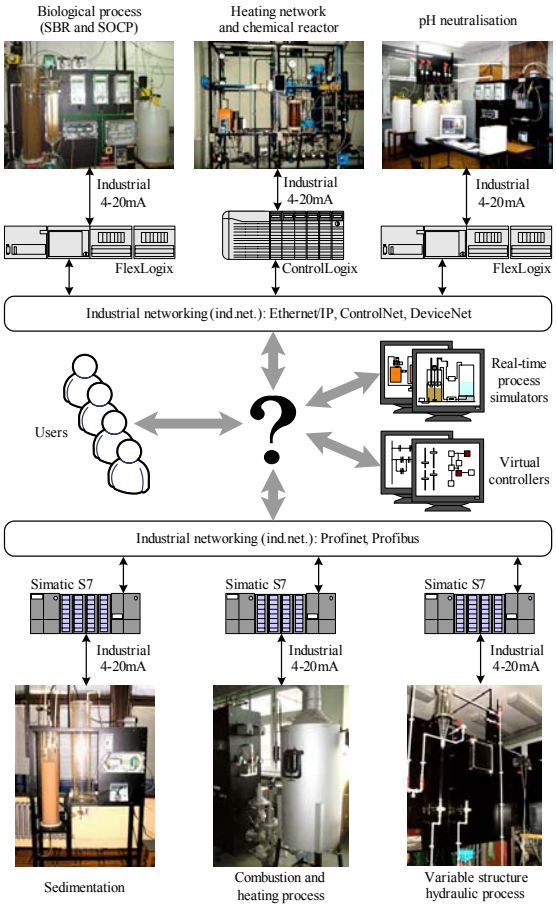


Fig. 4. Physical structure of system under consideration.

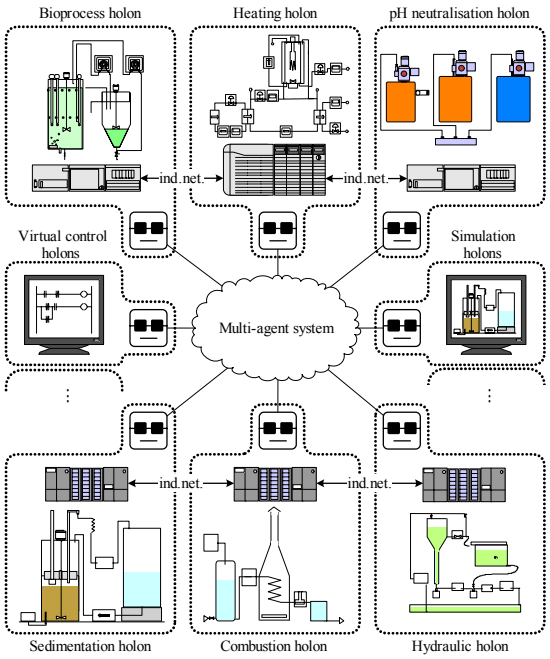


Fig. 5. Holarchy as a method of system integration.

Producer-distributor-consumer communication scheme in Ethernet

G. Polaków, M. Metzger

In a typical three layered structure of a distributed control system nodes belonging to distinctive layers of a system need to communicate with the system in a various ways. Communication in each of layers has different characteristics (i.e. required round trip time, total number of connections established, amount of data transmitted in a time period). Requirements for these properties strongly vary form layer to layer.

It is interesting how particularly popular Ethernet networking standard is placed in this context. Ethernet, which is a standard of local area networking, was designed specifically for office and home use and is easily integrated with the Internet. Ethernet is by its design predestined to work efficiently with the internet protocol suite (IP, TCP, UDP), with a typical scenario of relatively infrequent transmissions of relatively large data chunks (files, website pages). Because of this properties, Ethernet is perfect solution as an environment for integration of distributed control systems in highest layer dealing with the visualization, data storing and management cooperation. However, popularity of the standard caused it to be considered as a medium for low level networking and raw process data transmission also. To make such application of Ethernet possible, it is required to develop new protocol (on top of the Ethernet's native low level protocol) which will be able to encapsulate control system's process data.

There are such protocols available as retail products (e.g. Ethernet/IP, Industrial Ethernet, ProfiNET), with broad range of openness and compatibility, starting with closed proprietary protocols requiring modified networking hardware (with guaranteed time determinism), ending with completely open and free protocols compatible with office-grade cabling and standard hardware (although with unspecified timing properties).

In case of protocols compatible with standard Ethernet hardware, it becomes important to know, what are physical timing properties of Ethernet equipment, as this information is required to properly define achievable timings of periodic data transmissions (which are common in sampled continuous control systems). To make such experiments conductible in an open way, with no perturbations coming from properties of specific retail products, transparent protocol (with no use of previously existing and potentially restricted intellectual property) was developed. The protocol runs on top of the internet protocol suite and exploits specific properties of the UDP protocol to model exact behavior of producer-distributor-consumer scheme based low level industrial protocols.

Stage of the protocol design is currently over. The result of the accompanying theoretical analysis of the Ethernet networking properties is a set of main requirements (technology, cabling, topology, theoretical number of nodes), which have to be fulfilled to assure that times of cyclic transmissions are determined. The most important issue is an elimination of the carrier sense and collision detection (CSMA/CD) algorithm, which introduces stochastic unpredictable behavior. Total elimination of the algorithm is possible only in networks built using switching technology with full cabling allowing for full-duplex mode of communication. However, switching technology (while eliminates stochastic CSMA/CD) introduces another potential source of transmission delays i.e. packet queues implemented in ports of switches.

Currently, in the CSCI group there is a research ongoing which has to determine practical limits of the time capabilities of popular Ethernet switches available as retail products. Switches are tested with the developed protocol, which is used in this case as a model of a typical process data traffic present in industrial networks. Expected result is a function showing how minimal achievable time period of cyclical transmissions depends on a number of network nodes using the protocol. Influence of the disturbances caused by external network traffic (in the same cabling) on the protocol's characteristics will be also investigated.

Simple engineering tuning of DMC controller

T. Kłopot, M. Metzger

Predictive control algorithms have many of advantages, however, a number of practical implementations is still smaller than a number of traditional PID controllers using to control. This case concern also to another advanced control algorithms. Basing on this, it is possible to say that the traditional PID controllers still playing main role in control applications. Mainly it is caused by more complicated construction of algorithms, but also difficult stage of controller tune. Up until now, many attempts have been made to create universal formulas for tuning of prediction controllers. Thanks this, stage of controller tuning would be simpler and shorter. However, in spite of success in create tuning strategies, those strategies offered too complicated dependences and very often gives equivocal answer. Moreover, parameters obtained using offered formulas meet

difficulties in realisation on commercial PLC controllers. Hence, the process engineers still wait for not complicated tools for tune of predictive algorithms. The work was focused on finding the tuning strategy for analytical version of SISO DMC algorithm which is using for process, which could be approximated by FOPDT model.

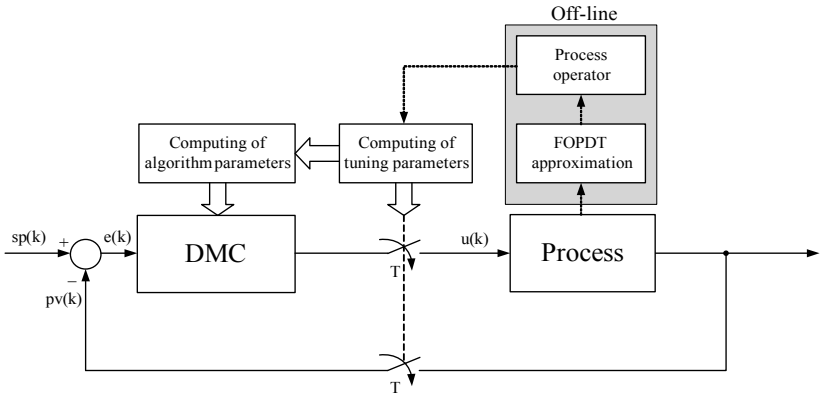


Fig.1. Idea of suggested tuning strategy.

Thanks to obtained tuning strategy, stage of controller tuning has been shorten, thus it 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 but also untypical plants like processes with lead time. Very important fact is that for presented class of plants 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 [III.26], [III.27] proved correctness of proposed approach and designed control algorithm.

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 (Fig. 1.)

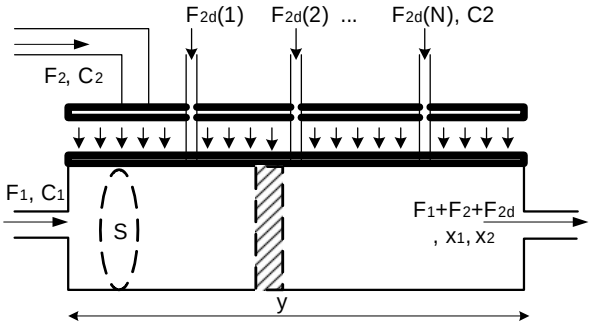


Fig. 1. Complete form of distributed parameters process.

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.

Programmable pH measurement correction in application to control

K. Stebel, D. Choiński

Programmable pH measure correction monitor is computer based and in this sense it is a kind of Soft PLC. Good controller performance is important to process safety, product quality, and manufacturing costs. But once a controller is tuned, changes in the process can make a controller undesirably sluggish or aggressive, erratic or ineffective. Linear control algorithms work well in most cases. However, when nonlinear or nonstationary processes are considered, more sophisticated algorithms are needed to obtain satisfactory performance in long time periods. Process models are needed for synthesis of such nonlinear algorithms, but such models are usually complicated and computationally inefficient. Alternatively simple linear control algorithm may also be used but its performance has to be frequently evaluated. Maintains staff or an automated performance monitor can do it. The idea of performance monitor can be successfully applied to pH control process.

The concentration change of the solution around the pH electrode induces Henderson's potential. This potential is a disturbance in pH measurements and appears on the interface of solutions with different concentrations or different ion mobility. Local concentration of ions depends on ions activity that is possible to calculate using the Debye–Hückel theory but it is useful for effective preparing of solutions for the

electrode calibration and not for on-line compensation. A statistical description of this structure is general enough for treating the equilibrium and dynamical case of ionic solutions.

The pilot plant installation considered in the work consists of three tanks for reagents and two coupled reactors. It is equipped with FeldPoint I/O system connected to the computer control system based on LabView. A standard PI control algorithm was chosen for control. Usually, the controlled variable (CV) fluctuates around setpoint value. Statistically, it can be expected that the difference between time when CV<SP and the time when CV>SP is close to zero with some variance. Hence χ^2 test with one degree of freedom was applied to monitor difference of this time. It was assumed that the null hypothesis can be rejected when current chi-square value is grater than critical chi-square value with level α=0.1 of significance. When null hypothesis is rejected than controller SP is corrected. Correction is done if necessary only once at the end of each time window allowing controller and process to react on SP correction. Proposed idea was applied and tested on real-world pilot plant installation, sampled with 1-second interval.

Application of the proposed programmable monitor was successful. It allows avoiding sophisticated nonlinear control. This monitor is a kind of a filter but it does not reduce information coming from measurement. It reacts only when statistically certain conditions are not fulfilled and correct SP to eliminate this influence. Another advantage of it is that, it may easily be implemented using a PC or a PLC (as an additional function that may be used in the existing systems).

Architectures of local-SCADA, remote-SCADA and docking virtual controllers for NI-FieldPoint-based control experiments via Internet

M. Metzger

The user-defined PC-based controller, while also equipped with appropriate professional features, can be a very interesting, low-cost alternative to controllers from commercial producers. We can refer to this kind of controllers as the virtual controllers. The NI FieldPoint system presented above is especially suitable for application of such virtual controllers running both on the PC computers and on the NI FieldPoint modules. Although the physical signals are connected to the system by the industry standard the virtual applications can also change data using TCP/IP connection.

At the CSCI group several virtual controllers have been developed in recent years for educational and research purposes such as for example single PI, PID controllers as well as advanced PFC, GMC and self-tuning PID controllers. All of them are equipped with standard professional features such as antireset windup and bumpless M/A switching. Finally virtual versions of professional programmable multifunction controllers such as for example well-known Sipart DR 24 from Siemens are also developed. All of these virtual controllers can be used for control in DCS presented in one of the preceeding notes.

An original conceptual contribution of this note deals with a new concept of easy performed control experiments on pilot plants with an application of virtual controllers [III.16].

The architecture of basic system for each of the processes (a pilot plant) is presented in Fig.1. The system containing several components connected by TCP/IP localhost data transmission runs on one PC or on one FieldPoint, which also ensures industry standard process connections. The central component – a SCADA system ensures process communication, monitoring and visualisation as well as can work as TCP/IP server for chosen signals. The control algorithms can be embedded in the SCADA system but it is more useful to connect different virtual controllers (only one in time) by localhost as docking controllers. In such a way the virtual controllers are applications separately developed and compiled. Although formally the TCP/IP connection is not time determined the localhost transmission do not change the control properties.

The architecture of the control system with a possibility of remote performed experiments is shown in Fig. 2. The SCADA system and the virtual controller actually connected should be equipped with remote operating panels as http pages accessible by operator-defined ports and for operator-defined IP remote workstations. The control is locally performed, whereas monitoring, visualisation and setting can be carried out from other computers in the Intranet or by the Internet.

The experimenter can additionally observe some results of the control by web-cams (for example water level or LED lights on controllers) as well as can store the control responses on HD for presentations. In principle such kind of experiments is reserved for staff only.

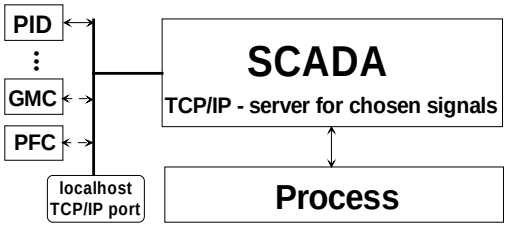


Fig. 1. Basic control system without remote possibilities.

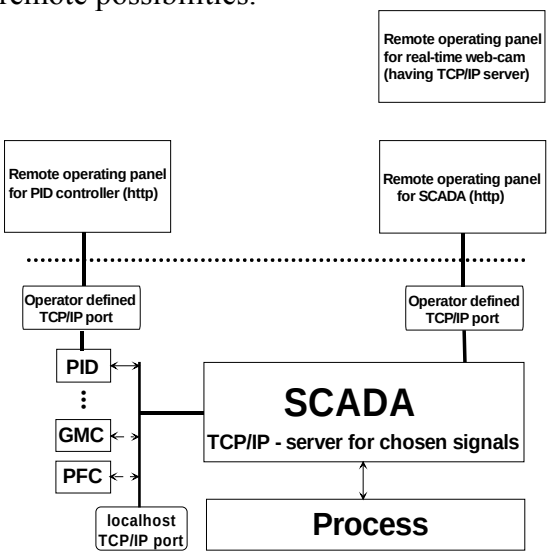


Fig. 2. Architecture of the control system with remote capabilities

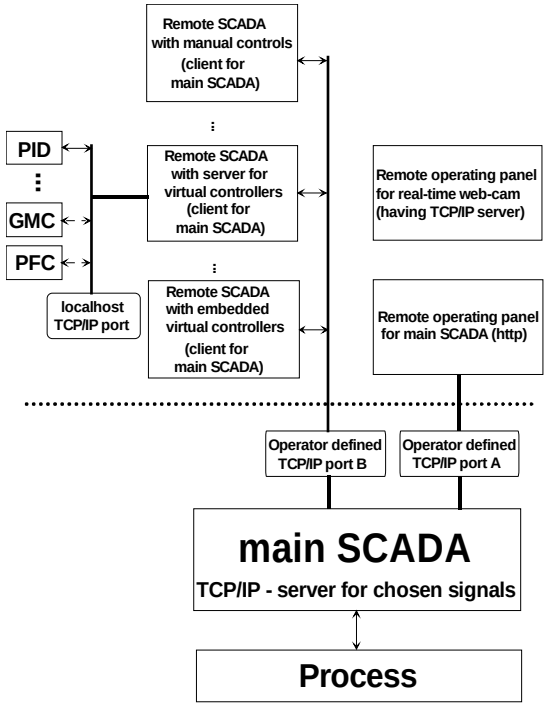


Fig. 3. Architecture of the system with remote experimenter-programmed components.

The architecture of the system dedicated for students or other distant experimenters is presented in Fig. 3. A professional main SCADA system has been developed by the staff. This SCADA system offers all controls and indicators in local mode as well as the web-based operating panel remotely for staff. This system has the possibility of staff-defined signals (input/output) to be offered on the TCP/IP server using the staff-defined TCP/IP port. Only authorised students know the right sequence of signal transmission, the staff-defined number of the port, and staff-defined password.

Students should design and develop their own remote SCADA applications (as clients for main SCADA) for appropriate experiments. At the moment three typical remote SCADA systems can be distinguished: a SCADA system with manual controls, a SCADA system with embedded controllers and a SCADA system with the TCP/IP server for controllers programmed as separate executables. These controllers can be connected to the remote SCADA systems using also the "localhost" connection. The programming of such student's applications can be included in the teaching procedure. In the final phase, students perform remote experiments on the real-world pilot plants and observe and store some results of the control.

Summing up, it can be niticed that a new concept of easy performed control experiments on pilot plants with an application of virtual controllers evidently improves research and teaching capabilities and therefore becomes attractive and convenient. The remote data monitoring is possible for all interested in, as well as the view from five remotely controlled web-cams, whereas only authorised users can exert the control.

Mathematical modelling of distributed feed in continuous sedimentation

W. Nocoń

Sedimentation is one of the most widely used processes for separation of solid particles from water in chemical and mineral industries as well as in wastewater treatment. Most of the continuous sedimentation models are based on the theory introduced by Kynch, according to which the settling velocity of solids particles depends only on the local suspended solids concentration. The process is described by a scalar conservation law in the form of a partial differential equation. Concentration discontinuities are present in this model and it is difficult to classify the steady-state solutions for changing feed flux values (different values of feed flow and feed concentration). Those discontinuities are introduced by the point source at the feed of solids and by the two outlets (top and bottom) of the settler.

A new method of modelling the feed section of the continuous sedimentation process is proposed [III. 6]. It takes into account the fact that the material entering the settler is distributed over a set of layers in the feed zone. In a one-dimensional modelling of sedimentation process it is assumed that the suspended solids concentration is only a function of depth and time. It is reasonable to expect that in the clarification and thickening zones this assumption will be met. However, that is not the case in the feed zone, where a significant horizontal flux of suspended solids exists.

What makes the proposed model distinct form the previous one-dimensional models presented in literature (point-source models, Figure 1b) is that the feed zone in not a lumped-parameter system. Instead, the feed zone of the continuous sedimentation process is in itself represented as a distributed parameter model (distributed-source model, Figure 1c). In addition, depth of the feed zone is not dependent on the space discretisation step.

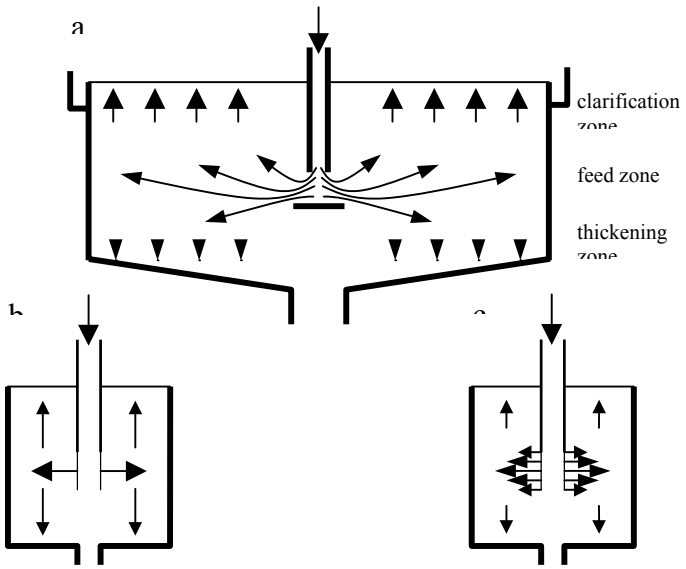


Fig.1. The general flow pattern in a real continuous sedimentation process (a) compared with the classical point-source 1D model (b) and the proposed distributed source 1D model (c).

The proposed model of distributed feed zone in the continuous sedimentation is based on the following postulates:

- *Imperfect mixing* - it is assumed that the feed zone does not consist of only one layer with perfect mixing. Instead, a set of layers is included in the feed zone and imperfect mixing is assumed between those layers,

- *Distribution function* - The amount of material entering each layer is not the same for every layer. A distribution function $f_d(r)$ (Fig. 2) is incorporated. This function distributes the material entering the settler over the layers in the feed zone,

- *Bulk flux zones* - The third postulate is based on the basic assumption that the flow into the settler equals the sum of underflow and overflow. Since, in the proposed model the feed zone consists of many layers, one particular layer has to be chosen to represent the boundary between the downward and upward bulk flux zones (Fig. 2). This is performed by a proper integration of the distribution function.

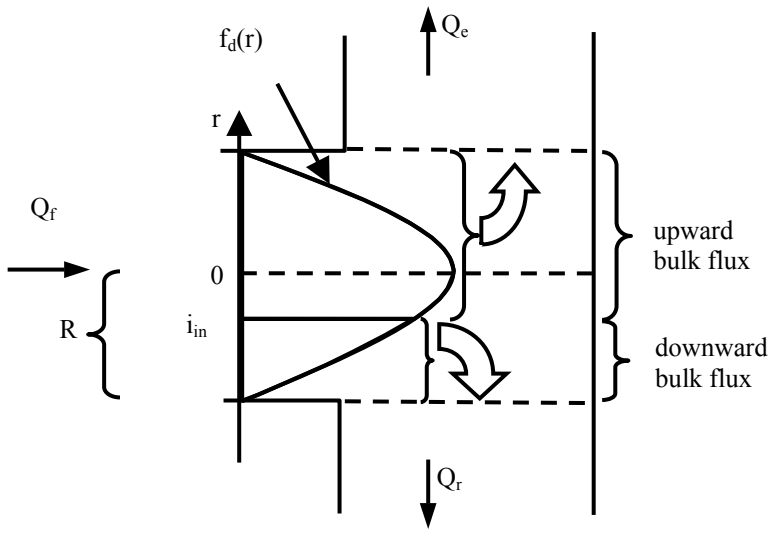


Fig. 2. Illustration of the proposed feed zone model.

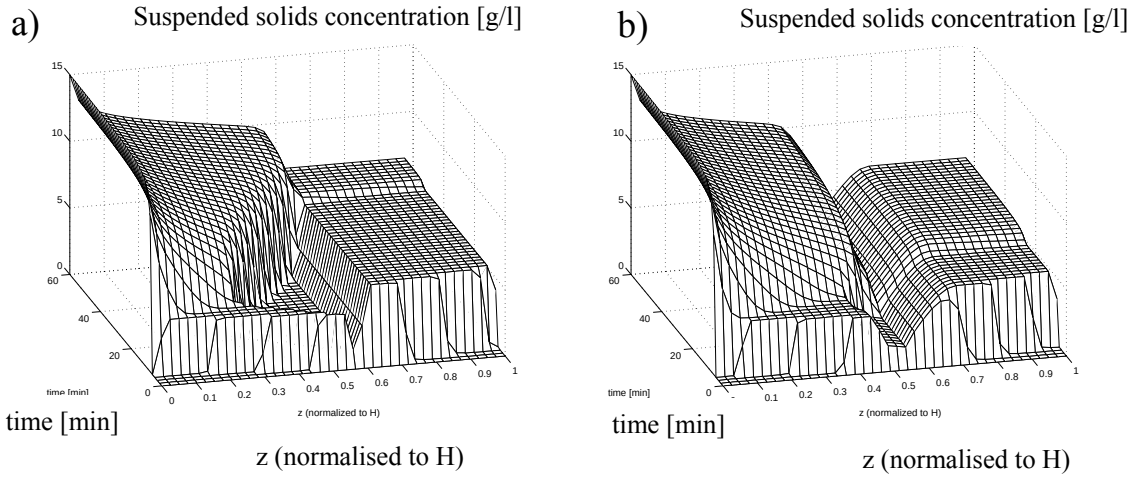


Fig. 3. Q_f=500[cm^3/min]; Q_r=50[cm^3/min]; X_f=6 [g/l]; a) feed zone with 1 layer; b) feed zone with 21 layers.

Figure 3 presents simulation results for the model with one feed zone layer (a) and 21 feed zone layers (b). The distributed feed model is thus compared with the standard point source model. In can be observed that the steady state values of X_r and X_e are identical for both models. The traditional models are considered accurate enough for predicting the general behaviour of the continuous settler. However, the dynamics of the settler and the steady state concentration distributions in the settler are different. As expected, the greatest differences are within the feed zone. In the traditional model a discontinuity of concentration is present (Figure 3a) which is eliminated in the proposed distributed source model (Figure 3b).

MEASUREMENT SYSTEM GROUP

RESEARCH ACTIVITIES

The research activities of the Measurement System Group are concentrating in the following main topics:

- Theory of Physical and Technical Measurement,
- Modelling of Measurement Signals and Systems,
- Principles of Industrial Measurement for Control Applications,
- Sensors and Sensor Interfaces,
- Methods of Calibration of Sensors and Measurement Instruments,
- Electrical Apparatus for Potentially Explosive Atmospheres; Intrinsically Safe Systems,
- Reliability, Functional Safety,
- Fuzzy Logic in Decisions Making.

Research on electrical apparatus for potentially explosive atmospheres; intrinsically safe apparatus and systems; sensors; reliability; functional safety

J. Frączek

The research problems of sensors (intelligent sensors, transducers and transmitters), apparatus and systems designing, including optical equipment (the measuring systems using laser and fibre optics), when they are destined for using in potentially explosive atmospheres. The main topics of these problems concern:

1. Sources of explosion hazards,
2. Characteristic parameters of intrinsic safety,
3. Classifications of apparatus and locations, grouping of gases, vapours, dusts and fibres,
4. Spark test apparatus,
5. Testing the intrinsically safe conditions,
6. Connecting lines in intrinsically safe systems,

7. Problems of reliability in intrinsically safe systems,
8. Reliability models of intrinsically safe systems and safety factors,
9. Functional safety,
10. Designing of intrinsically safe apparatus and systems,
11. Intensive sources of light in potentially explosive atmospheres,
12. Adoption of European Directives (ATEX 100A and ATEX 137) and Harmonized Standards in Poland, concerning apparatus and systems for potentially explosive atmospheres.

Research on industrial measurements; mathematical modelling of flowmeter sensors, flow measurement, radiation measurement, fundamentals of measurements

S. Waluś

1. Mathematical modelling of flowmeter primary devices,
2. Metrological optimisation of sampling flowmeters,
3. Construction of ultrasonic flowmeters and averaging impact tubes,
4. Measurement of flow-rate in closed conduits and in open channels,
5. Sensors of non-electrical quantities,
6. Didactic of metrology,
7. Fundamentals of measurements,
8. Radiation measurements and radiological protections,

Research on methods of calibration of sensors and measurement instruments

J. Żelezik

Calibration system for pressure sensors and transmitters

The pressure sensors system (Fig.1) is based on the set of IEEE-488 controlled measurement instruments linked with personal computer, which takes complete control of the calibration (acquisition, analysis documentation and presentation). It measures metrological characteristics, intrinsic and temperature errors of pressure sensors and transmitters. An accuracy of the pressure calibrator is 0.04 [%] in two ranges: 20 [kPa] and 200 [kPa].

The system also enables temperature errors compensation for silicon piezoresistive pressure sensors. It can be used in production process of sensors. In this process the most important are: compensation of errors and normalization of characteristics. These are made in three stages:

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

This system enables to carry on a similar research of pressure sensors with standard signals 4-20 mA and 0-20 mA. He was repeatedly used in research works for the industry.

Fig. 1. Calibration system for pressure sensors and transmitters

Methods of primary calibration and temperature compensation in the smart transmitters

In conventional transducer design, calibration and compensation are performed in the analog 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 nonvolatile 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:

- Analog 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 analog domain, without signal quantization.
- 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 analog domain using a D/A converter (DAC).

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. In this processor four digitally controlled analog 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. Up to 120 segments can be used for compensation of zero and F.S. over the operating temperature range. The selection of coefficients for each of the temperature segments is accomplished by controlling the address of the EEPROM with the output of the 8-bit A/D converter driven by the temperature-dependent bridge voltage.

A two-stage procedure of the temperature errors compensation was worked out. In the situation, when temperature errors at the beginning are big and non-linear therefore applying this procedure gives the best results of compensation: in the first stage compensation for linear components of errors (quasi-linear compensation), 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. Experimental examinations carried out for pressure sensors with the span of 100 kPa showed, that it was possible to limit the initial temperature errors of the 3% FSO to the 0.05% FSO level over a temperature range of 0ºC to 50ºC.

At present there is a computer laboratory stand worked out which will connect individual stages of production smart transmitters - pretest, temperature compensation, calibration and final test - into one automated process.

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. Two calibration procedures were analyzed. In the first procedure – classical – coefficients of the processing model of measurement block of the transmitter are estimated. For the reproducing of the measurand the inverse model to the processing model is assumed. In the second method the model for the reproducing of the measurand is estimated directly according to minimization of measuring errors, which are done with using of calibrated transmitter. In this case the quality coefficient used during estimation corresponds with the main goal of calibration.

System of monitoring of climatic parameters in measuring laboratories

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, he is required in particular in accredited measuring laboratories. The whole system was designed and realized from grounds in the Measurements System Group. 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.

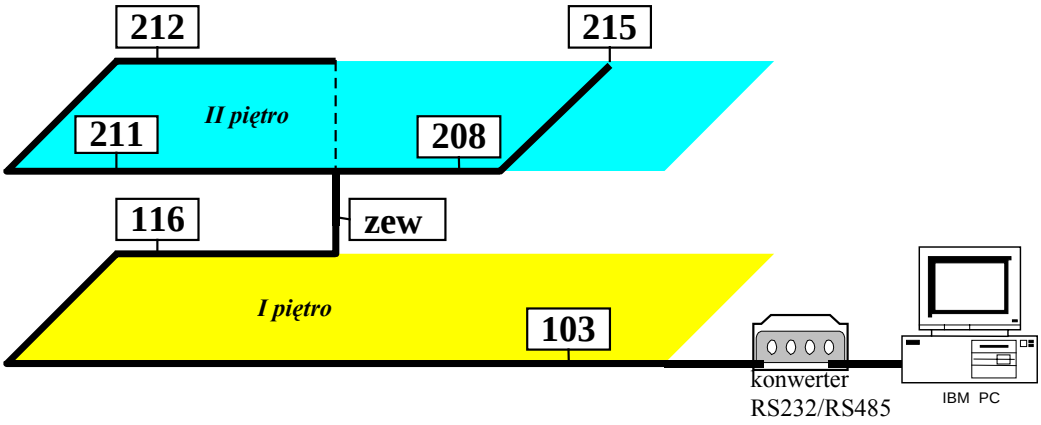
On fig. 1 appearance of one of transmitters installed in laboratories was shown. The most important metrological characteristics are given in the table 1.

Fig. 1. Appearance of the transmitter installed in the laboratory.

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 on fig. 2.



Rys. 2. Arranging elements of the system of monitoring in the building AEiI.

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 internet side: www.zsp.polsl.pl/klimat/petla.htm. 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 on fig.3 and 4.

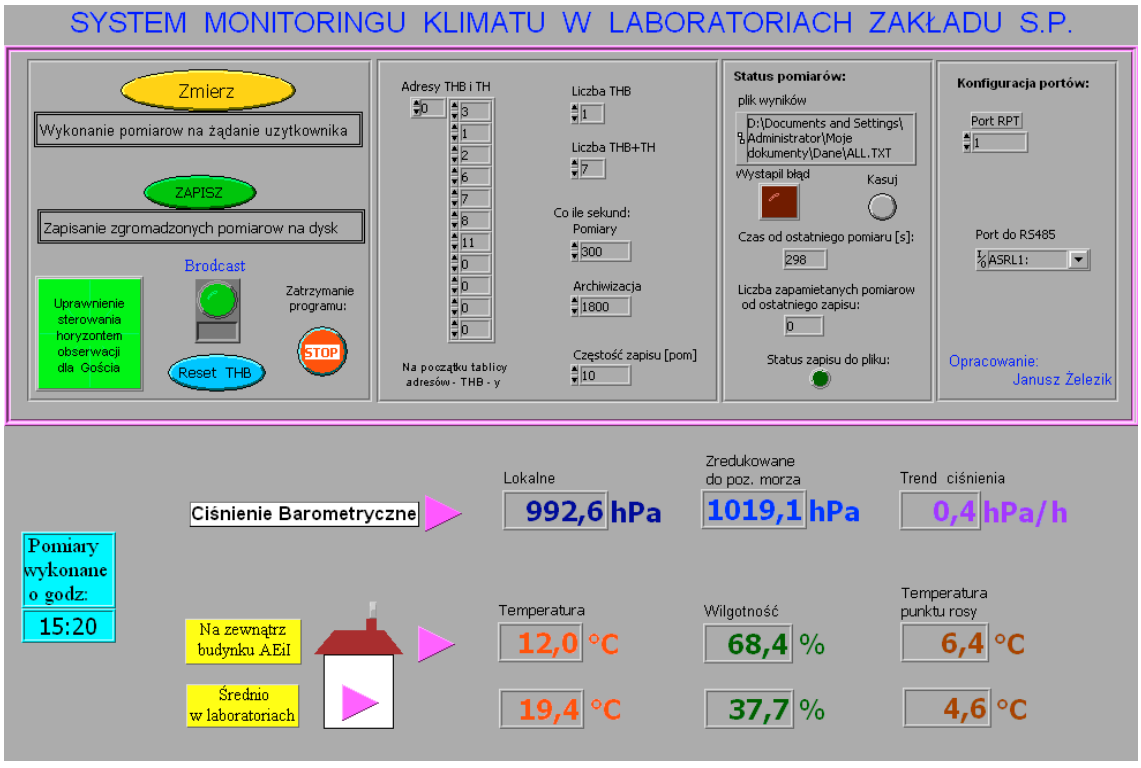


Fig. 3. Configuration and data presentation panel.

Fig. 4. Graphical presentation of results of measurements

Research on Least Median of Squares method in measuring instruments calibration

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.

The research is focused on an assessment of the quality of the LMS regression coefficients. The variance of the LMS regression coefficients is used as a measure of the quality. Procedures of a priori and a posteriori estimation of the variance of the LMS coefficients have been developed. The first procedure allows estimation of the variance of the LMS regression coefficients before making of an experiment. The second procedure is applied where results of the earlier measurement are available.

The problem of the computation of the LMS regression coefficients is also under investigation. There are also examined computational algorithms based on PROGRESS, a genetic algorithm, a simplex method and other procedures.

Measuring interfaces and smart measuring transducers

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 Fig. 1. 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. 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 Fig. 2.

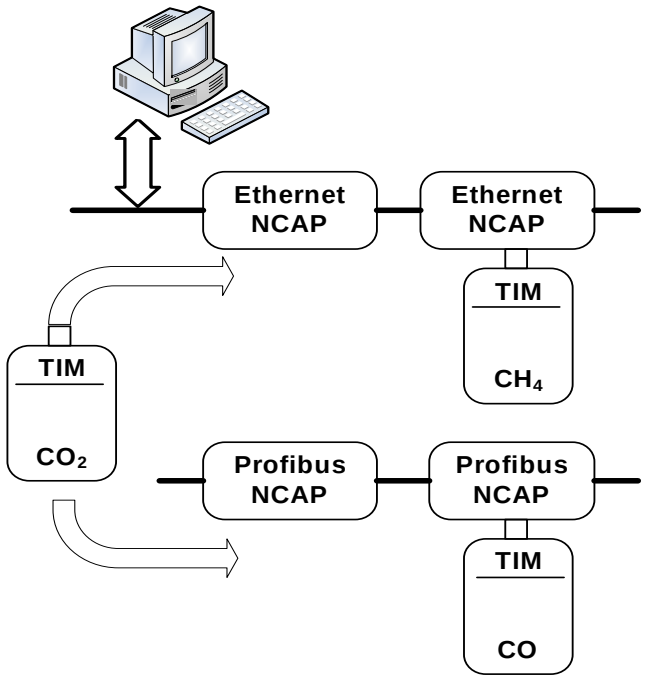


Fig. 1. The concept of the plug-and-play sensors.

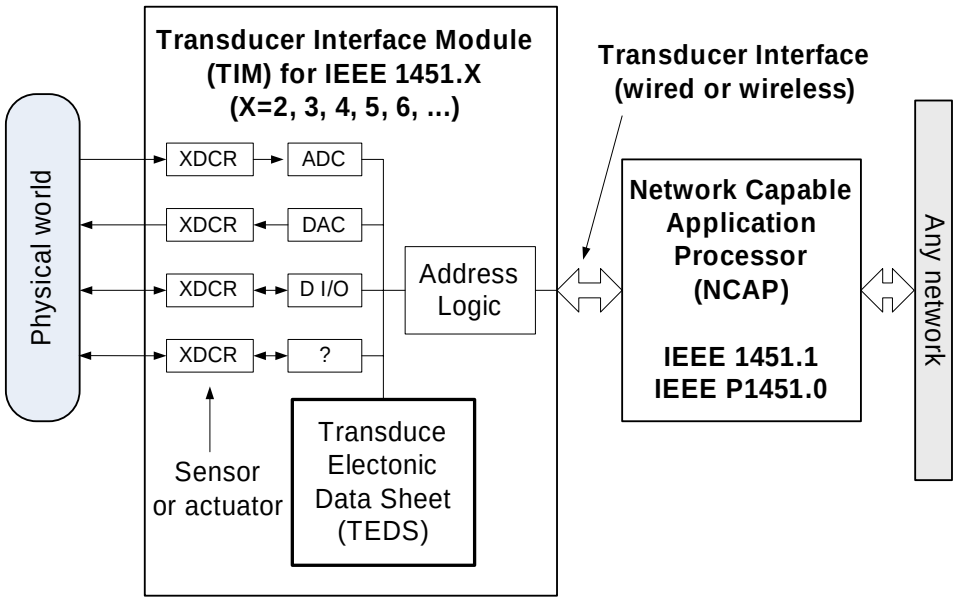


Fig. 2. IEEE 1451 concept diagram. In the case of IEEE 1451.4 the NCAP may be replaced by measuring instrument.

The example of the IEEE 1451.4 measuring system used in our laboratories, consist of PC based computer equipped with the DAQ board and IEEE 1451.4 dedicated input panel with signal conditioning modules for temperature sensors as well as universal feed through modules.

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. 1). In Polish coalmines, 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.

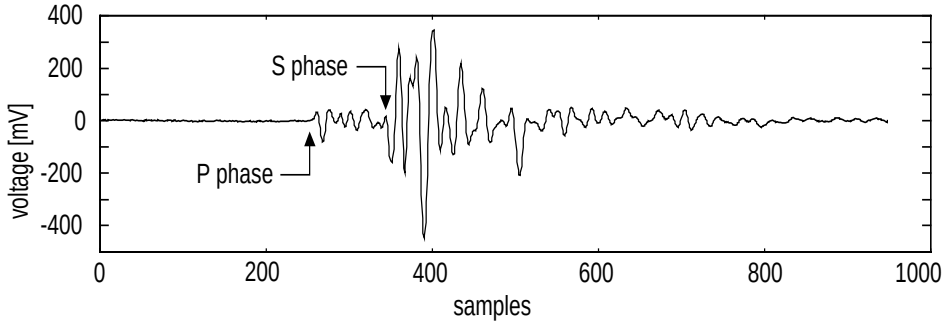


Fig. 1. Example of one-component seismogram registered in a coal mine. The P and S phases times arrivals is depicted

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, which block diagram is presented in Fig. 2.

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 1kHz, and continuously transmitted to the master station (MS). The transmission line length is up to 10km. 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 10J while the strongest events has energy about 1010J. Therefore the dynamic rang is about 90dB, which gives us the required resolution of the A/D conversion at least 15 bits.

[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

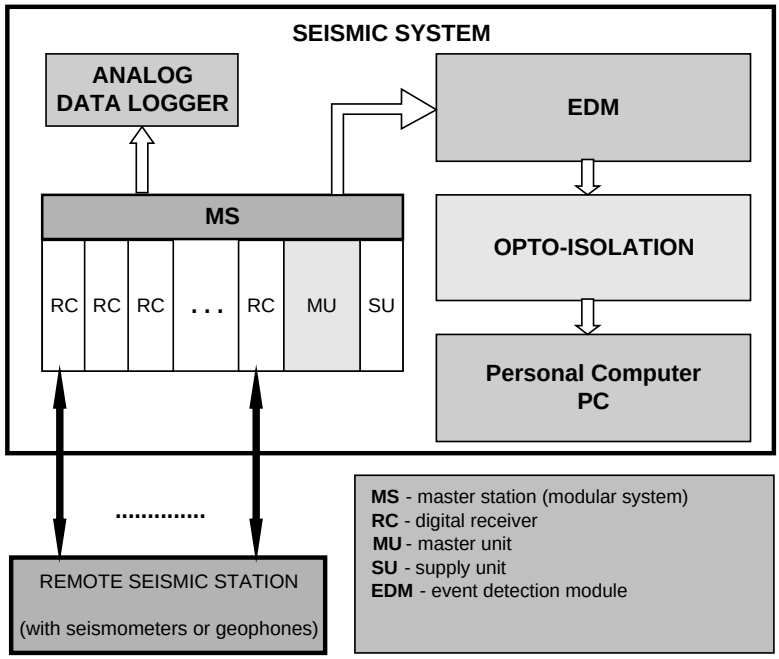


Fig. 2. System for seismic event detection in coal mines

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. 2) 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 and tested the new digital receiver module (RC). In previous version it is equipped with 8bit microcontroller PIC16F677. We have replaced it (to keep the pin-to-pin and software compatibility) with the newer PIC18F458, with built in CAN controller.

In addition the new analog data logger has been developed for the system (Fig. 4). It consist of personal PC and fast plotter. The PC is used detect the seismic event and sent it to the plotter. The logged data are presented also on PC visualization panel (see Fig. 5). The advantages of the new data-logger are as follows (in opposition to older one):

- better printout legibility of the seismic signals,
- additional information about seismic events available on print outs,
- recording of the seismic events on the PC hard disc for future analysis,
- elimination of the external delay line (required for proper print out on older data logger),
- elimination of the external seismic event detection module.

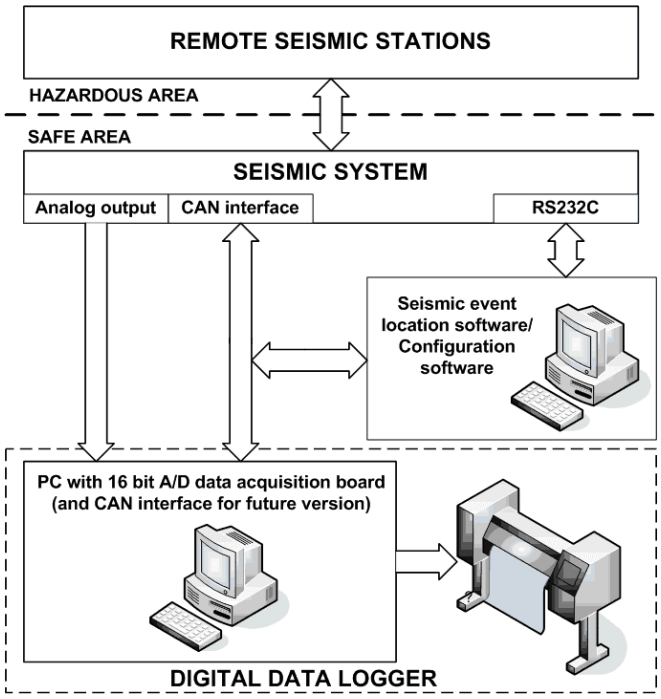


Fig. 4. Seismic system with new digital data logger. The CAN interface is for future version of the seismic system

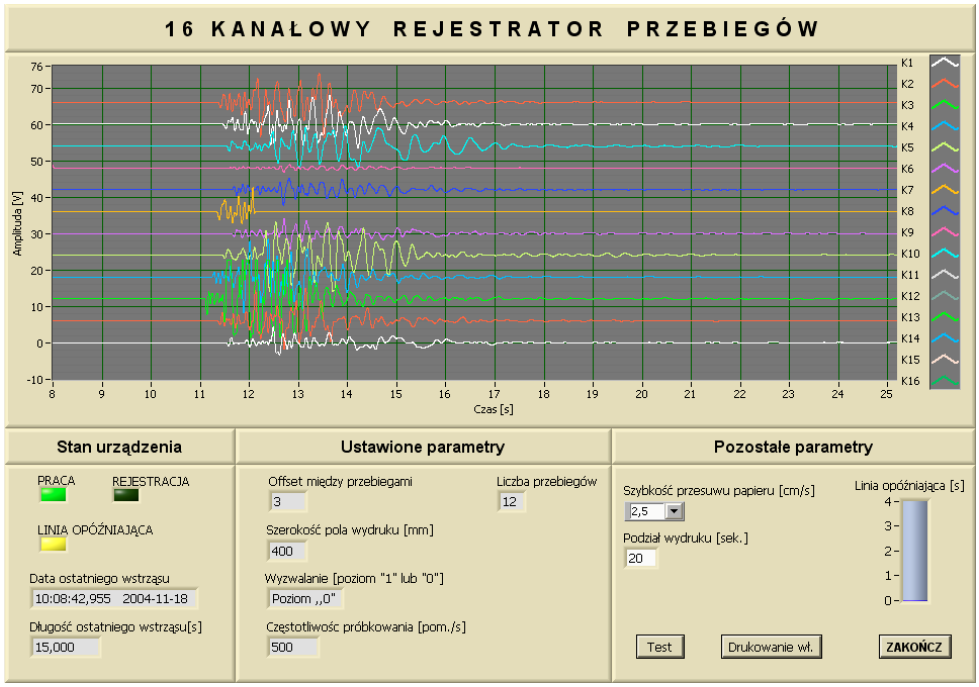


Fig. 5 Visualization panel of the new analog data

Acceleration transducer for biomedical applications[2]

R. Wyżgolik and D. Buchczik

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 Fig. 1 and the view of the transducers is presented in Fig. 2. 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.

Table 1 Short specification of the applied monolithic accelerometers. (amax – acceleration range, S – nominal sensitivity at 0 Hz, for power supply voltage 5 V and 3,3 V for MMA7260Q, fmax – 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

Calibration of the transducers is performed using a calibration set-up, whose schematic diagram is shown in Fig. 3. The view of the calibration set-up is presented in Fig. 4. The test stand 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 6221data 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

[2] Research performed in cooperation with S. Pietraszek from Institute of Electronics, Silesian University of Technology

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 tiaxial mount.

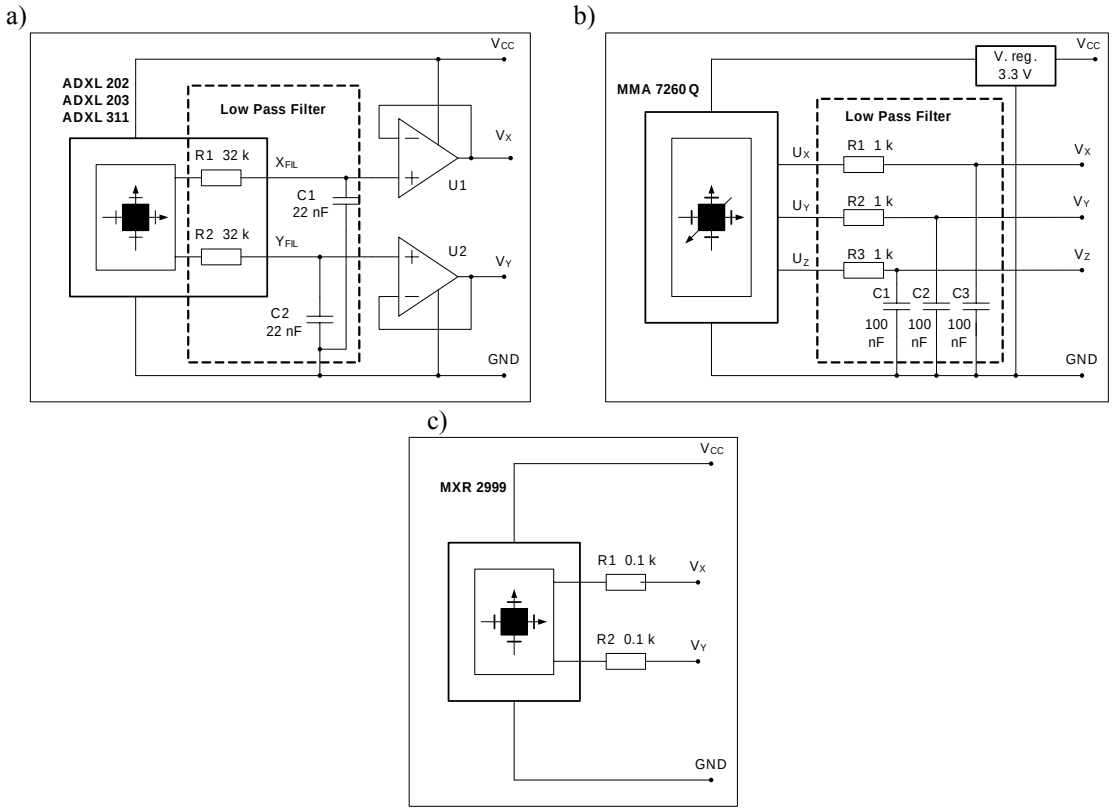


Fig. 1. Board schematic for acceleration transducers: a) based on ADXL 202/203/311, b) based on MMA 7260Q, c) based on MXA 2990.

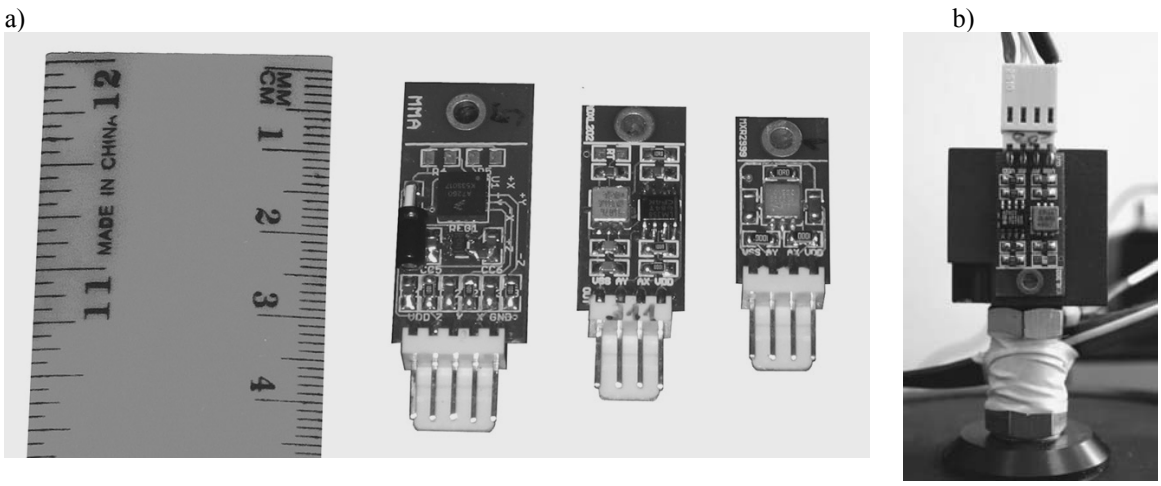


Fig. 2. Acceleration transducers: a) from left, based on: MMA 7260Q, ADXL 202, MXA 2990, b) view of the ADXL 203 based transducer on the calibration set-up

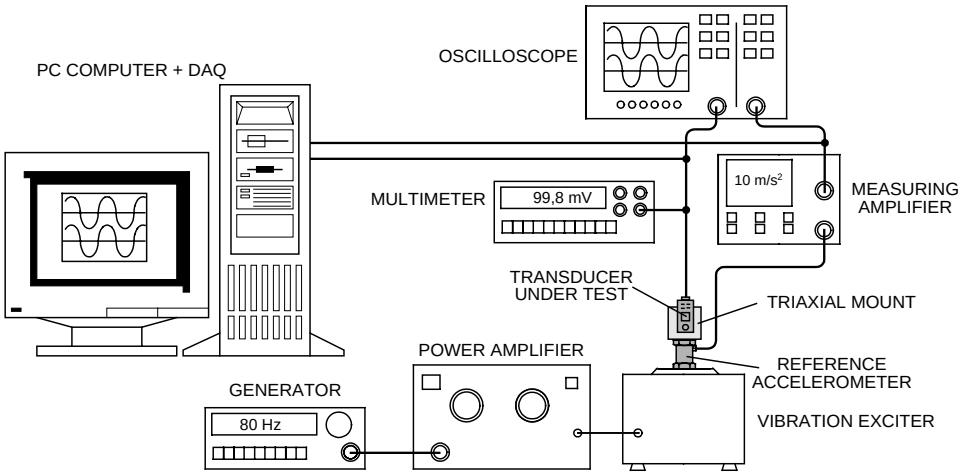


Fig. 3. Diagram of the calibration set-up.

Fig. 4. View of the calibration set-up.

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, 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.

Fig. 1. Chromatographic stand with Varian 3800 Gas Chromatograph

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.

Research on principles of industrial measurement for control applications Measurement of proprieties of Ion Selective Electrodes for multi-component measurements purpose

J. Frączek, A. Kozyra

The application of chemo-metrics in multi-component analysis is rapidly expanding area of analytical chemistry. Ion Selective Electrodes (ISEs) have found use especially for the direct determination of ionic activity in biological samples (food, blood, serum, urine) and determination of the water quality. The potential of the ISE depends on chemical activities of particular ions in a solution.

A typical measurement, using the ISE, needs a specially prepared sample to eliminate interference of other ions on which this electrode also reacts. Recently, more selective electrodes can be used to determine ion activities of multi-ion samples. In multi-component measurements (MCM) an array of multiple electrodes is applied. Each electrode reacts on many other ions in solution. The relationship is described by an empirical Nikolsky-Eisenmann equation (Fig.2b). The potential of an ion selective indicator electrode is measured against a reference electrode, the potential of which should remain constant. When we know the parameters of electrodes, we can estimate the amount of ions in the sample. But before the measurement, the calibration of electrodes array is necessary, because the parameters of electrodes could change.

The adequate accuracy is required in the measurements, number of measurements and complicated procedure of calibration requires a special stand for the MCM (Fig.1). The stand consist of the ISEs and a temperature sensor, a signal conditioner, 16-bit A/D with microprocessor based communication module. All data are acquired by computer. A special calibration and ion activity multi-component measurements procedures are implemented. Typical electrode characteristic is shown on Fig. 2a. Each electrode is characterised 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 different factors which influence electrode potential such as temperature, electrode potential drift and contamination of the electrode membrane.

It is very important to recalibrate them with the proper frequency. For this purpose a set of reference solutions must be prepared, in which the activity values of individual ions, have to cover the whole range of activities assumed to appear in the real solution.

a)

b)

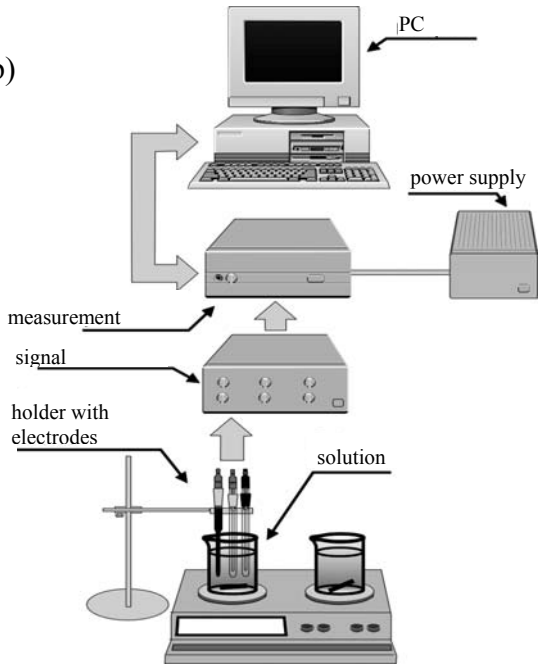
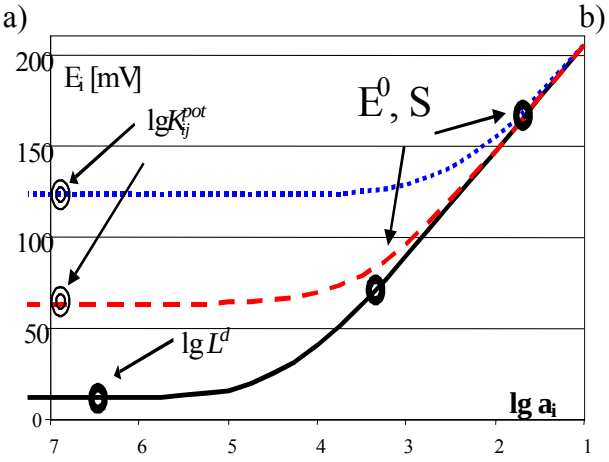


Fig. 1 The stand for multi-component ion-selective measurements:
a) photo, b) schematic draw.



$$E_i = E^0 + S \cdot \lg\left(a_i + \sum_j K_{ij}^{pot} a_j^{z_i/z_j} + L^d \right)$$

where:
- E_i - SEM of electrode
- a_i;a_j - ions activities (main and interference)

calibration parameters:
- E^0 - reference potential
- S - slope
- K_{ij}^{pot} - selectivity coefficients
- L^d - limit of detection

Fig. 2. a) Characteristic of Na^+ electrode potential in pure NaCl solution (black solid line) and in presence of interfering ion (NH_4^+ pX=0.7 or K^+ pX=2 dashed red and dotted blue line respectively). There are examples of calibration points used for calibration. b) ISE electrode model used for measurement analysis.

In our investigations new calibration procedures are developed and tested to find simpler and more suitable procedures for MCM measurements. Procedures where different ISEs (electrodes selective on different ions) are calibrated simultaneously in the same calibration solution.

Evaluated parameters of electrodes are used for determination of ion activities in many aqueous solutions (mineral, tap water, dissolved ground samples, dissolved medicine pills, tooth-paste etc). Not only activity but also uncertainty of measurements had to be evaluated – it is very important because in the same situation the direct MCM are impossible due to masking proprieties of interference ions.

Research on metrological properties of models describing Ion-Selective Electrodes

J. Frączek, J. Wiora

Ion-selective electrodes (ISEs) are electrochemical sensors constructed for potentiometric determination of the activity or concentration of certain free ions in the presence of other ions, which are dissolved in a solution, usually aqueous one. A measured signal of the electrode is its potential, which is dependent mainly on the logarithm of activity of the *primary ion*, to which the electrode is sensitive. The ISE's response is also influenced by temperature and activities of other ions present in the solution, called *interfering ions*.

Ion-selective measurements performed by using ISEs allow one to determine the activity by measuring the potential difference between two electrodes. Due to some specific properties, this analytical method cannot be replaced with any other one. The main properties are: the direct measurements of ion activity in given solution, possibility of the continuous measurements and possibility of making the *in vivo* measurements.

The potential difference is unfortunately not directly connected with concentration (molarity) of the determined ion. The potential is dependent on activity of the primary ion, as well as on activities of other ions present in probed solution and on temperature. There exist several models in the literature describing the relationship. The models are nonlinear and consist of several parameters, such as: the limit of detection, the Nernstian slope and the potentiometric selectivity coefficients. The ion activity is connected with molality by the activity coefficient, which can be expressed by very simple models, but not accurate, or by one of two very complex ones. The molality and the molarity are also related with each other by some models. Additionally, the liquid-junction potential of reference electrode should also be modeled. All of above makes that the measurements are not as easy as they may appear.

The research concentrates on the ordering of the already known static models of the phenomena which take place during the measurement. Large number of parameters influence on the result. However, if the given maximum measuring accuracy is assumed, it is not necessary to take into consideration all of these parameters. Otherwise, the model would become unnecessarily complex.

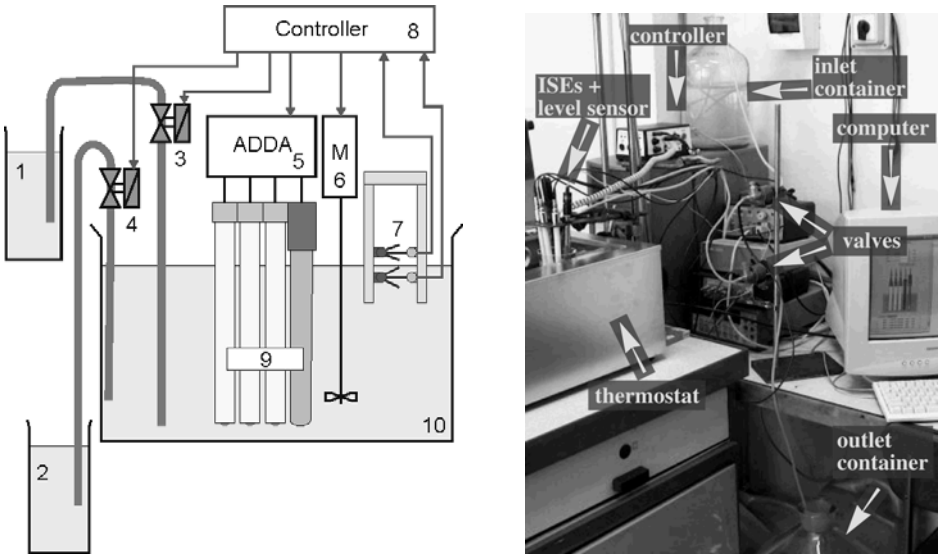


Fig. 1. Schematic diagram of the measuring set-up and a photo illustrating the system in the laboratory. 1. Inlet container. 2. Outlet container. 3. Electric inlet valve. 4. Electric outlet valve. 5. Data acquisition system. 6. Stirrer. 7. Dual optical liquid level sensor. 8. Control device. 9. Measuring electrodes.

The research consists in the calculation and simulation of the value of the measured quantity *vs.* the changes in influence parameters. In this way the final accuracies can be estimated. In the next step, the application criterion of models are formed. The nature of studied phenomena is strong nonlinear, hence there are many difficulties, *eg*. the determination of the calibration coefficients that can be obtained either by numerical solving the nonlinear equations or by using the artificial neural network. The studied theories are verified by experiments. A special system for automatic determination on the characteristic shapes of ISE has been built (presented in Fig. 1). It allows determining the shape using multiple dilution method in an automatic way. The set-up is not expensive and the presence of experimenter in the laboratory is not necessary during the test of the electrode. Additionally, the system allows for simultaneous investigation of several electrodes.

Research on dynamic behaviour of the Ion-Selective Electrodes

J. Frączek, A. Wiora

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 the response time t_{90}, which is defined as a time, within the electrode achieve 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 on external factors (temperature and flow of the sample, time constant of the measuring instruments).

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

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

The measuring set-up contains three elements (Fig. 1): a flow-cell with a measurement cell (1), data acquisition system (2) and PC computer (3).

The flow-cell consists two blocks made from Plexiglas. The first one is a block **A** of measuring duct, the second one is a block **B** of valve. Two electrodes (diameter 12 mm) are mounted into block **A** making measuring cell. A duct (diameter 5 mm) has been drilled through the block. The block is made in such a way that only electrodes' membranes are placed in the duct. The block **B** has three ducts: two inlets and one outlet. All of the ducts are placed coplanar. The movable part of the block (frustum of a cone) perfectly fits to the whole of the immovable part. The cone has drilled two parallel ducts. The change of inlet is done by a rotation of the movable part. Photography of the flow-cell is in Fig. 2. Two electrodes are shown there, which are fastened using special screws. In the front two diodes of the optical sensor are visible. On the right side is the block **B** with a handle of the movable part.

The data acquisition system (DAS) has been designed and made in the Measurement Systems Group of the Silesian University of Technology. The present version posses four inputs for ISEs, one input for reference electrode and one for Pt-100 temperature sensor. The electrical circuit is built of: 1) signal conditioner – impedance converter, anti-aliasing filter and temperature to voltage converter: 2) 16-bit a/c converter with analogue multiplexer: 3) digital elements – microprocessor, parallel communication interface: 4) power supply adaptor – +15V, –15V and +5V. DAS while working in the dynamic mode allows to measure four voltages with frequency from the range of 1 to 5,000 Hz for each of inputs and to transmit the results from DAS to the PC.

The optical sensor is built of two pairs of LEDs. The measurement of the flow is realized by dyeing one of the samples flowing into the flow-cell's inlet. Analysing the response registered by DAS, makes it possible to identify the time of the change in solution colour in the point of placing the LEDs and to determine the flow rate.

The set-up contains also a PC computer. It is dedicated to reading the data from DAS and storing it on a disk. 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 10% for t_{90} for measurements made at the same conditions.

Exemplary dynamic response of the optical sensor and ISE obtained from the measuring set-up is presented in the Fig. 3.

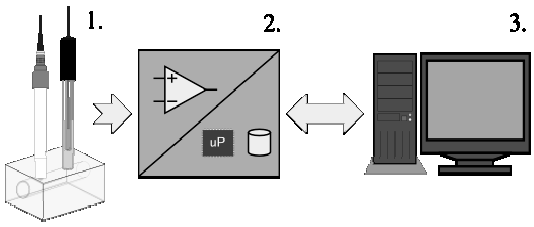


Fig. 1. Block diagram of the measuring set-up

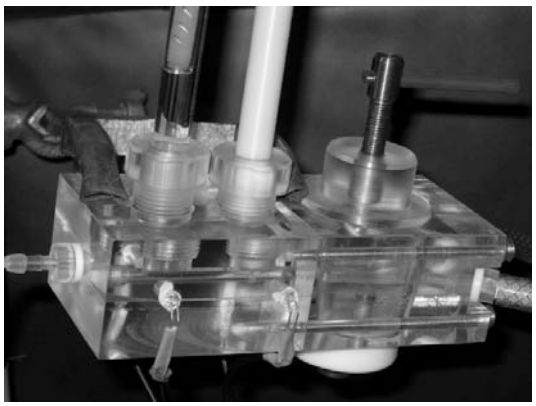


Fig. 2. A photo of the flow-cell dedicated to the research on dynamics of ISEs

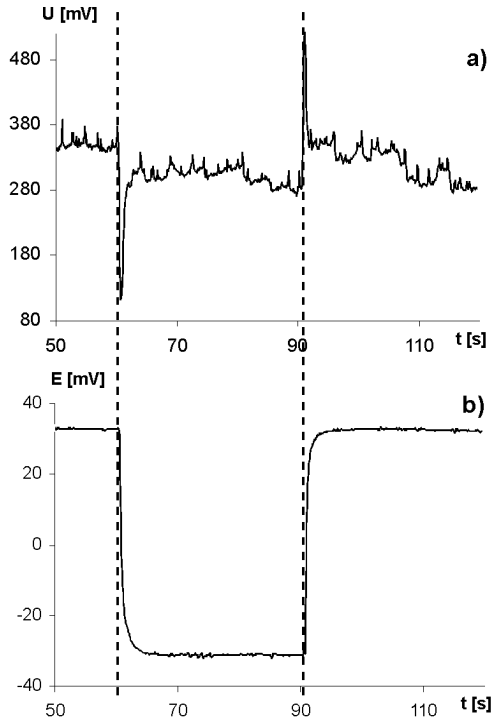


Fig.3. Dynamic response of a) the optical sensor, b) an ion-selective electrode

Use of fuzzy logic to support an operator of monitoring system of coal mine atmosphere.

J. Frączek, T. Grychowski

In the thesis the use of fuzzy logic and its inference mechanisms to effectively support an operator at monitoring coal mine atmosphere are presented. 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.

A few options of the automatic decision support system have been build as well as the chosen mechanisms of fuzzy inference system which influence the results of inference have been compared. The property of the Author's system have been compared to the already existing systems. The laboratory system was build to control the physical parameters of the air – fig 1.

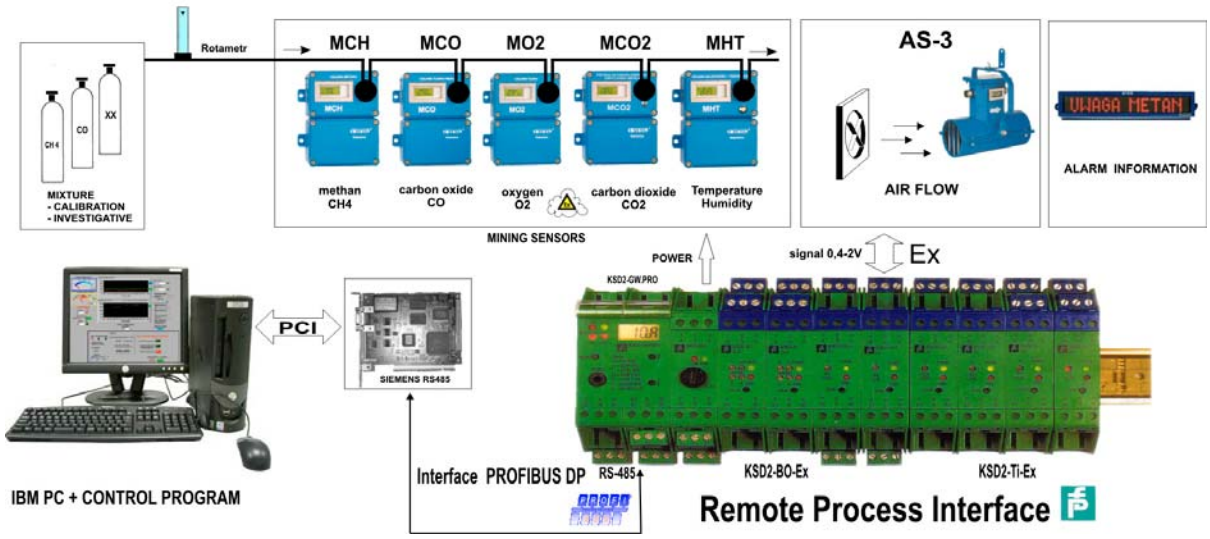


Fig 1. The laboratory system with mining sensors and intrinsically safe system.

The measuring experimental installation includes the "Remote Process Interface" intrinsically safe system and mine sensors to control toxic and combustible gases which appear in mine atmosphere. This system enables simulation of gas hazards, testing software supporting the operator 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 2 presents example of tuning panel of fire support system created on the basis of the information from an human-expert and recorded in the language so-called linguistic rules which is comprehensible to him. 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.

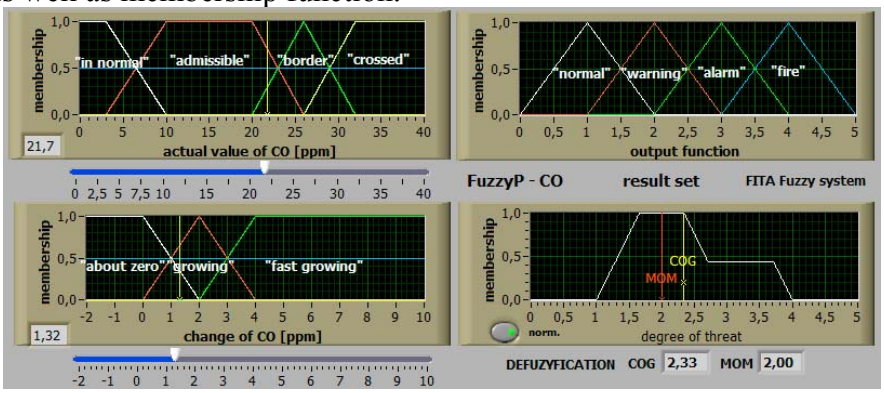


Fig 2. Tuning panel of fire threat support system in labVIEW environment.

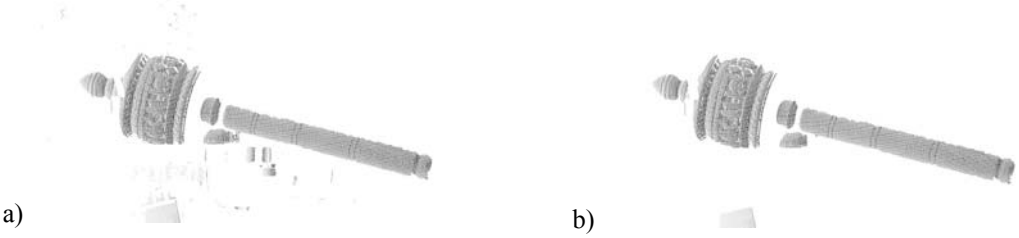
Research on methods for three dimensional measurement data conversion

K. Wojciechowski, S. Budzan

With the increasing use of 3D scanner and the growth in complexity of this models, the necessity of robust method for denoising 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, with applications in many disciplines.

Cloud of points often requires some of pre-processing methods, e.g. elimination of bad points, smoothing, decimation, triangulation. The most common reasons for such situations are: undesirable background geometry measured with the object, badly illuminated points or surface with not acceptable noise.

At first effective and robust noise reduction (Fig.1) in three dimensional measurement data algorithm has been analysed. Often the noise source are optical elements from the 3D scanner. This noise commonly is the separate groups of points with high amplitude or single points with low amplitude. Main idea of applied algorithm depends on maximize distance – distance between points in three dimensional space – nearest neighbours in sliding 3D window. The proposed and analysed filter class is based on the nonparametric estimation of the density probability function in a sliding filter window. Modification of decimation algorithm has been also analysed. Main idea of proposed algorithm depends on adding a priori decimation level – number of the data points, which must be deleted from the dataset.



a) b)

Fig.1. Noise reduction algorithm. (a) – original image – 41938 points, (b) – image after filtration – 35067 points.

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 poor properties of the Hough transform stood themselves cause of proposing of the new hybrid algorithm for detection of 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 region growing which increase the efficiency of the algorithm.

Currently, the main destination of the research is to optimization of the algorithms for segmentation the 3D scanner data. The application is still under development.

ADDITIONAL INFORMATIONS

The members of MS Group are involved in several science and research societies:

J. Frączek:

- Commission of Metrology of Katowice Branch of Polish Academy of Science (chairman),
- Polish Society of Sensors Technology (member),
- Editorial Board of national journal: Mechanizacja i Automatyzacja Górnictwa (member),
- Editorial Board of national journal: Elektronika(member),
- Polish Committee on Automation of Mines and Quarries (PCAMC) (member).
- National Elaboration Group for the Polish Edition of the Directive ATEX 100A (member),
- Polish Standardization Committee, Technical Commission No 64: Electrical apparatus for potentially explosive atmospheres (member),
- The Quality Assurance Council of the Certifying Body at the Central Mining Institute (chairmen),
- The Quality Assurance Council at the TÜW Nord Poland plc Katowice (chairman),
- Chairmen of the National Conferences: 1). IX Conf. ZONA'2005 "Selection of electrical apparatus in potentially explosive atmospheres". 2). X Conf. – ZONA'2006 – "Safety of objects in the fire zones and in the potentially explosive atmospheres". 3). ENERGO-EKO-TECH'2005 Conf. on "The law status in Poland in the context of the ATEX 100A Directive".

S. Waluś:

- Commission of Metrology of Katowice Branch of Polish Academy of Sciences (secretary),
- Polish Society of Sensors Technology (member),
- Polish Society of Metrology (member).

J. Żelezik, R. Wyżgolik, W. Ilewicz, D. Buchcik, A. Kozyra, A. Wiora, J. Wiora:

– Commission of Metrology of Katowice Branch of Polish Academy of Sciences (members).

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

Molecular Genetics at the Institute of Automation

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 .

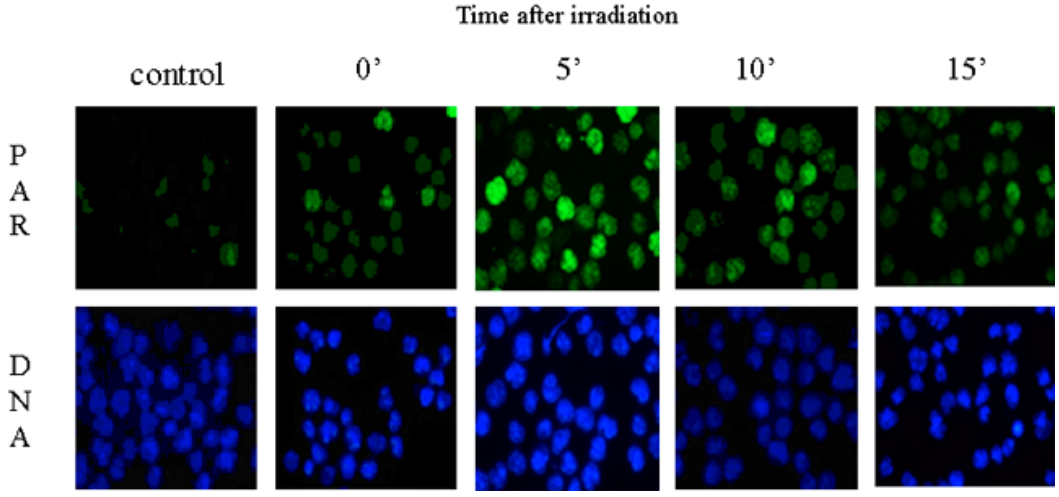


Fig. 1. The synthesis of poly(ADP-ribose) (PAR) in Raji cells exposed to X-rays. Upper row shows labelling with anti - poly(ADP-ribose) antibody in control cells and at different time after exposure to X-rays, and lower row the same cells stained with DAPI dye that stains DNA

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 .

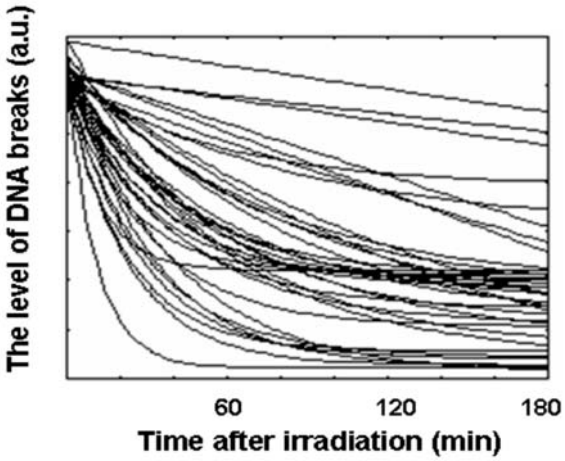


Fig. 2. Interindividual differences in DNA repair. Lymphocytes obtained from the blood samples of individual donors were irradiated and the level of DNA breaks was measured by comet assays at different times after irradiation. Each curve shows the results obtained for lymphocytes of one individual donor.

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

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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).

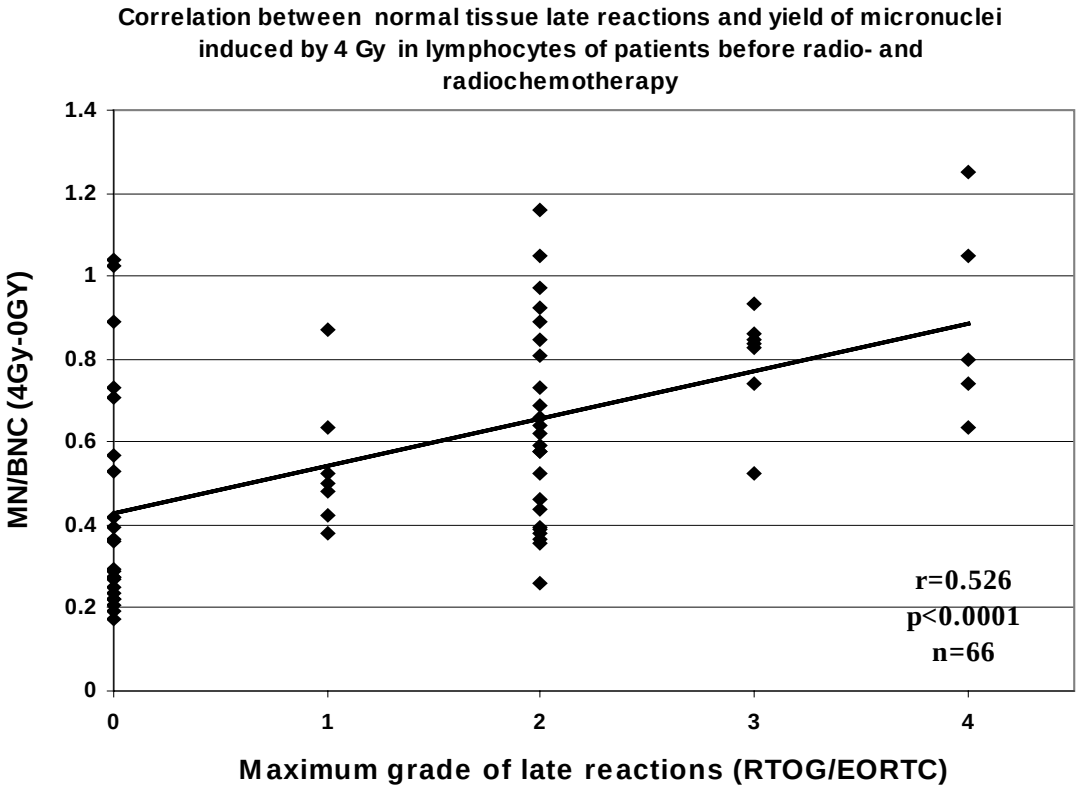

Fig. 1. Correlation between normal tissue late reactions and yield of micronuclei induced by 4 Gy in lymphocytes of patients before radio- and radiochemotherapy

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 (Fig.2), 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.3). 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.

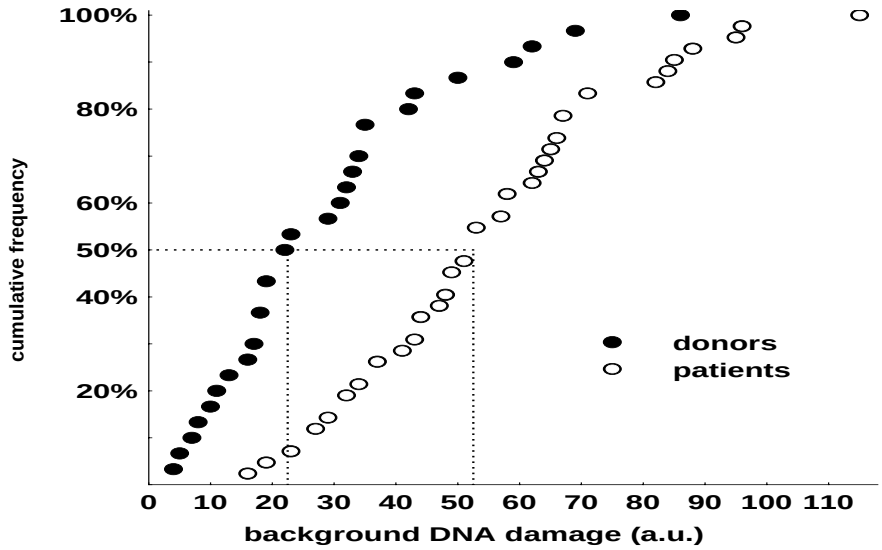

Fig. 2. Cumulative frequency distribution of basal DNA damage in lymphocytes of patients with cervical carcinoma (n=42) and of controls (n=30). The median values are significantly different at p=0.000005.

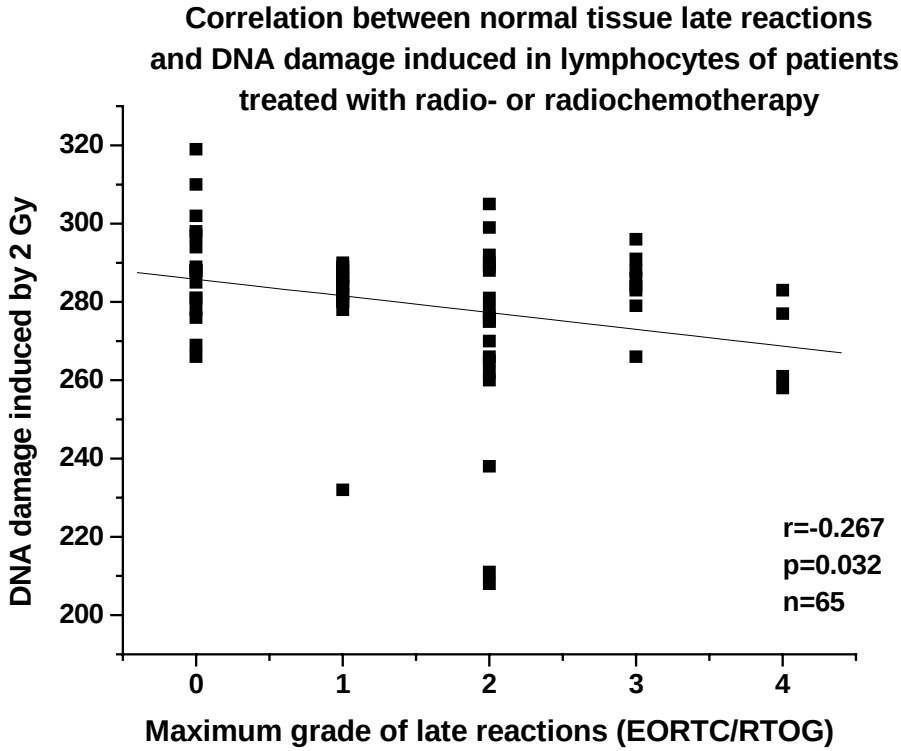

Fig. 3. Correlation between normal tissue late reactions and DNA damage induced in lymphocytes of patients treated with radio– and radiochemotherapy

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

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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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[1]Department of Experimental and Clinical Radiobiology, Maria Sklodowska-Curie Memorial Cancer Centre and Institute of Oncology, Gliwice, [2]A.Chelkowski Institute of Physics, University of Silesia, Katowice, [3]Department of Tumour Biology, Maria Sklodowska-Curie Memorial Cancer Centre and Institute of Oncology, Gliwice.

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)*

$^3F^* + RH = FH^{\cdot} + R^{\cdot}$ *(H atom transfer)*

$^3F^* + RH = F^{\cdot -} + RH^{\cdot -}$ *(electron transfer)*

The radical species then reacts with ground state oxygen so that overall the reaction is photochemically initiated autoxidation, thus:

$FH^{\cdot} + {}^3O_2 = {}^1F_0 + HO_2^{\cdot}$

$F^{\cdot -} + {}^3O_2 = {}^1F_0 + O_2^{\cdot -}$

II mechanism *(generation of singlet oxygen, in presence of molecular oxygen)*

$^3F^* + {}^3O_2 = {}^1O_2^* + {}^1F_0$

$^3F^*$ = *excited photosensitiser*

$^1O_2^*$ = *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.

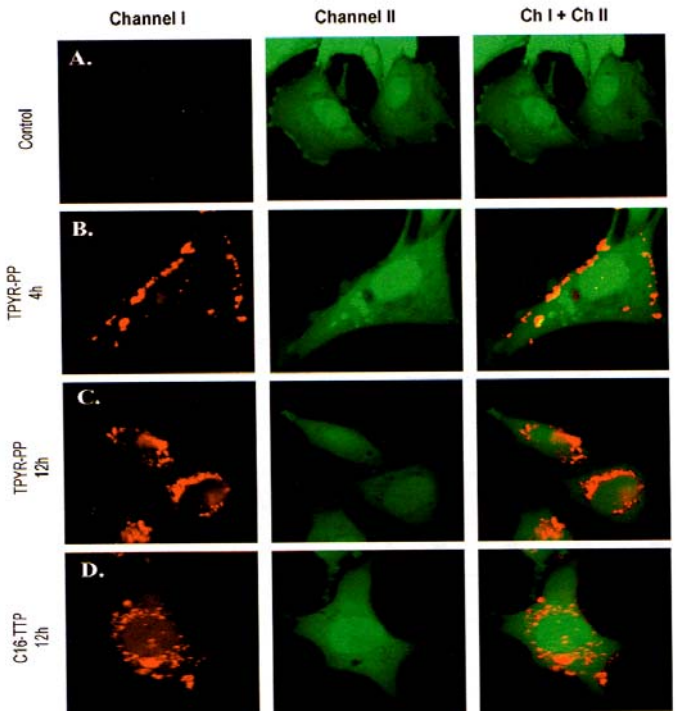

Fig.1. Example of porphyrin localization in human melanoma cells Me45 evaluated by confocal microscopy

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.

Gaussian mixture approach to the analysis of microarray data

J.Polańska, A.Polański

An approach, which has a potential to support analyzing DNA microarray data is mixture modeling of probability distribution of gene expression levels. This approach is based on the empirical observation that probability density functions of gene expressions can be represented by using mixtures of distributions and uses the hypothesis that parameters of approximating mixture distributions contain useful information. Several researches in this field appeared in the literature. Approximating probability density functions (pdfs) of logarithms of expression levels or fluorescence intensities of probes by mixtures of distributions can be used to solve several issues in the interpretation of DNA microarray data. We developed methods for obtaining parameters of mixtures of different distributions and proposes to use mixtures of factor analyzers for unsupervised classification gene expression datasets. The decomposition of expression level probability density functions into Gaussian components can be also

used to set thresholds to classify expression levels as „change", „no change", „overexpressed", „underexpressed" etc. We address the problem of analysis of transient time course data of expression profiles too. Like others we accept the assumption that coexpression of genes can be related to their belonging to the same component. We assume that parameters of Gaussian components, means and variances, can differ between time instants. However, the gene composition of components is unchanged between time instants. For such problem formulation we derive the appropriate version of the Expectation Maximization (EM) algorithm recursions for estimation of model parameters. We apply the derived method to the data on gene expression profiles of human K562 erythroleucemic cells and we discuss the obtained gene clustering.

Inferring cause – effect relations from gene expression profiles

A.Polański, J.Polańska

Comparisons of gene expression profiles in cancer and normal cells, abundant in the literature lead to discovering and publishing lists of differentially expressed genes and to large collections of cancer–versus–normal gene expression profiles available in electronic databases. Data on cancer–versus–normal expression profiles support the research in carcinogenesis in the sense that they confirm and/or verify existing knowledge on roles of genes in neoplastic transformations and they provide genes – candidates for further studies. It should be, however, noted that at present for most of discovered differentially expressed genes, their roles in neoplastic processes are unknown. When analyzing lists of differentially expressed genes in cancer – versus – normal comparisons, a question arises on causality of relations implied by the detected differences. If a gene is expressed differentially in cancer and normal cells, then is it a cause or rather an effect of the ongoing neoplastic transformation? This question is of great importance. Knowledge on the distinction between causes and effects among differentially expressed genes, not only supports researches on their potential roles in tumor biology but also helps in developing diagnostic and prognostic clinical tests based on measured gene expressions.

Data on expression profiles of normal versus cancer cells are of observational type where there are no experimental interventions and there is no time order of signals. Therefore labeling genes as causes or effects of the neoplastic transformation, based solely on their patterns of expressions is difficult and even problematic. Nevertheless, since cause versus effect tests, even with low specificity and selectivity, can lead to improvements in many fields it seems to us that the question stated is worth studying. We developed the methodology allowing to partially answer the questions (i) whether distinction of causes versus effects leaves a signature in the cancer versus normal gene expression profiles and (ii) whether roles of genes, causes or effects can be inferred from repeated measurements of gene expressions. We address the question of causative dependencies by the use of Bayesian networks (BNs), which are natural models for representing multidimensional joint probability distributions. Nodes of BNs correspond to random variables representing measurements or observations, and directed edges correspond to relations between these random variables. Causality relations are implied by directions of (non reversible) edges of BNs. The basic obstacle in using BNs for studying causality relations is the need to estimate the topology of a BN from observations. The problem of estimating topology of BN is difficult, due to the large amount of uncertainty and to serious computational complexity even for BNs of very

moderate sizes. Therefore we take a different approach of constructing a declarative BN, which models a scenario of triggering neoplastic processes by altered gene expressions. In the next step we solve the node assignment problem for the constructed BN. The assignments of genes to the nodes of the BN imply their classification as causes or effects. Applying our methodology to real gene expression data from cancer – versus – normal comparisons confirms that our BN models have the ability to explain some aspects of observational evidence. Effects of neoplastic transformations are most distinctly seen among genes with the highest power to differentiate between normal and cancer cells. Likelihoods of BNs depend on the biological role of selected genes, defined by Gene Ontology. Also predictions of our BN models are coherent with the set of putative causes and effects constructed based on our data set of papillary thyroid cancer.

Model of evolution at a pair of SNP loci under mutation, genetic drift and recombination

M.Kimmel, J.Polańska

Linkage Disequilibrium (LD) has been one of the most intensely studied subjects in population genetics. Introduction of Single Nucleotide Polymorphisms (SNPs) and sequencing of the human genome seem to be the turning points for these studies. Ubiquity of SNPs and the possibility of anchoring them in the human genome sequence contribute in this trend. Why are we interested in LD? Pragmatic reasons include identification of regions with markers appropriate for disease-association studies. However, there also exist basic questions regarding evolution of the modern human genome which may be elucidated by studying LD. One of these questions is the influence of past demographic trends on current LD. Another question is the age of SNPs. Still another is the relative importance of the basic genetic forces for evolution of LD. Genetic forces responsible for the observed pattern of LD are recombination, genetic drift, mutation and selection. Even if selective neutrality is assumed, joint consideration of the remaining three forces is quite complicated and is usually considered to require simulation methods. These usually are based on the coalescence process and are powerful but computationally intensive. To answer these questions a model of evolution at a pair of SNP loci, under mutation, genetic drift and recombination is proposed where mutation is modeled using a two-state Markov model. The model is extremely fast computationally, which makes possible to review a large number of parameter values and different demographic scenarios in a short time. We obtain estimates of the age of population expansion of modern humans, which are consistent with the consensus estimates. In addition, we are able to estimate the ages of the polymorphisms observed in different genomic regions and we find that they vary widely with respect to their age.

Statistical evaluation of familial risk factors in type 1 diabetes mellitus

J.Polańska

Type 1 diabetes is a juvenile immune system disease that leads to destruction of pancreatic cells and, eventually, to the loss of the ability of insulin production. In many

countries (among them Poland) the incidence of type 1 diabetes has been substantially increasing in recent years. Increasing incidence and unknown aetiology of the disease motivates epidemiological studies of possible risk factors (autoimmunological, genetic or environmental). It is believed that the immunopathogenic process may be triggered by several environmental factors such as viral infections, stress or chemical substances from the air or water. It also seems that susceptibility of a child to the disease can be associated to perinatal factors, e.g. birth weight or parental age at the moment of the child's birth. It is well known that maternal age over 35 years of age results in increased susceptibility of the child to several diseases. So it seems possible that increasing incidence of type 1 diabetes can be at least partly related to the tendency of late motherhood observed more frequently in industrialized countries. However, in order to be precise in statements regarding the growing incidence of type 1 diabetes to increased maternal age at the moment of giving birth to their children, a statistical study must be performed to answer the following questions: (i) are children born from mothers over 35 years of age exposed to increased risk of being affected by type 1 diabetes?, (ii) how does this risk depend on mother's age at the moment of child's birth? Statistical research on familiar risks for type 1 diabetes must be rather carefully designed, due to the existence of the mechanism of bias in estimating levels of risk resulting from different susceptibilities to risk to type 1 diabetes of children born in different birth order in the family. In order to avoid bias, maternal age must be analyzed in parallel with other risk factors, specifically with the child's birth order. Several approaches could be applied for estimating risks: contingency tables and odds ratios, logistic regression and, most general, non - parametric models with moment estimators for coefficients.

The EM algorithm and its implementation for the estimation of frequencies of SNP-haplotypes

J.Polańska, M.Kimmel

Much of recent research in clinical genetics relies on resolving genetic structure of complex diseases (traits). Complex genetic traits are linked with DNA loci located in multiple regions in the genome. Eventually, the studies will allow associating risks for complex diseases with sets of specified haplotypes. Problems to be solved to achieve this aim stem from necessity to carry out large population-based studies and to collect large amount of data, and necessity to develop robust and efficient numerical algorithms for haplotype reconstruction from unphased genotypes. The first practical approach to solve the problem of haplotype reconstruction from unphased genotype data was a parsimony - type method. Necessity to better use the information contained in the collected samples led to the increased interest in maximum likelihood estimates of haplotype structure. However, the likelihood function associated with samples of unphased genotypes with underlying haplotype structure is complicated and cannot be maximized by standard techniques. A breakthrough was the application of the Expectation Maximization (EM) method to maximize the likelihood of observed genotype data. Due to the interest in haplotype blocks, coming from the abundance of SNP data, the problem of accuracy and reliability of haplotype reconstruction methods significantly gained importance. Despite many studies on the properties of the EM algorithm, several problems related to its application are still unsolved. Among the most important are: determining the speed of convergence, sensitivity to the stopping

criterion and existence of multiple local maxima. We have developed a Matlab - based implementation of the EM method. Using our program we study and illustrate several aspects of the EM application: speed of convergence, reliability of estimates, and existence of multiple solutions.

The mathematical modelling of the dynamics of DNA repair.

J.Polańska, J.Rzeszowska

DNA single-strand breaks (SSBs), resulting from γ-irradiation are usually quantified by single-cell gel electrophoresis (commet assay). We propose the data for the SSB levels measured immediately after irradiation and during repair for each individual to be fitted by the Gauss-Newton nonlinear least-squares procedure to the equation $D(t)=(a\cdot e^{t/b}+c)\mathbf{1}(t)$, where $D(t)$ is the SSB level at time t after irradiation. The biological interpretation of model parameters is well defined; a is the level of SSB immediately after irradiation, b is a time constant inversely related to the repair rate, and c is the estimated level of unrepaired SSBs. The statistical analysis of cancer versus normal cells data demonstrated that there are significant differences in these parameters between groups. The relatively low rate of repair process and high level of unrepaired SSBs were classified as risk factors for developing head/neck cancer. The common analysis of DNA repair process and polymorphisms of genes that encode proteins of different DNA repair pathways (XPD codon 312 Asp→Asn and 751 Lys→Gln, XRCC1 399 Arg→Gln, and MGMT 84 Leu→Phe) demonstrated that the presence of variant alleles coding for Asn at XPD312 is associated with more radiation-induced SSBs and fewer unrepaired SSBs. The phenotype (high induced SSBs / low unrepaired SSBs) was seen in the majority of XPD312 Asn/Asn homozygotes; the odds ratio for variant homozygotes to show this phenotype was 5.2 (95% confidence interval 1.4–19.9). XPD can participate in repair of ionizing radiation-induced DNA damage. While it cannot be excluded that the effects observed are due to cosegregating polymorphisms or that the responses of lymphocytes are not typical of other cell types, the results suggest that polymorphism of DNA repair genes, particularly XPD, is one factor implicated in the variability of responses to ionizing radiation between different individuals.

Genetic risk factors for autoimmunological diseases

J.Polańska

Diabetes mellitus type 1 (DMT1) and Graves-Basedov diseases (GB) are both classified into the group of autoimmunology diseases, where both genetic and environmental factors play important role in developing it. It is currently accepted that genetic susceptibility interacting with unknown environmental factors is responsible for the autoimmune basis of DMT1 and GB. Both genome screens and studies searching candidate genes have confirmed that DMT1 and GB are the heterogeneous polygenic disorders, with a about 20 of loci contributing to the susceptibility to disease. The most important genes, responsible for above 50% genetic risk of developing diabetes, are located in HLA region on chromosome 6p21. The first region of HLA connected with susceptibility to DMT1 (HLA class I B8 and B15) was found thirty years ago. The positive association of certain HLA class II alleles with DMT1 – DQ8/DR4 and

DQ2/DR3 in most Caucasian populations has been very well documented. The tumor necrosis factor α (TNF-α) is known as proinflammatory cytokine implicated in the pathogenesis of autoimmune and infectious diseases. The genes of TNF-α are located in the region HLA class III (250 kb centromeric of the HLA-B and 850 kb telomeric of the class II HLA-DR genes in humans). Although contribution of TNF-α to DMT1 and GB is not well established in humans in multicenter studies, it has been shown in animal model that TNF-α can be cytotoxic for β-cells supported by both interleukin-1 and interferon-γ. It has been pointed in several studies, that TNF-α region contains a few polymorphisms (single nucleotide polymorphisms – SNP) which could be connected with a different cytokine secretion. Probably different places in the promotor region, in the first intron, in the 3'untranslated region and microsatellites could determine different levels of TNF-α production. The TNF-α promotor polymorphism -308 in the human involving the substitution of guanine (known as TNF1) by adenosine (known as TNF2) has been most often used in the associated studies. TNF2 allele seems to have a real functional significance because it is a much stronger transcriptional activator than the common allele TNF1. In view of gene location, it has been speculated that polymorphism of this locus might contribute to HLA association with DMT1 and GB. We suggest that these associations may originate from the typical for HLA linkage disequilibria (LD) between estimated alleles in the TNF locus and other alleles of HLA region.

Maximum likelihood method for MALDI spectral alignment

J.Polańska, A.Polański

Over the last few years, mass spectrometry MS techniques (MALDI and SELDI - TOF MS) have undergone important improvements, enabling the exploration of proteins along a wide range of molecular weights in biological samples. Similar to DNA microarrays and genetics, mass spectrometers have been a revolution to the field of proteomics, allowing the researchers to build "signatures" or proteomic patterns specific to different conditions or pathological states. These profiles will provide us with proteomic biomarkers suitable for the diagnosis and prognosis of diseases, such as cancer. The big amount of data generated, however, makes it necessary to perform accurate data preprocessing and analysis. The standard steps in spectra analysis are: (i) data preprocessing and (ii) classification, clusterisation, data mining. Reproducibility of biomarker identification depends in part on careful data preprocessing: spectral calibration; spectral denoising; baseline correction; normalization; smoothing, binning; peak detection and peak quantification. Due to effects caused by temperature variation, column ageing and small variations in mobile phase composition, peak shifts are observed. To correct these peak shifts, several aligning techniques have been proposed in the literature, among them correlation optimized warping (COW), dynamic time warping (DTW), parametric time warping (PTW), peak alignment by a genetic algorithm (PAGA) and fuzzy warping (FW). Recently, a new aligning method called semi-parametric time warping (STW) has been proposed offering a better flexibility of alignment. STW is computationally a simple and fast method, which does not require peak detection and does not necessarily require the fine tuning of input parameters. Therefore, STW could be an interesting alternative to COW and PTW. The peaks can be modeled based on the selected function using, for example, the Levenberg-Marquart least square fitting algorithm. Peak modeling not only enables the areas of peaks to be

accurately estimated, but it also allows overlapping peaks to be resolves therefore giving more accurate area measurements compared to integration of the area under the peak curve. The most popular models are: Gaussian; Lorentzian (1/(1+x2) type); pseudo-Voigt (weighted sum of Gaussian and Lorentzian functions); and log-normal.

Our peak (spectral) alignment algorithm relies on the decomposition of signals into Gaussian components and estimation of components parameters, means, standard deviations and weights, by using maximum likelihood method. The developed approach by Gaussian mixture decomposition is competitive compared to other methods. Leads to: (i) good fit between spectra m/z functions and their mixture models; (ii) peak alignment; (iii) stable detection of differentiating peaks. The approach by Gaussian mixture decomposition depicts the need for redefining the concept of peaks and aligned peaks in spectra. The analyses confirm statistically significant differences between healthy and cancer samples.

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 (Control and Robotics Group), 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.

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.

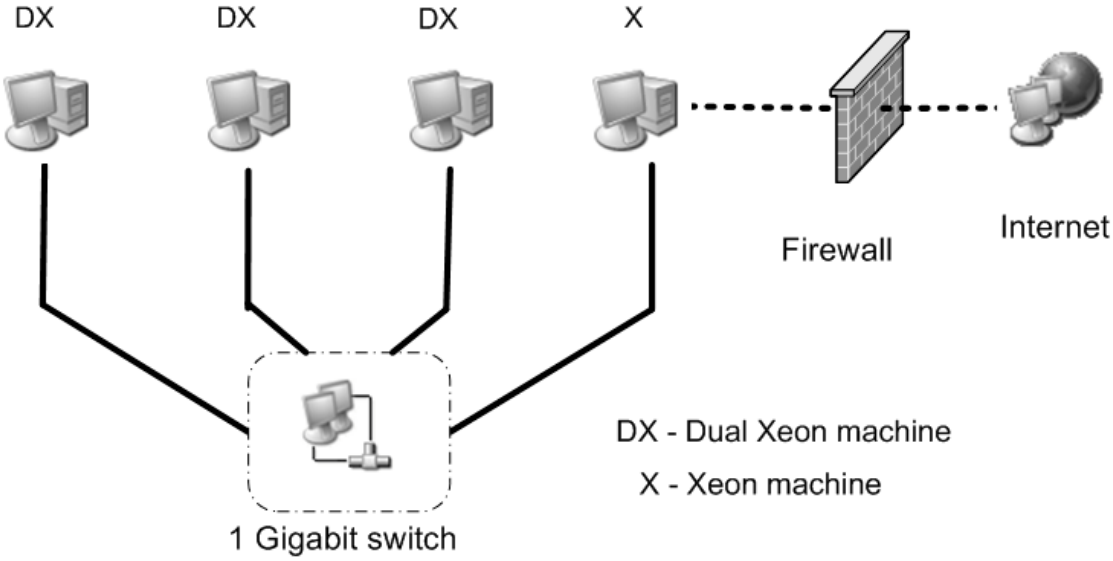

Fig. 1. Hardware cluster architecture.

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.

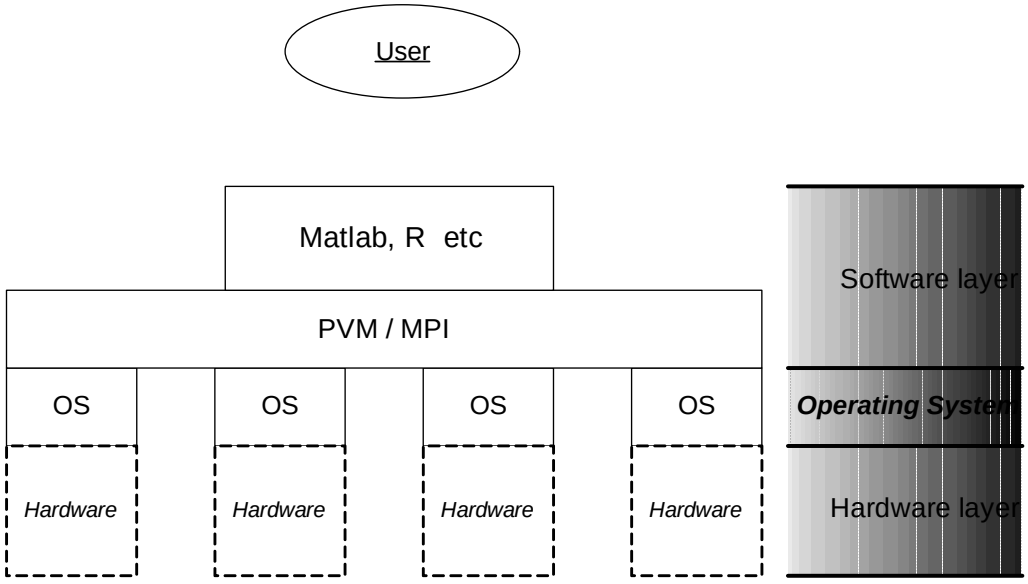

Fig. 2. Software architecture.

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.

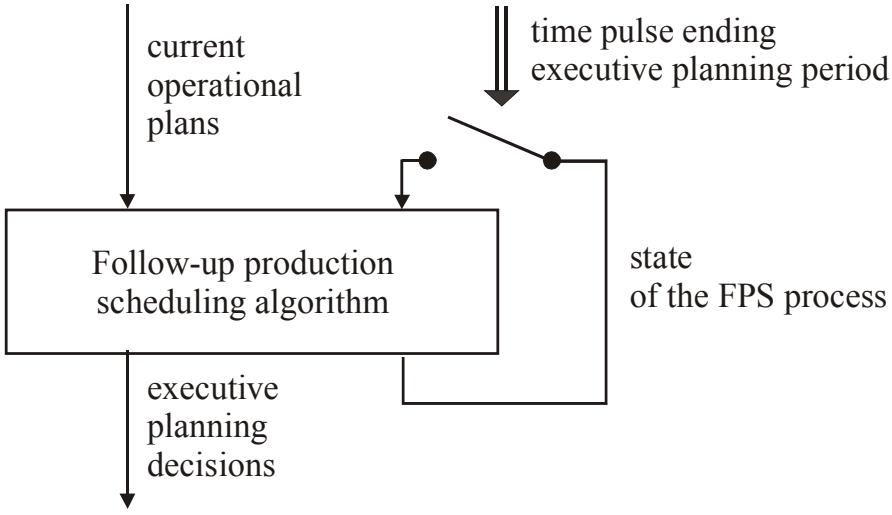

Fig.1. Application of the follow-up production scheduling to make current decision of the executive planning

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).

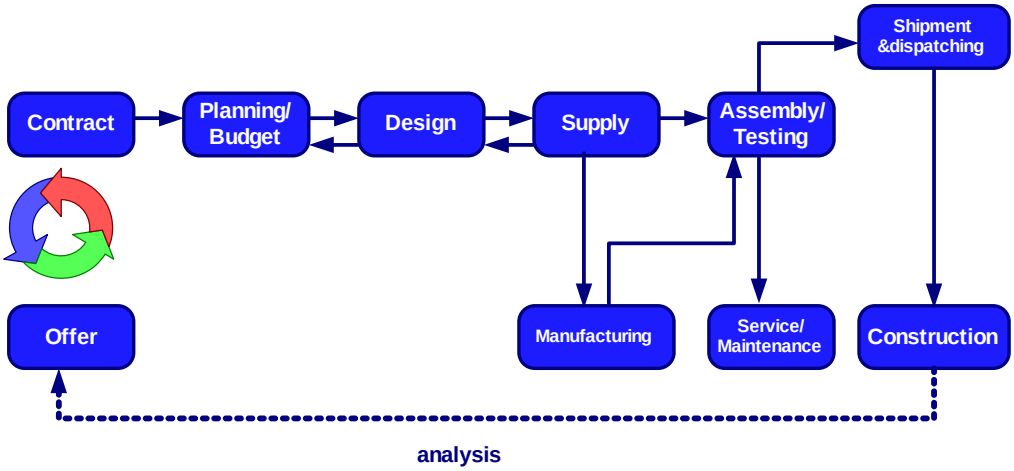

Fig.1. The product life cycle in IFS Applications system.

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 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.

Moreover, together with the Control Systems and Control Instrumentation Group, two important educational enterprises are undertaken. The first one started in the fall 2003 initiated 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 for which enrollment started in the 2005.

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After receiving his doctoral degree in Poland, Professor Kimmel moved to New York, where he spent eight years at the Sloan-Kettering Institute. He collaborated with biologists and statisticians on a range of issues, including screening for cancer, action of anticancer drugs on cells in vitro and in vivo, and dynamics of the cell cycle.

In recent years, mainly after coming to Rice in 1990, Professor Kimmel has been researching gene amplification and rapid evolution of DNA, including such related questions as sequence and linkage analysis. He is collaborating with biologists at the University of Texas Center for Genetics, Baylor College of Medicine and Rutgers University. The main biological problem of interest in this research is the creation and proliferation of repeat patterns in the genomes that are linked with human inherited disease and cancer. The mathematics used includes novel stochastic models of evolving DNA. Recently, these studies have gained importance and feasibility in connection with the Human Genome initiative.

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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In 1981 and 1991 he was awarded the Polish Academy of Sciences awards. In 1978, 1982 1990 and 2004 he received the awards of the Ministry of Education. Moreover, in 1994 he was awarded the Polish Mathematical Society award.

In 1991 he has published the monograph "Controllability of Dynamical Systems", Kluwer Academic Publishers, Dordrecht, The Netherlands. In the last thirty years he has published more than 100 papers in international journals, e.g., in IEEE Transactions on Automatic Control, Automatica, International Journal of Control, Journal of Mathematical Analysis and Applications, Systems and Control Letters, Foundations of Control Engineering, Systems Science, Kybernetika, IMA Journal on Mathematical Control and Information, Nonlinear Analysis, Theory, Methods and Applications, Systems Analysis, Modelling, Simulation, Archives of Control Science, Applied Mathematics and Computer Science, Advances in Systems Science and Applications, Bulletin of the Polish Academy of Sciences, Mathematical Population Dynamics, Lecture Notes in Control and Information Sciences, Analele Universitati din Timisoara, Acta Mathematicae Silesiane. He took part in many international Congresses, Conferences and Symposiums.

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He authored the following books (in Polish): "Multivariable Control Systems" ("Układy wielowymiarowe automatyki"), WNT, 1974.; 2-volumes of "Digital Industrial Control Systems" ("Systemy cyfrowe automatyki przemysłowej"), WNT, 1977; "Systems and Control. An Introduction to Control and Technical Cybernetics" ("Systemy i sterowanie. Wstęp do automatyki i cybernetyki technicznej") PWN 1983; 2-volumes of "Industrial Computer Control Systems" ("Systemy komputerowe automatyki przemysłowej"), WNT 1984,1985; "Microprocessors –Microcomputers -Microsystems" ("Mikroprocesory –mikrokomputery -mikrosystemy") WSP, 4 editions, 1978-1987; "Adaptive Control" ("Regulacja adaptacyjna"), PWN 1995 - with J.Mościński and Z.Ogonowski; "Multi-Edip. A Multivariable System and Signal Analyzer") "Multi-Edip Analiza wielowymiarowych sygnałów i obiektów" Pol.Sl. 1997 - with J.Kasprzyk and J.Figwer; "Rule-based Expert Systems" ("Regułowe systemy ekspertowe") PKJS 2000; "Rule- and Model Based Expert Systems" ("Regułowo-modelowe systemy ekspertowe") PKJS 2006.

He is currently full professor of control engineering at the Institute of Automation of the Silesian Technical University in Gliwice. His major managerial responsibility included serving as Rector of the Silesian Technical University for the term 1984-87. He authored about 80 research papers, some of them in journals like Automatica, IEEE Trans. on AC, IEEE Trans. on SP, Proc. IEEE and Int. Journal of Control. He served for many years as consultant on control and identification problems to the chemical and coal industry.

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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 gives lectures on fundamentals of measurements and industrial measurements and is the co-author of 9 scripts and co-editor of one of them: "Laboratory of industrial measurements" – 1997. His main field of interest is modelling of sampling flowmeters and measurements of flow rate in closed conduits and in open channels. S. Waluś is a member of Polish Society of Sensor Technique, Polish Society of Metrology and Committee of Metrology of Katowice Branch of Polish Academy of Science. Since 1990 he is the secretary of this Committee.

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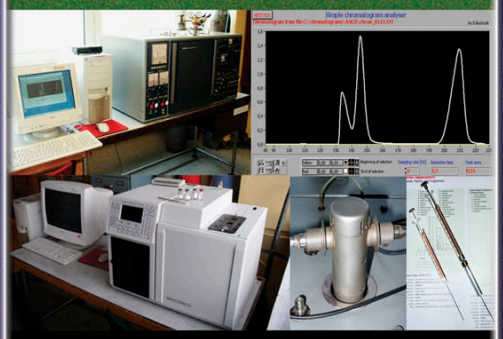

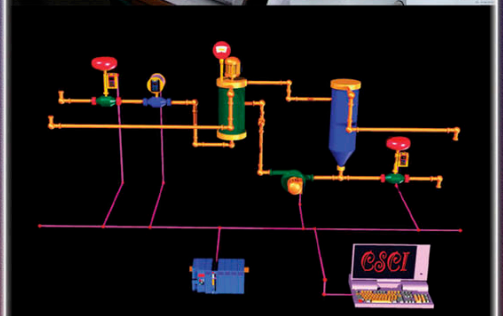

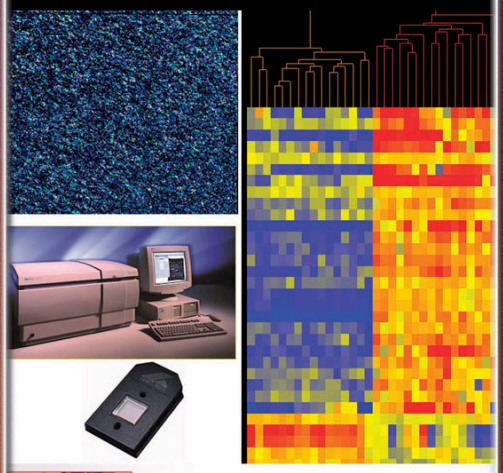

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