International Academy for Production Engineering
The 10th International Conference on Axiomatic Design – Xi'an, China, Sept. 21-23, 2016

Axiomatic design applied to the development of a system for monitoring and teleoperation of a CNC machine through the internet

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Outlines

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2. Axiomatic Design for software system development
3. Applying AD for software system development

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   3.2. *Definition of the full design matrix*

   3.3. *System architecture generation*
4. Conclusions

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1.Introduction

1.Introduction

- The Industry 4.0 paradigm has as main purpose the consolidation of smart factories.
- This new paradigm promotes a virtualized manufacturing, converting physical systems in services, using ICTs extensively.
- It is based on Cyber-physical systems (CPSs) and Internet of things (IoT).

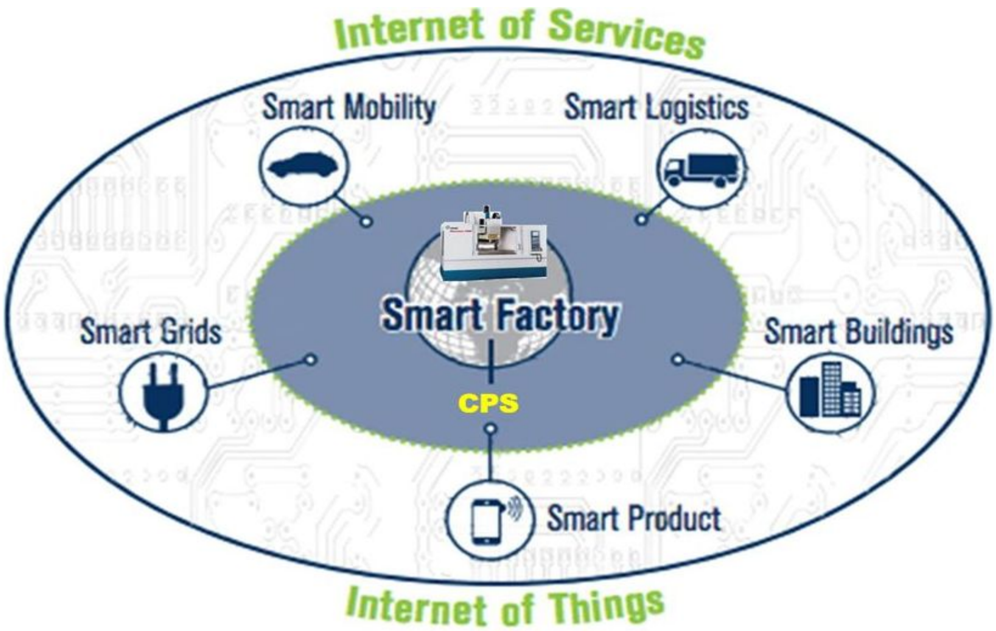


Fig.1 - Internet of Things and Services

1.Introduction

The implementation of smart factories involves requiments, such as:

- horizontal integration;
- end-to-end engineering;
- vertical integration and networked manufacturing systems;
- end-to-end transparency;
- a comprehensive broadband infrastructure for industry;
- energy efficiency;
- standardization and reference architecture…

- Regarding the capacity to connect manufacturing equipament through Web-based networks, exists the key standards MTConnect.

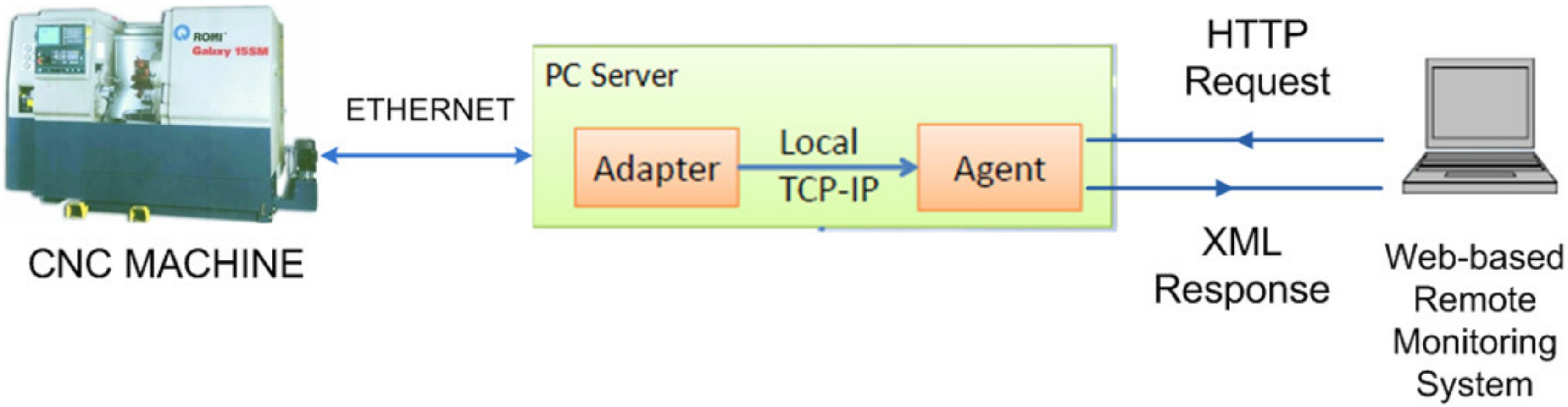
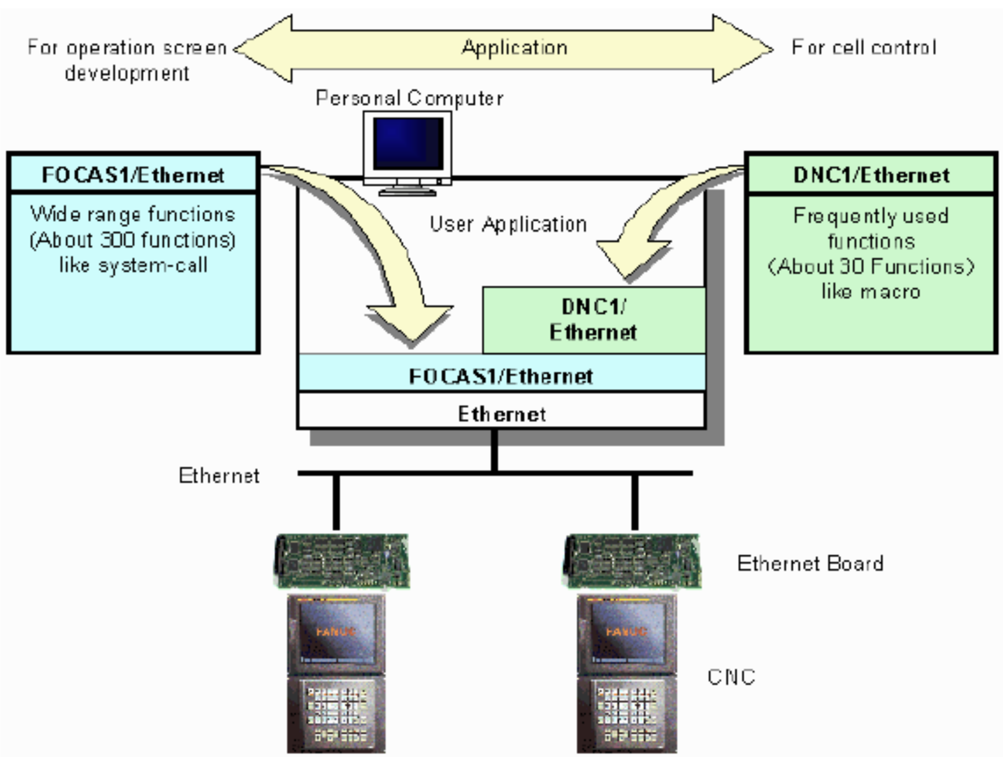
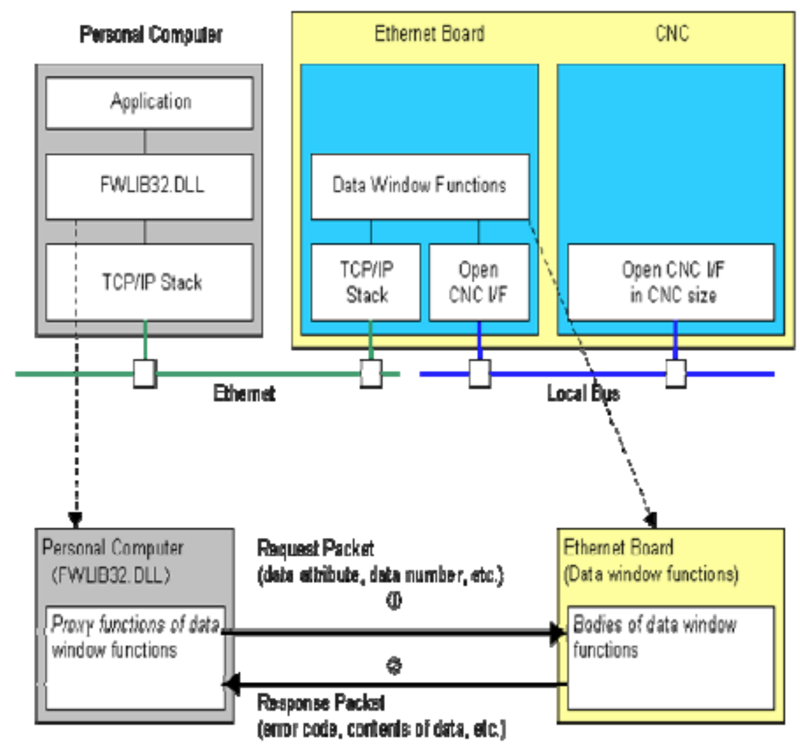


Fig.2 - Information flow among MTConnect elements (CPS)

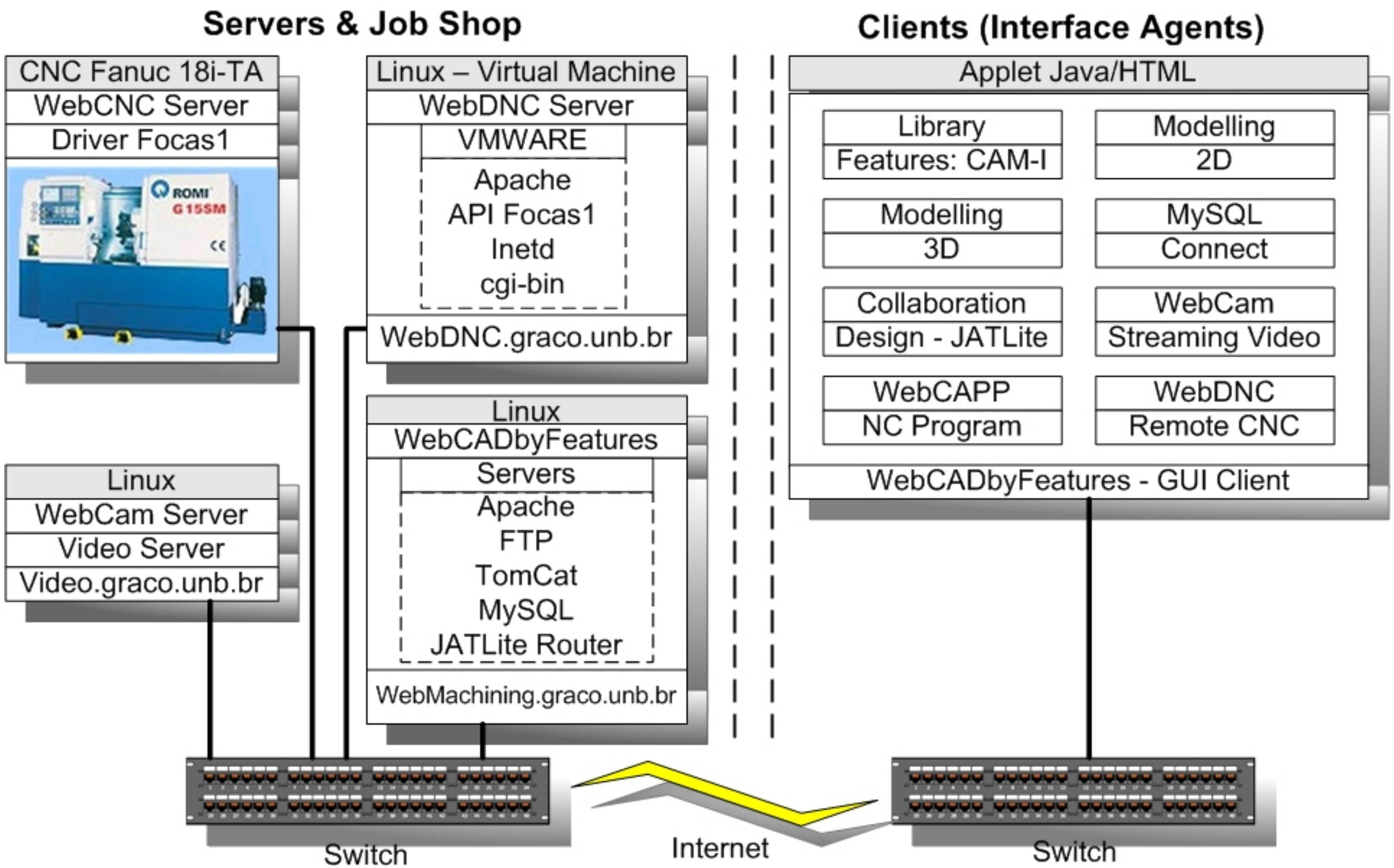
Protocols CNC Fanuc: Focas1/DNC1/OPC

(Fanuc Open CNC API Specifications)

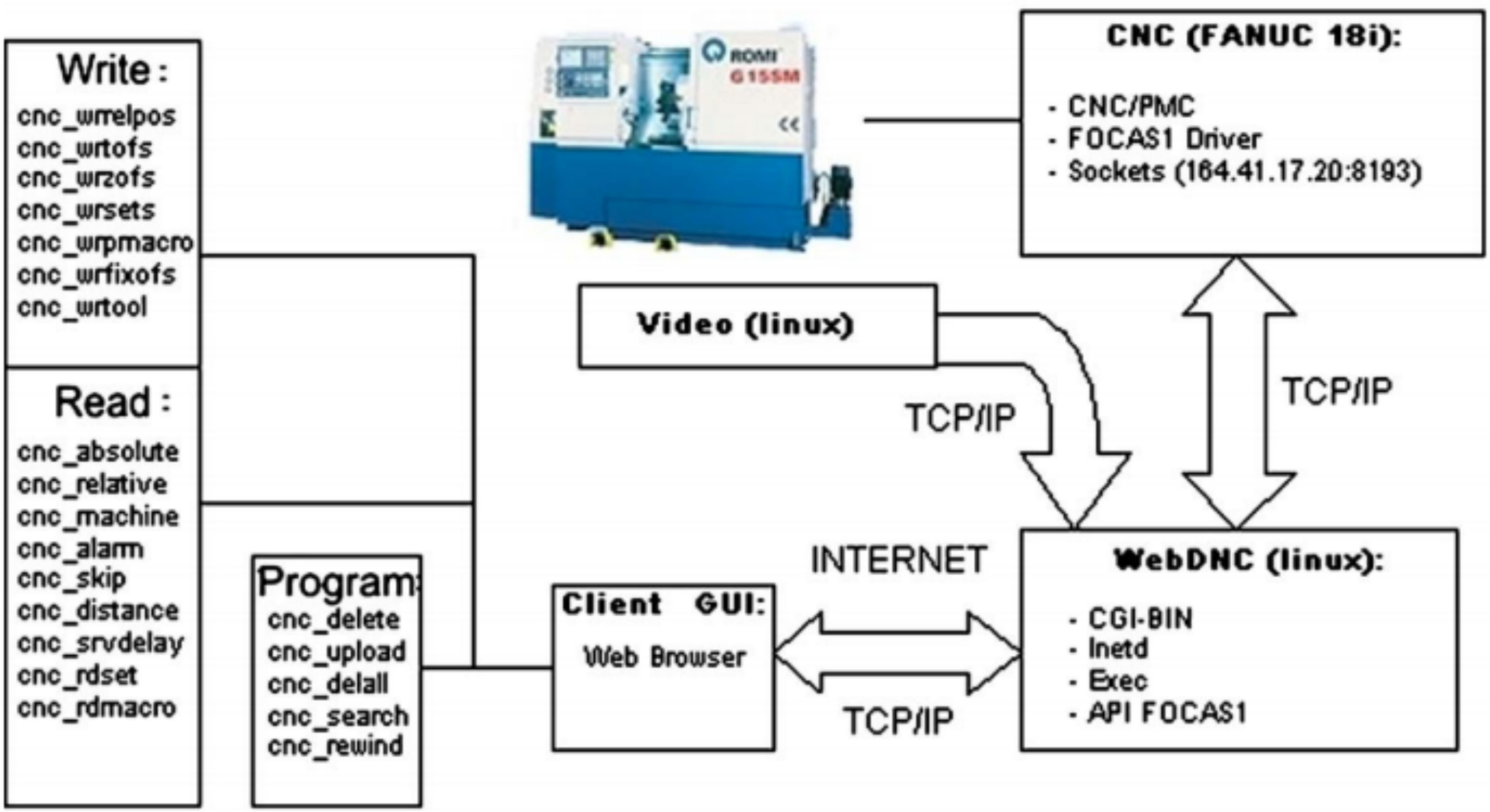


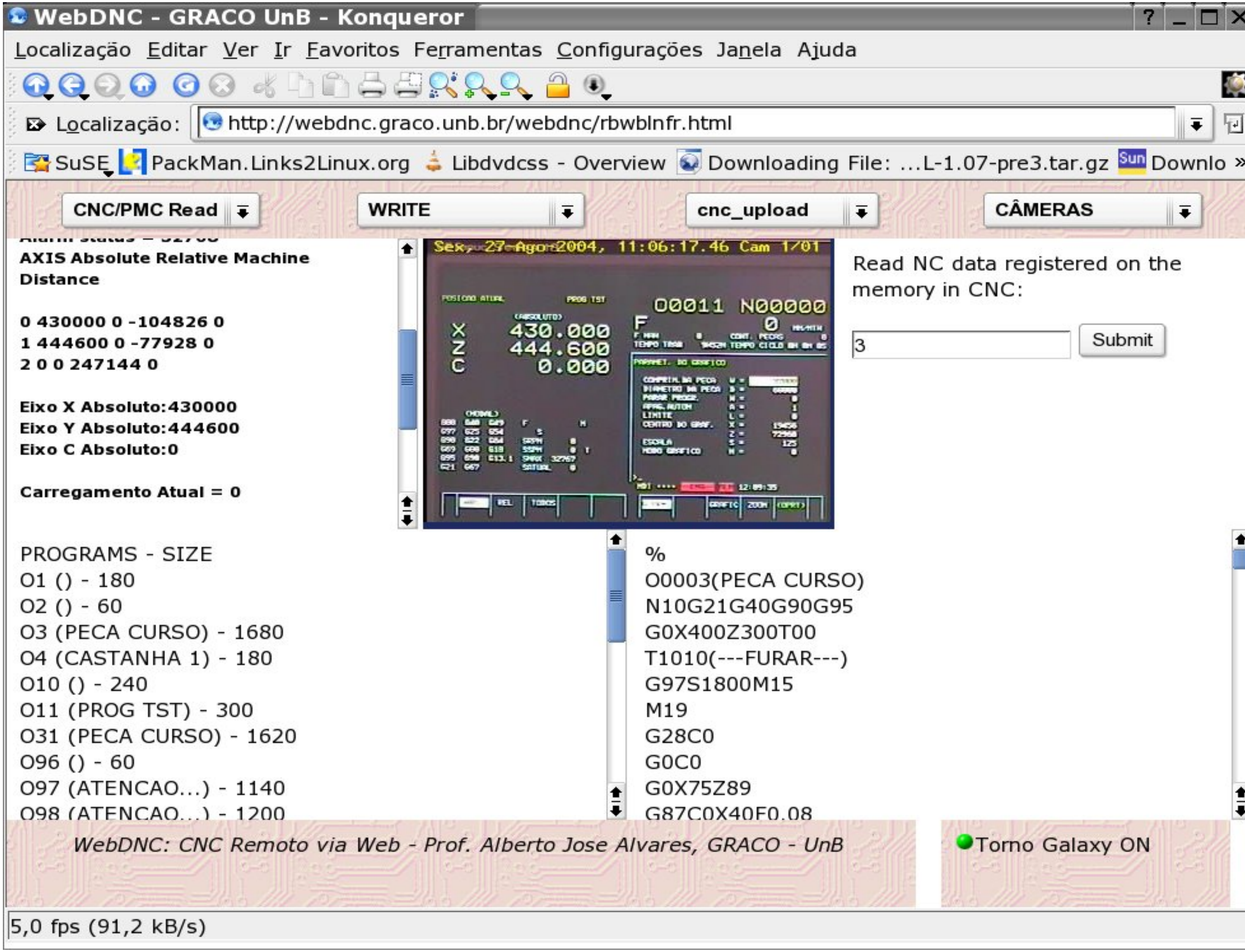


Architecture WebTurning: Original

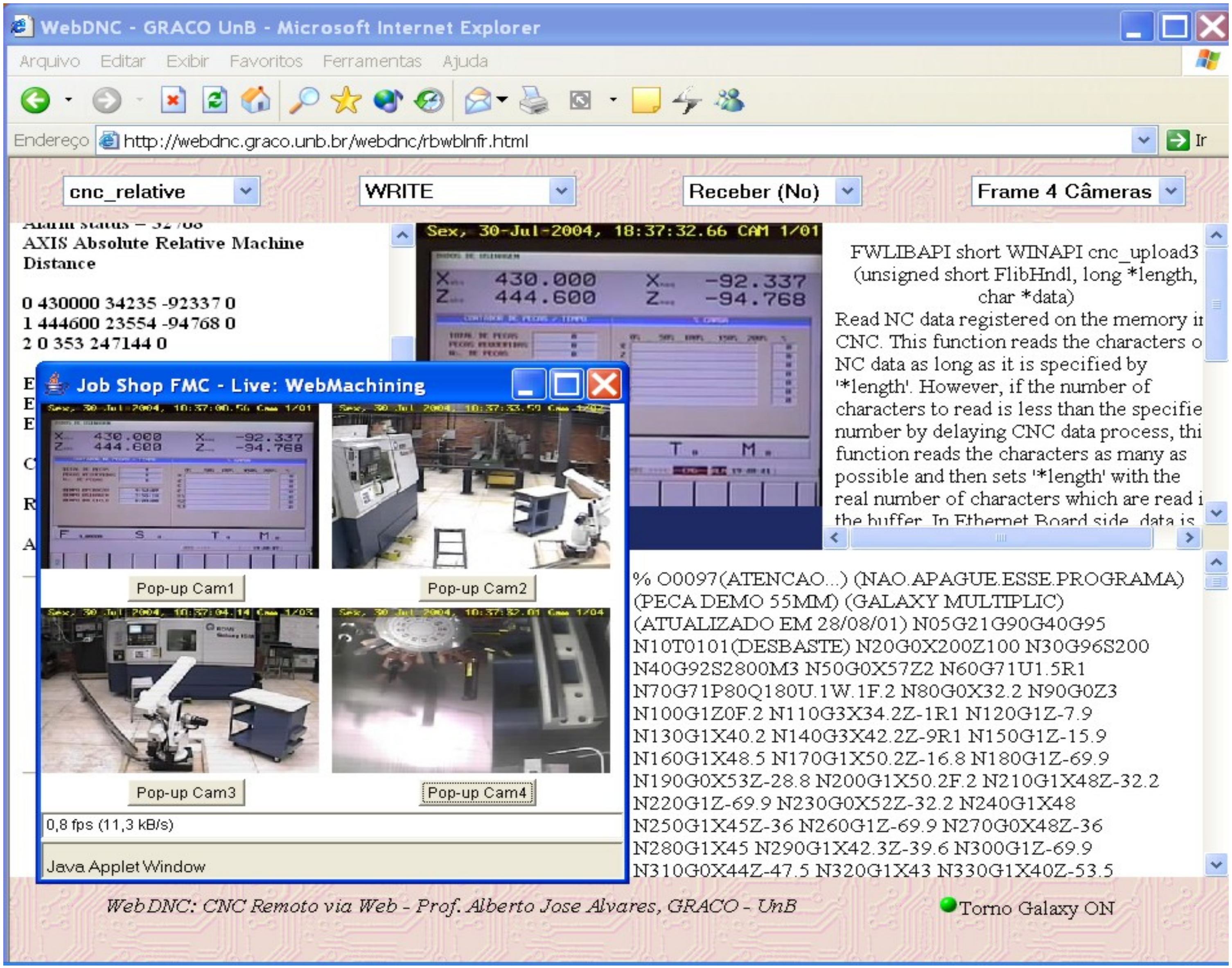


Architecture Teleoperation




WebDNC - GRACO UnB - Konqueror
Localização Editar Ver Ir Favoritos Ferramentas Configurações Janela Ajuda
Localização: http://webdnc.graco.unb.br/webdnc/rbwbInfr.html
SuSE PackMan.Links2Linux.org Libdvdcss - Overview Downloading File: ...L-1.07-pre3.tar.gz Downlo »
CNC/PMC Read
WRITE
cnc_upload
CÂMERAS
AXIS Absolute Relative Machine Distance
0 430000 0 -104826 0
1 444600 0 -77928 0
2 0 0 247144 0
Eixo X Absoluto:430000
Eixo Y Absoluto:444600
Eixo C Absoluto:0
Carregamento Atual = 0
Sex, 27-Ago-2004, 11:06:17.46 Cam 1/01
O0011 N00000
X 430.000
Z 444.600
C 0.000
Read NC data registered on the memory in CNC:
3
Submit
PROGRAMS - SIZE
O1 () - 180
O2 () - 60
O3 (PECA CURSO) - 1680
O4 (CASTANHA 1) - 180
O10 () - 240
O11 (PROG TST) - 300
O31 (PECA CURSO) - 1620
O96 () - 60
O97 (ATENCAO...) - 1140
O98 (ATENCAO...) - 1200
%
O0003(PECA CURSO)
N10G21G40G90G95
G0X400Z300T00
T1010(---FURAR---)
G97S1800M15
M19
G28C0
G0C0
G0X75Z89
G87C0X40F0.08
WebDNC: CNC Remoto via Web - Prof. Alberto Jose Alvares, GRACO - UnB
Torno Galaxy ON
5,0 fps (91,2 kB/s)

WebTurning: WebDNC e WebCam



Video

NetCam Live Image: WebMachining Project - FMC Live - Microsoft Internet Explorer
Arquivo Editar Exibir Favoritos Ferramentas Ajuda
Endereço http://video.graco.unb.br/
Ir
Links
Assistente de Web
If you only see X's instead o f images, you'll need to install Java, available free here.
Job Shop - FMC Live: WebMachining
Ter, 12-Abr-2005, 20:58:08.02 CAM 1/01
Ter, 12-Abr-2005, 20:58:07.74 Cam 1/02
Ter, 12-Abr-2005, 20:58:08.027
320 x 240
Ter, 12-Abr-2005, 20:58:07.747
320 x 240
Ter, 12-Abr-2005, 20:58:07.95 Cam 1/03
Ter, 12-Abr-2005, 20:58:07.64 Cam 1/04
Applet NetCAM started
Internet

Video

- OPC-UA:

"...while MTConnect facilitates the connection of machine tools and other manufacturing equipment linked with a network for gathering data, OPC-UA promotes the needed interoperability for data communication throughout the plant." (Albert, 2015).

1.Introduction

- The evolution of industry 4.0 happens essentially through the development and implementation of software systems and connectivity protocols.

- The early stages of a software design are surrounded by many uncertainties and lack of accurate information.

- Axiomatic Design methodology (AD) is quite effective in the early stages of the design, when the deployment of customer needs in the design requirements (called Functional Requirements - FRs) is performed.

- AD + OOT = ADo-oSS

1.Introduction

- This work presents the development of a system architecture (definition of FRs and DPs) for monitoring and teleoperation of a CNC machine tool through the Internet based on the combination of the features of object-oriented methodology and axiomatic design.

- The combination of these methodologies is also used to contextualize the designed system as part of systems for industry 4.0.

2.Axiomatic Design for Software Systems Development

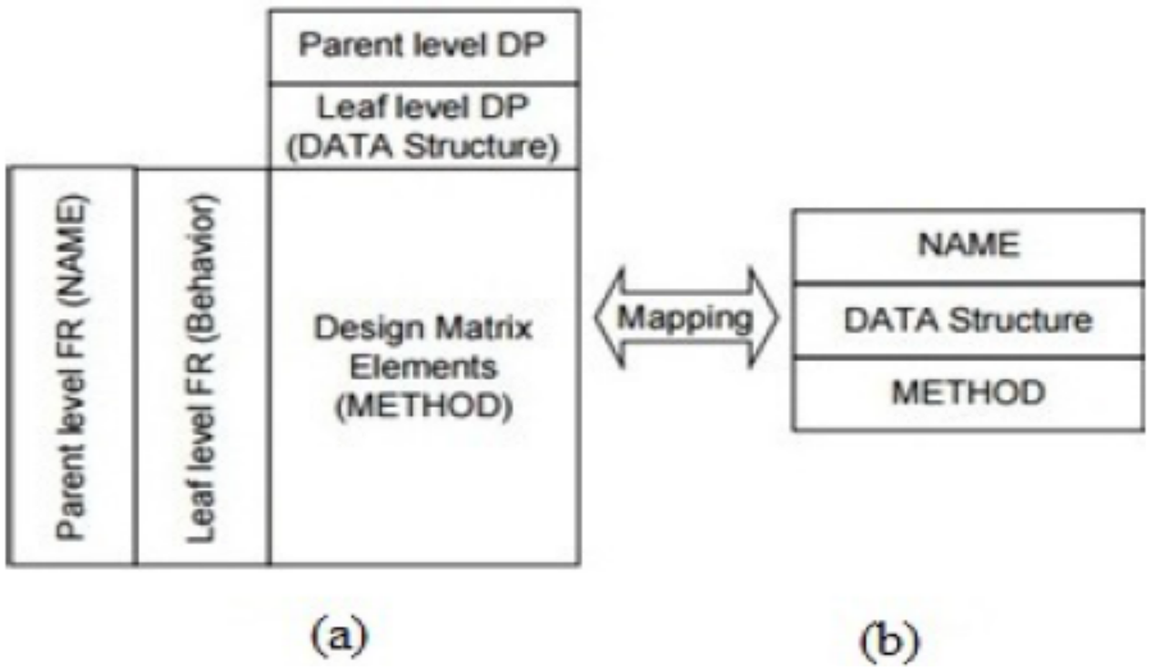


Fig. 3 - The Correspondence between the full design matrix and the OOT diagram, (a) Complete design matrix table, (b) Class diagram

3. Applying Axiomatic Design for Development of a Software System in Compliance with the Industry 4.0

Table 1: Costumers Needs

Costumers Needs	Description
CN1	View the current state of the process
CN2	View the current state of the machine
CN3	Allow to check machine operation historical data
CN4	Warn when there is a problem in the process
CN5	Provide a view of the shop floor in real time
CN6	Monitor the tool status
CN7	Intervenue in the manufacturing process remotely
CN8	Obtain data about the part
CN9	User-friendly intarface
CN10	Display charts
CN11	Provide reports

The next step was the choice of design constraints:

Cs1: The System is based on Internet as a Service;

Cs2: Use key-standards in compliance With The New industrial revolution;

Cs3: Having the data source available in the cloud;

Cs4: Virtual monitoring and control;

Cs5: Plataform independent system.

3.1. Definition of FRs and Mapping between the domains

It was determined the functional requirement to zero level (FR0), representing the main requirement of the hierarchy, and the corresponding design parameter (DP0):

FR0: To Build a tool for remote operation and monitoring of a CNC machine-tool, compliant with Industry 4.0 features.

DP0: A Web-based System for Teleoperation and Monitoring of a CNC machine-tool(CAM).

3.1. Definition of FRs and Mapping between the domains

FR \ DP	DP1	DP2	DP3	DP4
FR1	X	X	X	X
FR2	X	X	X	X
FR3			X	
FR4	X	X	X	X

Fig.4 - Mapping for the first level

x	FRx	DPx
1	Monitor the manufacturing process remotely	Functions for Web-based process monitoring
2	Interactivity with the process and the machine	Functions for machine configuration and control through the Internet
3	Create an intuitive user interface	Structured Graphical User Interface(GUI)
4	Define mechanisms for acessing historical data of the machine operation	System Query integrated with the machine operation database

3.1. Definition of FRs and Mapping between the domains

FR \ DP	DP 1.1	DP 1.2	DP 1.3	DP 1.4	DP 1.5	DP 1.6	DP 1.7	DP 1.8	DP 1.9	DP 1.10	DP 1.11	DP 1.12	DP 1.13
FR1.1	X												
FR1.2		X											
FR1.3			X										
FR1.4				X									
FR1.5					X								
FR1.6						X							
FR1.7							X						
FR1.8								X					
FR1.9									X				
FR1.10										X			
FR1.11											X		
FR1.12												X	
FR1.13													X

Fig.5 – Second level decomposition for FR1

x	FR1.x	DP1.x
1	Acquire Power machine Status(On/ Off)	OPC object to acquire power state
2	Acquire the control mode	OPC object to acquire variable Control Mode
3	Acquire machine door status	OPC object to acquire the status of the machine door
4	Acquire cooling status	OPC object to acquire the status of the coolant system

x	FR1.x	DP1.x
5	Acquire current feed-rate of the axes	method getActualFeedRate
6	Acquire axes' current position	method getAxesPosition (for axes X/Z/C)
7	Acquire the axes' load	method getAxesLoad (for axes X/Z/C)
8	Acquire Alarms Status	method getCurrentProgram
9	Acquire the name of the running program	method getSpindleSpeed
10	Acquire axes' rotation (Spindle Speed)	method getDistanceToGo
11	Acquire travel distance for the spindles	method getDistanceToGo
12	Acquire configuration data	method getDataSettings
13	Acquire images and audio from the shop-floor	WebCam Server (Graco/UnB)

3.1. Definition of FRs and Mapping between the domains

FR \ DP	DP 2.1	DP 2.2	DP 2.3	DP 2.4	DP 2.5	DP 2.6	DP 2.7	DP 2.8	DP 2.9	DP 2.10	DP 2.11	DP 2.12	DP 2.13	DP 2.14	DP 2.15	DP 2.16	DP 2.17	DP 2.18
FR2.1	X						X											
FR2.2		X																
FR2.3	X		X					X										
FR2.4			X	X														
FR2.5					X													
FR2.6					X	X												
FR2.7							X											
FR2.8								X										
FR2.9							X		X									
FR2.10			X							X								
FR2.11											X							
FR2.12												X						
FR2.13											X		X					
FR2.14							X							X				
FR2.15															X			
FR2.16				X			X									X		
FR2.17			X														X	
FR2.18			X															X

Fig.6 – Second level decomposition for FR2

x	FR2.x	DP2.x
1	Transmit a NC program to the machine controller	OPC object to transmit an NC Program to the controller
2	Receive a NC program from the machine controller	OPC object to receive an NC program from the controller
3	Start program execution (Cycle Start)	OPC object to start an NC program execution
4	Stop or Cancel program execution (Cycle Stop/RESET)	OPC object to cancel/stop the execution of an NC program
5	Turn On Refrigeration (Coolant ON)	OPC object to turn on the machine coolant
6	Turn Off Refrigeration (Coolant OFF)	OPC object to turn off the machine coolant

x	FR2.x	DP2.x
7	Define the controller operation mode	OPC object to activate/ deactivate controller operation modes (AUTO / EDIT / MDI /JOG)
8	Activate/Deactivate program execution options	OPC object to activate/ deactivate program execution options (SINGLE BLOCK / BLOCK DEL/ PROG TEST/ OPT STOP / DRY RUN)
9	Move axes manually out of operation	OPC object to handle directional keys of axes (+ X / -X / + Z / -Z)
10	Show tool data	OPC object to retrieve tool status information
11	Search a specified program	method searchProgramNC
12	Delete a specified program	method deleteProgNC
13	Open the CNC program directory	method openProgramDir
14	Activate zero-offset value	method sendWorkZeroOffSet
15	Write default axis relative position	method setRelAxisPosition
16	Transmit command lines to CNC	method sendMDIProgCommand
17	View program block execution	method getProgrblock
18	Receive error messages	method getErrorMessages

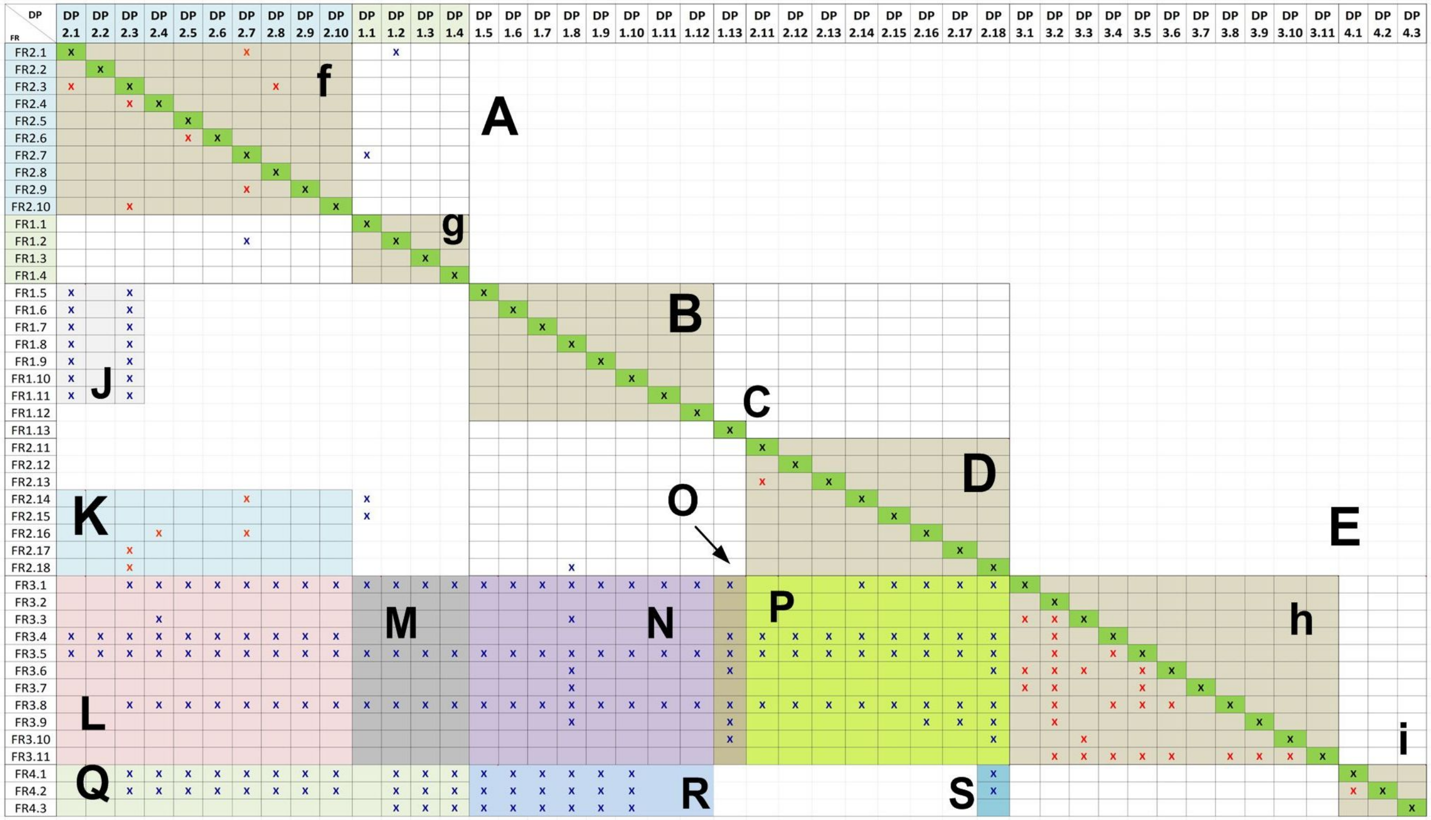


Fig.8 – Full design matrix (Rearranged)

A: OPC-UA Server / **B:** MTConnect Server (Adapter) / **C:** Video/audio streaming server / **D:** Machine command classes / **E:** User interface GUI controls / **f:** OPC-UA writing classes / **g:** OPC-UA reading classes / **h:** Remote command and process monitoring functionalities / **i:**Historical data query, reporting and charts generation.

J: Represents a control sequence / **K:** Represents a control sequence/ **L:** I/F between OPC-UA Server and client application for issuing commands / **M:** OPC-UA Server class to acquire machine status data to the GUI / **N:** I/F between the adapter and the GUI (MTConnect Agent) / **O:** I/F between the GUI and the video/audio server (WebCam) / **P:** I/F Class between the GUI and remote operation server of the CNC machine / **Q:** Class for storing and querying operation historical data from OPC-UA Server / **R:** Class for storing and querying CNC's historical data from MTConnect Server / **S:** Class to query alarms database.

3.3. System Architecture Generation

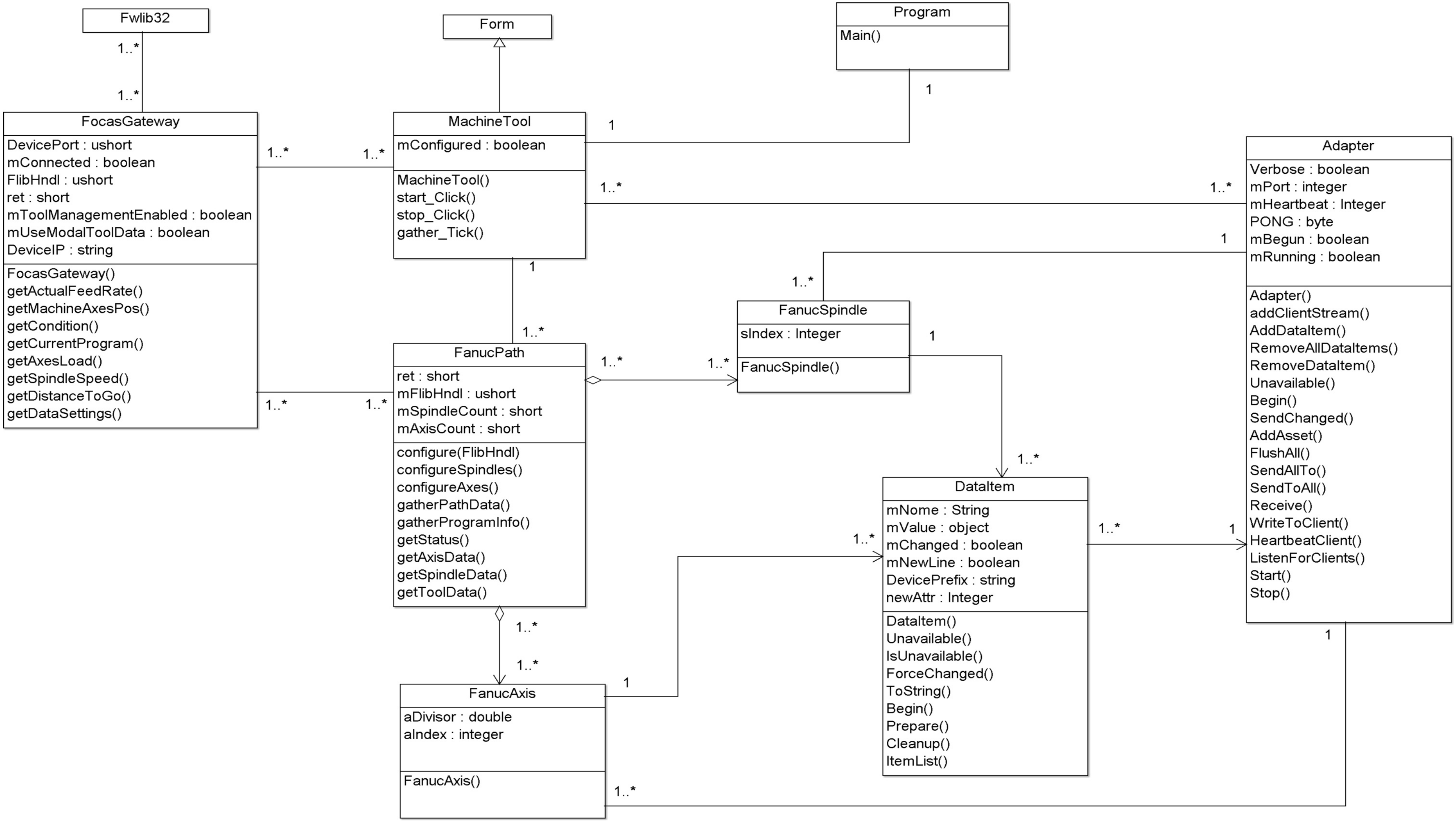


Fig.8 – Class diagram of the Adapter (MTConnect Server)

3.3. System Architecture Generation

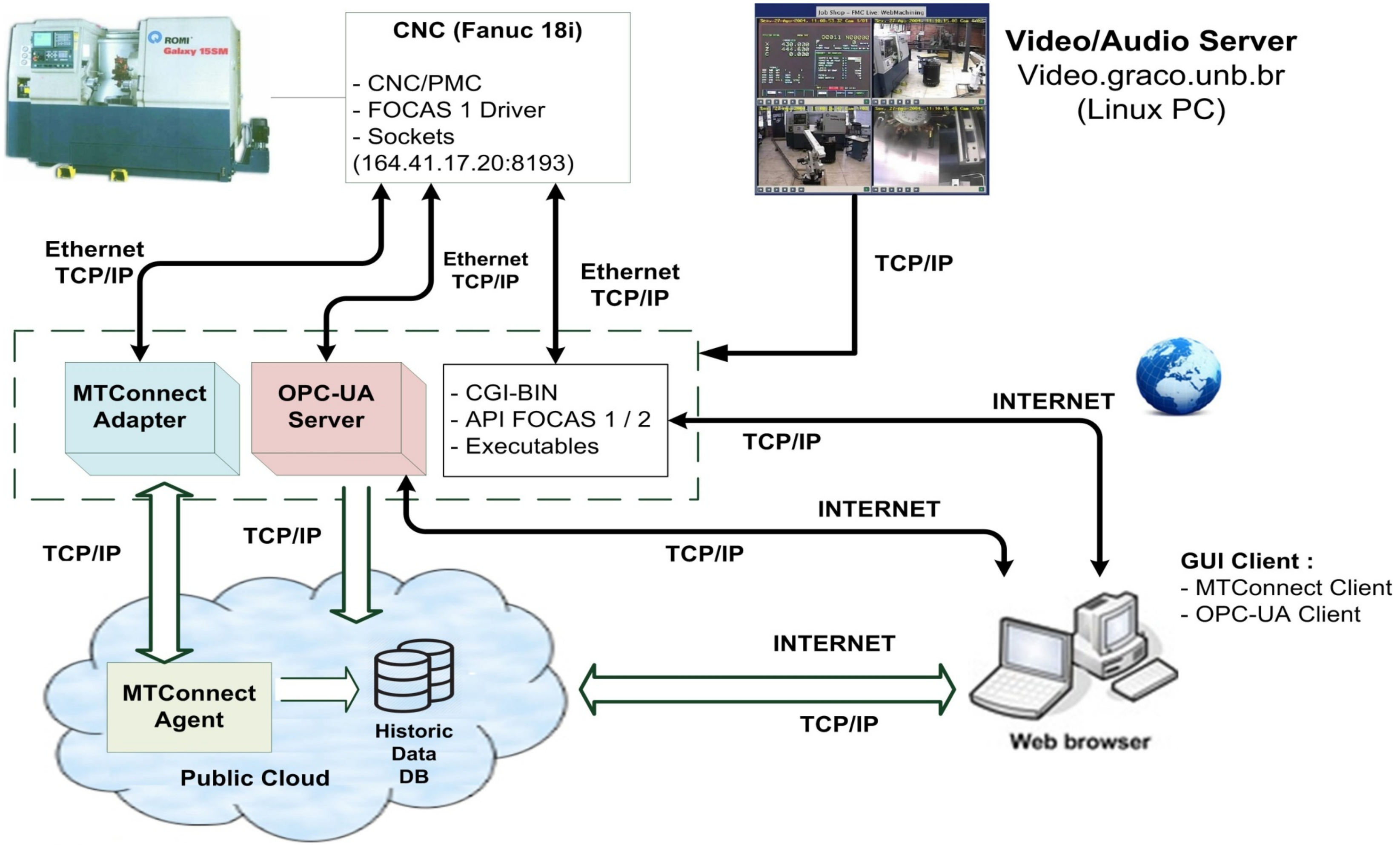


Fig.9 – Cyber-Physical Production Systems: architecture, data flow and some available services

4.Conclusion

3.3. Conclusion

- The use of axiomatic design for the design of a Client/Server system for the industry 4.0, with multiple layers, demonstrated the versatility of the methodology.

- It has been demonstrated the importance of the AD to the development of industry 4.0, through the promotion of the independence axiom between functional requirements as autonomous modules.

- To solve the problem related to bandwidth and the inherent delays of TCP/IP is necessary to endow the teleoperation system, in the server close to the CNC, with mechanisms that enable decision making in critical situations, without depending on the client side.

- It is necessary to endow the system with some intelligence to solve conflicts that can happen during the teleoperation process.

3.3. Conclusion - Suggestions for future works

- The axiomatic design methodology adapted to the system design for industry 4.0.
- AD applied to the design of a full-service architecture for manufacturing, available in a cloud-based platform

Acknowledgements

- The authors would like to thank the financial support of the Brazilian government agency MEC/CAPES/ CNPq and FAPDF.