Distributed/Virtual Manufacturing System Cell: An Experimental Installation

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Abstract

The main objectives of the "Distributed/Virtual Manufacturing System (D/V MS) Cell" project are: (1) The development of Tele-services technologies and organisation for the production planning and control functions; (2) The development of permanent high performance laboratory facilities that enable development and demonstration of D/V MS design and control, i.e., global distribution of production planning and control functions; (3) The development of an abstract environment, i.e., a virtual environment for design and real time control of manufacturing systems, or one of its elements, independent of the physical implementations. The D/V MS Cell satisfies the defined hierarchical distributed control model

The Hardware System of the D/V MS Cell is composed by: (1) *Machine tool cell*: CNC milling machine, external sensors and actuators, interface computer with communications links, (2) *Machine cell*: Two machine simulators, PLC, sensors and actuators, computer based local controller, (3) *Robot cell*: Robot SCORBOT ER-VII, artificial vision system, conveyor system, computer based local controller, (4) *Control centre*: Video projector, computer based remote controller, computer based real time video and audio system.

The Software System of the D/V MS Cell is composed by: (1) Applications for *Human-Computer Interface* (HMI): Interfaces for machine tool and robot programming and control, interface for production planning and control, (2) *Computer-Machine Interface*, via RS-232C, (3) *Computer-Computer Interface*, for communications via Internet.

The hardware structure of the (D/V MS) Cell is already implemented and interfaces for machine tool programming and control are developed (software system). The operation of the complete system is planned for the year 1999.

1. Introduction – State-of-the-art and definitions of Distributed and Virtual Manufacturing System

In order to satisfy requirements (user needs) which determine a future competitive manufacturing system/enterprise (MS/ME) organisation, different advanced organisational models are proposed. Among them, Distributed and Virtual Manufacturing Systems are expected to be the leading manufacturing system concepts in the future.

Distributed Manufacturing System

The most referred interpretations of Distributed Manufacturing Systems are related to the distributed control of manufacturing system, based on *Multi-Agent System* model, and to the spatial distribution of manufacturing system functions – physical components. The second interpretation of distributed manufacturing systems, the spatial distribution of manufacturing system components (Putnik G., 1998), does not imply distributed control in terms of *Multi-Agent Systems.* The second interpretation is the concern of the project presented.

An implementation of the distributed manufacturing system, in terms of its spatially distributed elements, is the well-known **Global Manufacturing** concept. Considering the hierarchical model of the manufacturing system control and organisation,

the global manufacturing concept is actually implemented only at the company business management level. Business management functions are distributed geographically and independent of a distance but the production planning and control functions remain aggregated to the work floor.

Theoretically, it is possible to consider equally the geographical distribution of the production planning and control functions. It means that these functions should be separated of the work floor.

The geographical distribution of the production planning and control functions has enormous potential. The actual manufacturing systems do not require that functionality. However the new concepts of manufacturing systems, developed in the last years, push, or suggest those needs The manufacturing equipment can not be extremely expensive. The production volume of this equipment must be much higher than the Tele-operated robots and ROVs[1] (Remotely Operated Vehicles) and the requisites of control, in terms of operational costs must be reduced.

At the present date we have no knowledge of any industrial installation. There are some experiences, developed since the beginning of the 90-decade brought to the light by Investigation centres.

In (Mitsuishi et al. 92) it is described one prototype installation for operation and control of a machining centre. This machine was installed at Tokyo University, Japan, and the operation centre was located at George Washington University, USA. The machine was controlled from different sites in the same building, at Tokyo, and from an operation centre at Washington. The prototype system was described by the authors as a base technology for the construction of an "inter-world intelligent manufacturing system", that allows project and manufacturing engineers, globally distributed, to collaborate in an efficient and convenient way in the conception, development and production of prototype products. The key technologies, described by the authors, for implementation of a global manufacturing system include:

- Man-Machine interfaces.
- Global access communication systems –between the control centre and the operation centre.
- External and state of the machine sensorial system - creating a virtual remote environment through the installation of several sensors near the machining-centre in order to keep the remote operator informed about the actual state of the system.

In 1996 Kao and Lin (Kao and Lin 96), from South Australia University, presented some extensions for CAD/CAM technologies based on remote and multiple locations. The proposed system allows co-edition of CAD geometry at distance. The system outputs as result a NC program and send it to a machining-centre for physical manufacturing of the product. The system is named as 'cocadcam'- Collaborative CAD/CAM. In the application example working on LANs, RDIS or INTERNET, the user that possesses the token, designated "creator", can generate or change the geometry. The other users, designated "observers" can not do it. This mechanism assures the reliability of the actions about the same objects.

Based on this approach the distributed manufacturing system is defined as:

P_DEFINITION 1: the distributed manufacturing system is defined as the manufacturing system whose functionality and performance is independent of the physical distance between system elements.

The technology and the organisational framework applied to operation of distributed systems are designated as "**Tele-operation**". Operation and control of devices from distant sites is usually referred as Tele-operation. Tele-operation consists on the extension of human manipulation and sensorial capabilities to a remote location. Space and time are factors that reveal the importance of the Tele-operation concept. Allowing globally distributed tasks and fast switching between them, Tele-operation brings spatial and temporal flexibility to persons that were never reached until now.

Virtual Manufacturing System

There is not an universally accepted definition of a **"Virtual Factory/Enterprise"**. The models presented in the literature are particular applications without rigorous indication of the structure (for D/V MS definitions) and experiments (for D/V MS control) validation. The publications (Browne 95), (Goossenaerts et al. 95), (Hormozi 94), (Kim 90), (Onosata and Iwata 93), (Iwata et al. 95), (Kidd 94) and (Goldman et al. 94), are representatives of the literature for a detailed analyses. Our analysis (Putnik G., 1998) shows at least two approaches. Combining two approaches, the virtual manufacturing system/enterprise could be defined as follows:

P_DEFINITION 2: A Virtual Manufacturing System/Enterprise is an optimised manufacturing system/enterprise synthesised over universal set of primitive resources with the real-time substitutable physical structure where one instantaneous physical structure has lifetime at most as the lifetime of the product. The design (synthesis) and control of the system is performed in an abstract, or virtual, environment.

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[1] The examples of equipment, object of Tele-operation (conceived as framework technology for D/V MS) are essentially robots and ROVs. These equipments are usually developed for specific applications, very expensive and conceived with functionality adapted to the type of control required, i.e., remote control.

The Distributed/Virtual Manufacturing System (D/V MS) Cell is a kind of a virtual manufacturing system conceived to provide:

a) an abstract, i.e. virtual environment, for design and control of a manufacturing systems/enterprise, or of its elements, independently of its/theirs physical implementation(s) (satisfying the requirement for an abstract environment for design and control structure – the first approach);

b) synthesis of the manufacturing system/enterprise over universal set of primitive, or complex, resources with the real-time substitutable physical structure (satisfying requirement for reconfigurability - the second approach).

The Distributed/Virtual Manufacturing System (D/V MS) Cell combines characteristics of the distributed and virtual manufacturing system/enterprise as we have defined above[2].

2. Objectives of the project

The **main objectives** of the "Distributed/Virtual Manufacturing System Cell" project are:

- Development of teleservices technologies and organization for the Production Planning and Control functions.

- Development of permanent high performance laboratorial facilities that enable development and demonstration of D/V MS design and control, i.e., global distribution of production planning and control functions.

- Development of an abstract environment, i.e., a virtual environment for design and real time control of manufacturing systems, or one of its elements, independent of the physical implementations

The Distributed and Virtual Manufacturing System/Enterprise Cell, is going to be used as:

- Distributed/Virtual Manufacturing Systems investigation platform for future research, related with other research projects, MSc. projects or PhD. projects.

- Demonstrator (demonstration facilities) for Distributed/Virtual Manufacturing Systems design and control, especially dedicated to industry, undergraduate students, MSc. students and public in general, with the objectives of advertising for new forms of enterprises organisations.

- Base installation for the "manufacturing cells (virtual) market", with interconnection capabilities allowing the synthesis of the large scale Distributed/Virtual Manufacturing Systems.

3. Distributed/Virtual Manufacturing System Cell specification

Specification of the Distributed/Virtual manufacturing system elementary structure

The functional specification of system is based on the hierarchical control model for manufacturing systems. The hierarchical model of machine tool control structure (NC machine tools and robots) is presented in figure 2a and is based in the model proposed in 1979 by Barbera, Albus and Fitzgerald (Barbera et al. 79).

NC machine tools, when considered object of Tele-operation have several conception problems, since they are designed and built assuming that a human operator will locally manipulate the machine control panel to perform the tasks or that the machine will be controlled by DNC-CAD/CAM system, figure 1.

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[2] It is important to notice that the definitions of the distributed manufacturing system and of the virtual manufacturing system do not correspond each to other, i.e. these two terms ("Distributed" and "Virtual") are not synonyms. It could be wrongly understood because of the term "Distributed/Virtual" used to describe a system that combines the characteristics of two concepts.
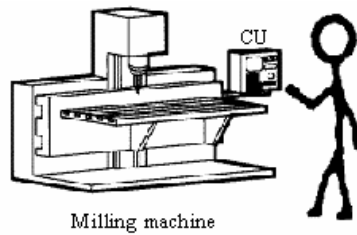
Figure 1. NC machine tool locally controlled by a human operator.

When operating a machine at distance some high level functions could be geographically distributed.

High level functions, for example a machine control program, could be co-ordinated at distance, which means dissemination of the control and monitoring functions. The figure 2b presents the hierarchical control model of a concrete application where control level 4 is realised by an human operator through computers and WAN networks which establishes the physical and logical means for remote control activities. Low level functions, i.e. control level 1 (servo control), control level 2 (axis control) and control level 3 (interpolation and auxiliary functions control) stay aggregated to the machine control unit.

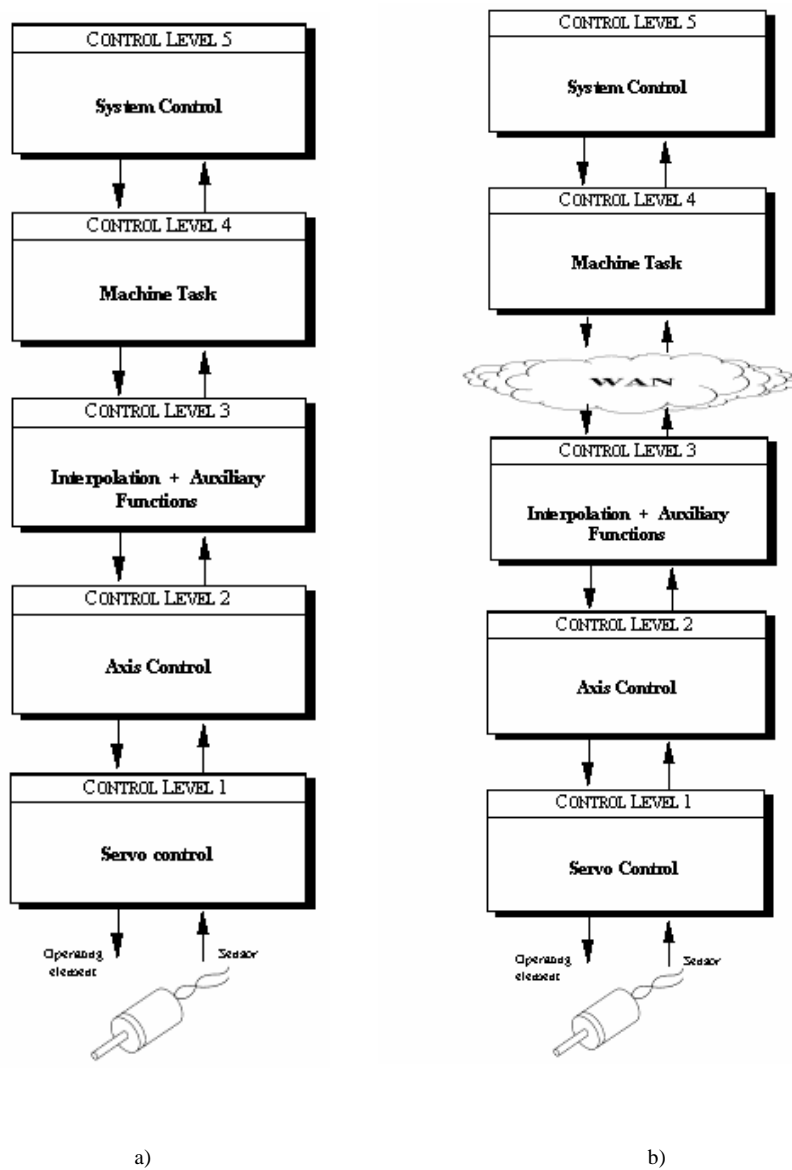a)   b)

Figure 2. (a) Hierarchical control structure of a machine tool, (b) Hierarchical control structure of a remote operated machine tool.

The control level 5 is responsible for the selection, monitoring and co-ordination of the entire system. This implies the search and selection of resources within the resources global net, in order to make a product. The negotiation of the global and specific conditions of resources utilisation and co-ordination of the globally distributed production are included in the forth and fifth control levels, i.e., the levels of machine tasks and system control.

This project concerns the control levels 4 (machine task) and 5 (system control), i.e., remote operator interface, global network communications interface, production equipment interface and remote monitoring of sensorial data.

This kind of the system is expected to reproduce the human sensorial and manipulation capabilities in order to take decisions and effectively control remote equipments/systems.

The elementary structure of the system is a functional pair "operator-machine". The model of this structure is presented in figures 3a and 3b:
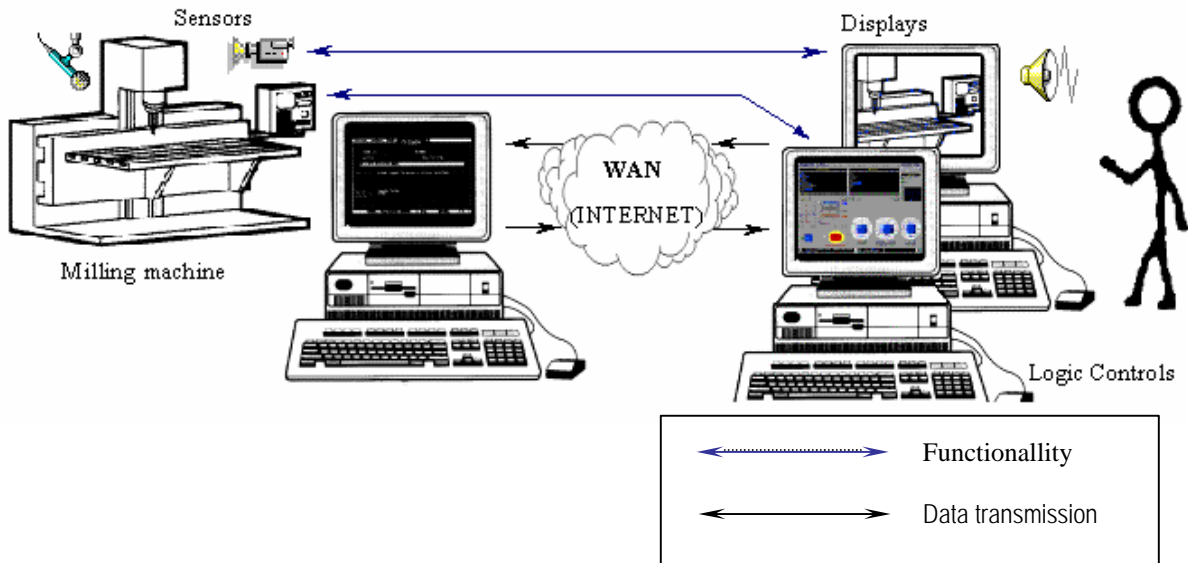
a)
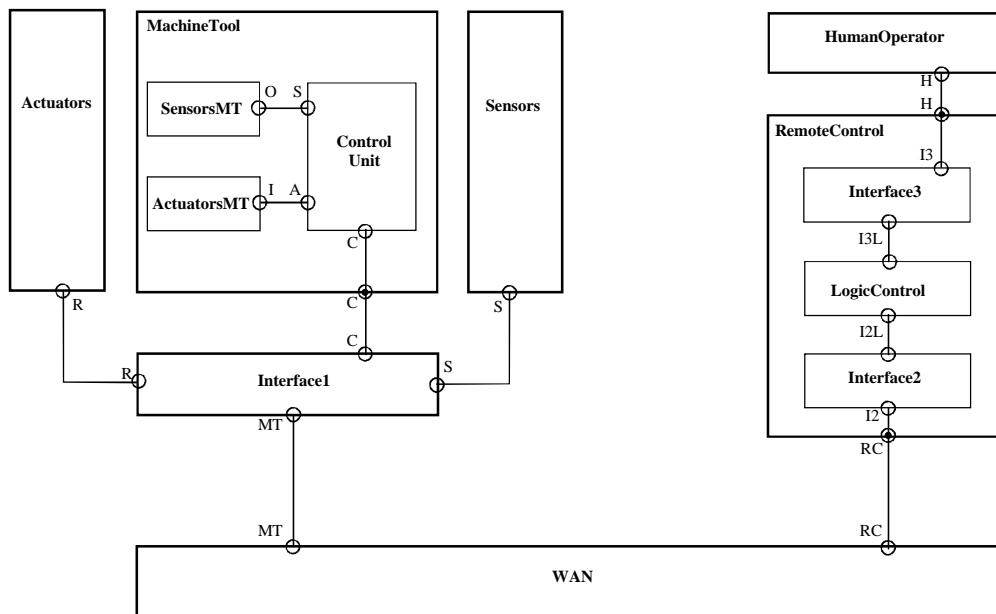
b)

Figure 3. (a) Informal representation of the elementary structure, (b) ESTELLE formal specification of the elementary structure

Specification of the Distributed/Virtual Manufacturing System Cell

The D/V MS Cell, satisfies the defined hierarchical distributed control model, and is composed by :

1. Hardware System
    1.1 *Machine tool cell*: CNC milling machine, external sensors and actuators, interface computer with communications links, located at Department of Mechanical Engineering (DEM) at the University of Minho.
    1.2 *Machine cell*: Two machine simulators, PLC, sensors and actuators, computer based local controller, located at Department of Production and Systems Engineering (DPS-LASAP) at the University of Minho.
    1.3 *Robot cell*: Robot SCORBOT ER-VII, artificial vision system, conveyor system, computer based local controller, located at Department of Production and Systems Engineering (DPS-LASAP).
    1.4 *Control center*: Video projector, computer based remote controller, computer based real time video and audio system, located at Department of Production and Systems Engineering (DPS-LASAP).

2. Software System
    2.1 Applications for *Human-Computer Interface* (HMI): Interfaces for machine tool and robot programming and control, interface for production planning and control.
    2.2 *Computer-Machine Interface*, via RS-232C.
    2.3 *Computer-Computer Interface*, for communications via Internet.

The cell structure is presented in figure 4 and its formal specification is given in figure 5.
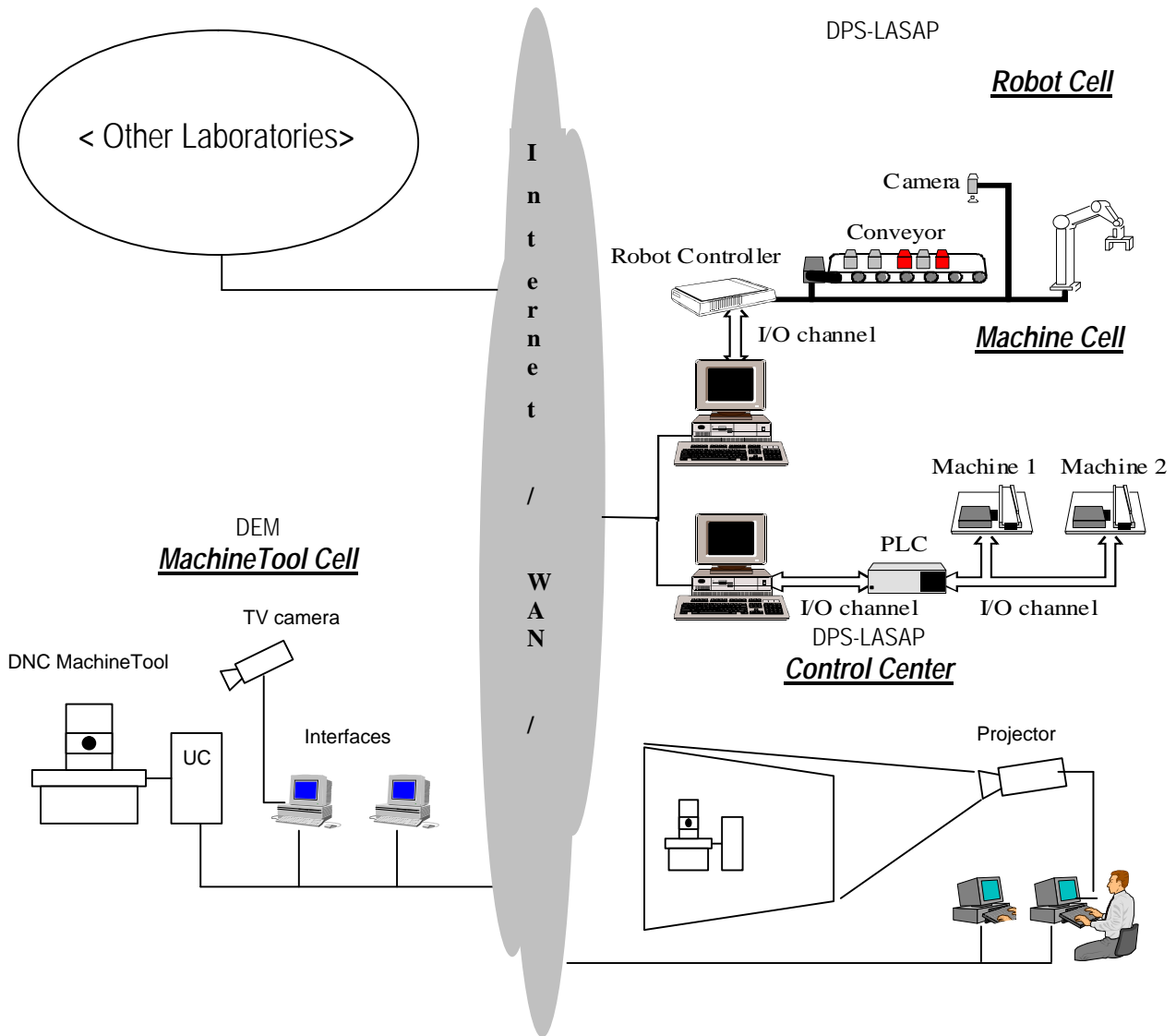

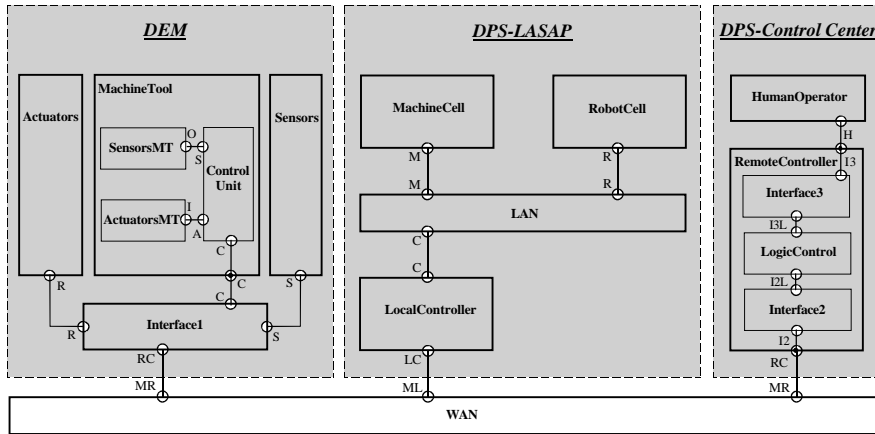Figure 4. Informal representation of the system structure.

Figure 5. Estelle formal representation of the D/V MS Cell – AURORA 98

The modules MachineCell and RobotCell are detailed in figure 6a) and 6b) :
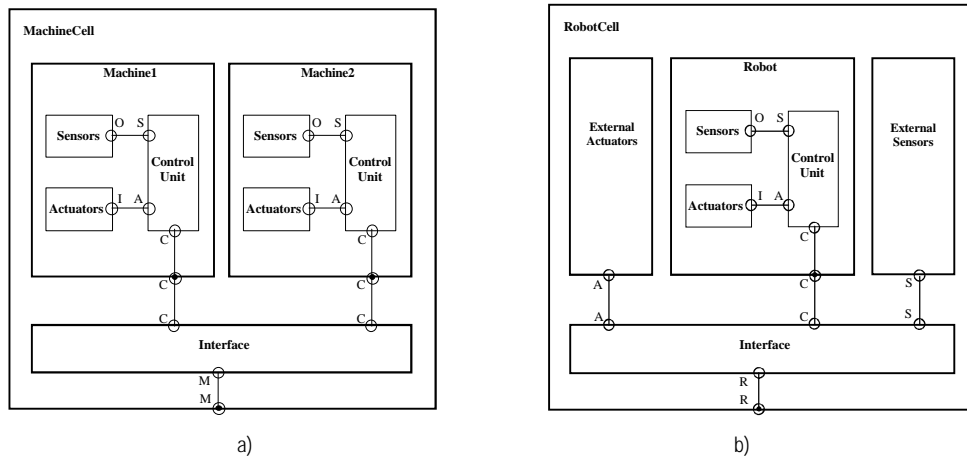

a)

b)

Figure 6. (a) Estelle formal representation of MachineCell module, (b) Estelle formal representation of RobotCell module.

The hardware structure of the (D/V MS) Cell is already implemented and interfaces for machine tool programming and control developed (software system) (Moreira F.; 1998). The operation of the complete system is planned for the year 1999.

On the figure 7. it is shown the virtual panel for the milling machine programing and control. On the figures 8. and 9. are presented conceptual design of Tele-service environment for the machine toll (or robot) control and a remote operator during a working session.

Figure 7 – Virtual Panel of the FFI FV-100 milling machine.

Figure 8 – Remote working session with real-time video and audio transmission.

Fig. 9 – Remote operator during a working session.

As we have said, the cell will serve as a base for creation of net bringing to life a virtual market of cells candidates for integration in a Distributed/Virtual Manufacturing System. Participants of this market will be other universities, research centres or companies. In fact an extension of the cell for the network/virtual market will be relatively simple considering that the project will provide the basic model and technology to realise it.

A formal specification of the network/virtual market is presented in figure 10, and the informal representation on figure 11:
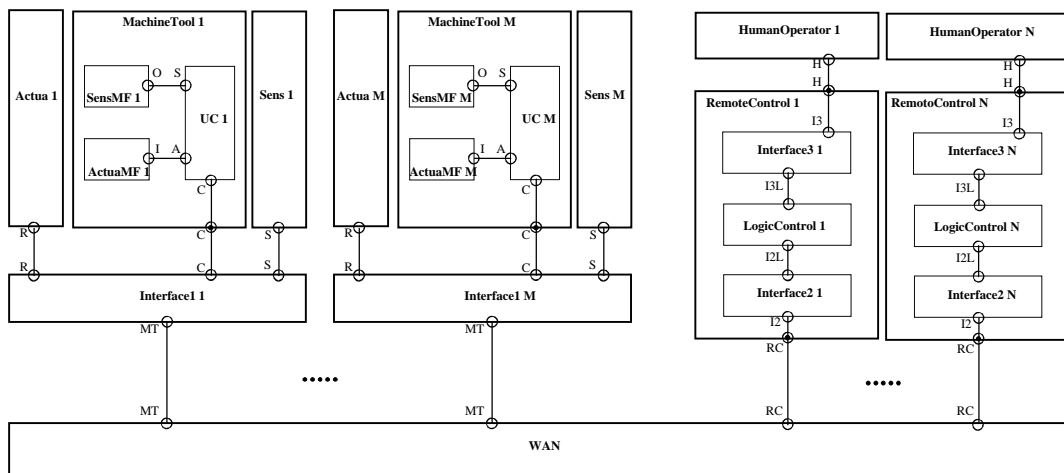

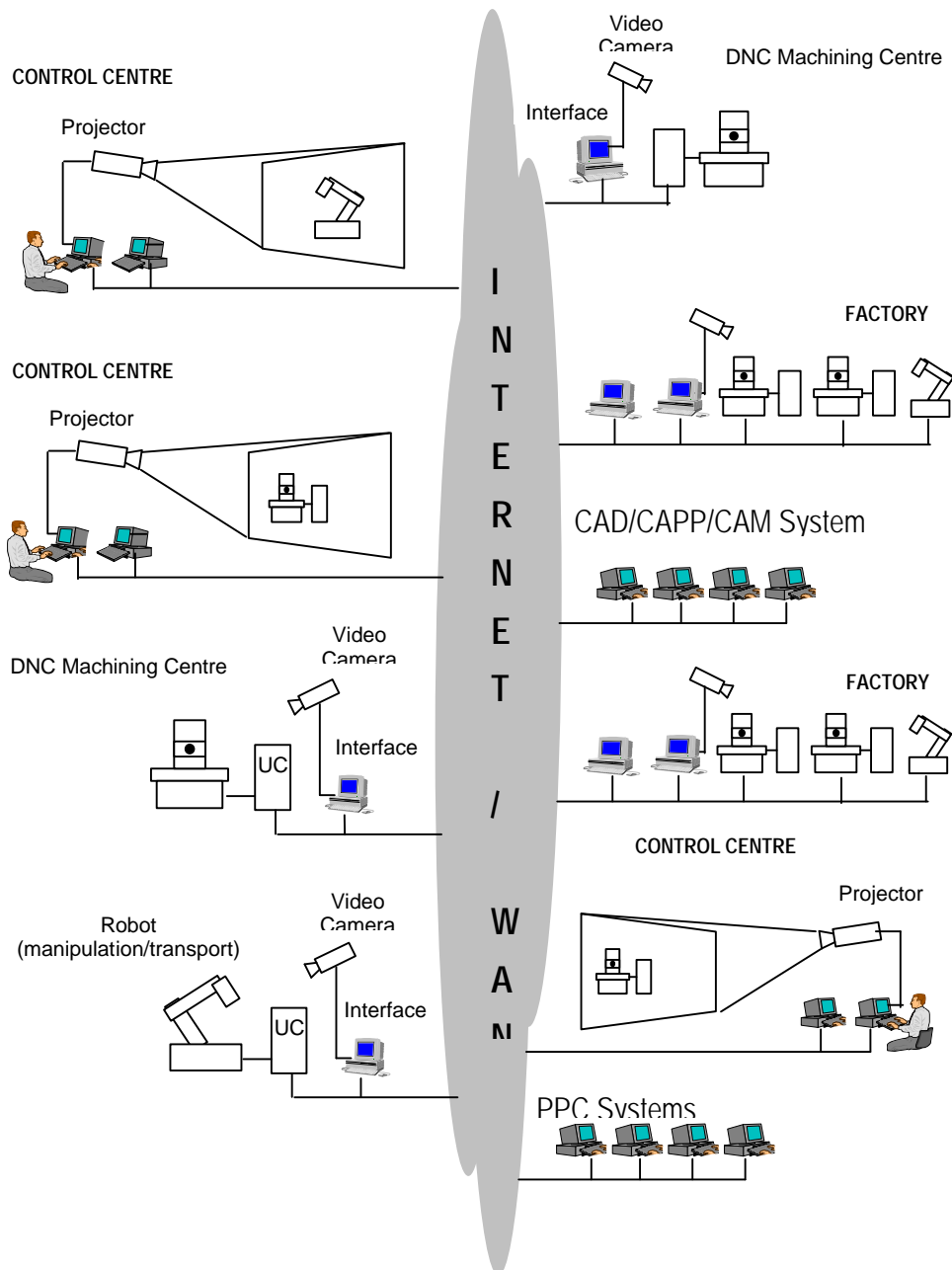Figure 10. Estelle formal specification of the network/virtual market.

Figure 11. Informal representation of the network/virtual market.

4. Project as a platform for an international co-operation

The co-operation of the Department of Production and Systems Engineering at the University of Minho and of the Department of Production Engineering, Mechanical Faculty at the Belgrade University, will be on development and applications of the **distributed simulation technology**. This technology will be used as a tool for D/V MS design and control. The further co-operation of these two Departments will be in the field of students' practical (Tele)work assignments, providing to the students of both Universities the access to remote laboratorial resources and training on distributed and virtual manufacturing systems design and operation.

It is expected that other Universities and Institutions, from different countries, will join the net.

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