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This paper presents the development of a remote monitoring and control system for a CIM plant. It discusses the main steps for the system specification. The purpose of the remote access system is to provide the user with facilities necessary to understand the system behavior, propose supervisory control strategies and test them.

1. INTRODUCTION

Generally, e-manufacturing is described as the use of Internet to exchange information and achieve rapid response in a distributed and disperse manufacturing environment. The concept of e-manufacturing has emerged during the last years as a consequence of the popularization of Internet applications in business processes. The so-called e-business has added speed to many activities related to the manufacturing industry, particularly to those related to the interaction with suppliers, partners and customers. The high-level of competition among industries, the need of minimizing lead-times, and the demand for optimized scheduling procedures are among the reasons that have been pushing the development of Internet-based applications to exchange information in all levels of an organization.

According to (Lee, 2003), e-manufacturing is a recent concept developed to answer the needs of e-business strategies and meet the requirements for the complete integration of all business elements including all suppliers, customer service networks and manufacturing units through the effective use of web-enabled computational tools and tether-free technologies. E-manufacturing includes remote facilities with the ability to monitor the plant floor assets, predict variation in performance, dynamically reschedule production and maintenance operations, and synchronize related and consequent actions in order to achieve a complete integration between manufacturing systems and upper-level enterprise applications.

E-manufacturing is a broad field of research. A number of examples of successful applications and researches can be found in literature and in industry.

In (Hao et al, 2005), the problem of factory integration is approached by proposing a framework based on Web Services and agents that actuates in all levels of the organization – from the virtual enterprise (inter-enterprise), to the enterprise (intra-enterprise) and shop floor levels. (Wang et al, 2001) explores the Internet for product data management. It proposes an integrated data model to the information integration for remote robot manufacturing. The data model is exchanged among geographically spread customers, suppliers, design and manufacturing companies,

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through the lifecycle stages of the product, from requirement specification and conception design, detailed design, fabrication and assembly, installation and operation.

Other web-based solutions focus on Supply-Chain Management (SCM) and Enterprise Resource Planning (ERP) systems. In (Frohlich, Westbrook, 2002) different strategies for demand and supply integration are discussed. Customers and suppliers are linked together into tightly integrated networks where real-time information travels immediately backwards through demand-driven supply chains while inventory flows swiftly forwards.

Another area of research is the development of a collaborative design environment by interconnecting CAD/CAE/CAM systems. Some examples are (Li et al, 2004; Zhan et al, 2003). These works provide an Internet based computational architecture that supports the sharing and transferring of knowledge and information amongst geographically distributed and disperse centers.

Finally, some works focus on the development of remote monitoring and control of manufacturing process. Among them, (Muto, 2003) presents a XML system called *@factory* that provides remote surveillance, video camera monitoring, schedule management and data analysis for CNC machines.

In the context of this last area of research, the purpose of the paper is to systematize the specification phase of remote monitoring and control systems. It proposes the division of the specification phase into a set of steps. Each step approaches a different problem of the specification of remote monitoring and control systems. The paper presents as an example the application of the e-manufacturing paradigm to a CIM (Computer Integrated Manufacturing) plant of a research laboratory. The focus is on the development of a computational tool for remote monitoring and control of the CIM. This work is been developed as part of the Brazilian Government Program TIDIA/KyaTera (TIDIA-KyaTera, 2006), which connects a number of research laboratories through an advanced high-speed optical network. The TIDIA/Kyatera network is been used as a testbed for research in different areas including the remote control of manufacturing systems.

The paper is organized as follows. Section 2 approaches the problem of specifying remote monitoring and control systems. Section 3 presents the remote control system developed for the CIM plant and Section 4 presents some conclusions.

2. SPECIFICATION OF REMOTE MONITORING AND CONTROL SYSTEMS

The specification of remote monitoring and control system can be organized into a sequence of steps. Each step approaches the system under a different perspective and increases the level of detail of the system specification. In each step, a set of questions must be answered, analyzing a different view of the remote system to be developed. The steps are organized in questions in order to guide and facilitate its applicability.

2.2 Step 1 – Monitoring or control?

The first step consists of defining the purposes of the remote access system. The first

point to be defined is if the system will have only monitoring functions or also control facilities. The answers given at this point may change due to limitations imposed by the characteristics of the manufacturing system and the available resources.

In a remote access system, the information collected from the local manufacturing system is available in real-time in the remote destination. So, a remote access system is justifiable only when the data collected is also *processed and used in real-time* in the destination. When the real-time availability is not a key issue, a simple solution is to store the data locally and use conventional tools for sharing databases through the Internet. The first questions to be answered are:

Question 1.1 – *What are the advantages of making information about the remote system available in real-time?*

Question 1.2 – *What kind of decision can be taken based on the available data in the remote destination?*

The motivations for providing control facilities are investigated by establishing what decisions are taken based on the data provided by the remote access system. Basically, the first point is to determine what system may be affected by the decisions of the remote system. Figure 1 illustrates some of the possible configurations for a remote access system. In Figure 1a) the decisions interfere in the evolution of a remote system. An example is when the parameters of the local production are used to control the evolution of a remote system. In Figure 1b) the data is processed by a remote computer or user and affects the evolution of the local system – this is the case of remote control. An example is when a remote operator does the maintenance of a local machine. A third kind of configuration is when the remote decisions are taken based on the combined information from several systems, which are also affected by the decisions. An example is when the scheduling and resource management of geographically spread plants are adjusted in real-time based on their current performance.

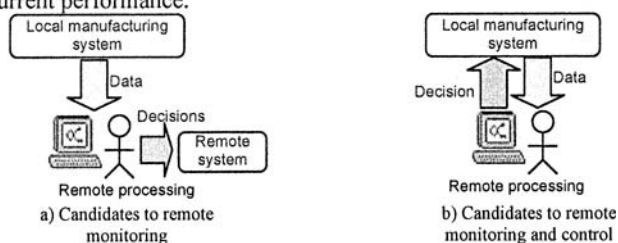


Figure 1. Configurations for remote monitoring and control.

2.3 Step 2 – Specification of use cases and exchanged information

In order to determine the data to be transmitted between the remote and local system the first question of Step 2 is:

Question 2.1 – *What are the system use-cases and who are their actors?*

This first question can be documented using the Use-Case Diagram of UML (Unified Modeling Language) (Rumbaugh et al, 2004). Among the points to be analyzed when specifying the use-cases is the maintenance of history records and databases, which can be in the local system or in a remote system. At this point, the

functional requirements of the system are considered at a high-level of abstraction. Other requirements, such as real-time restrictions are treated in the next steps.

Once the use-cases have been specified the next step is to make a list of the data needed on the remote processing point to take the decisions specified in Step 1. The second question of Step 2 is:

Question 2.2 – *What information is exchanged between local and remote systems?*

2.4 Step 3 – Hardware analysis

Step 3 analyzes the viability of the remote access from the hardware point of view:

Question 3.1 – *What are the system nodes and how they communicate among them?*

In the case that there is more than one node in the local system, the local nodes may communicate using local networks. Each local node can communicate directly to the remote system or they may be connected to a local server that centralizes and manages the communication via Internet with the remote system. Another point is how the local nodes are connected with databases and history recorders.

The next questions are:

Question 3.2 – *What is the hardware for communicating with the local manufacturing system by Internet?*

Question 3.3 – *What is the kind of programming language used for developing the remote access system and what are the technologies available for implementing the communication via Internet?*

This last question must specify if the remote access system will be a web-page, software developed using general purposes programming languages.

2.5 Step 4 – Software refinement

In this step each use-case is detailed. This can be done by representing the sequences of activities in UML Activity Diagrams. The question of Step 4 is:

Question 4.1 – *What are the sequence of activities for each use-case?*

Question 4.2 – *Can the local manufacturing system be accessed by multiples remote system (simultaneously or not)?*

Question 4.3 – *In the case of remote control system, how conflicts are managed?*

2.6 Step 5 – Requirements for remote access

The last step of the remote system specification regards the requirements related to the remote nature of the monitoring and control system. The questions to be answered are:

Question 5.1 – *What happens in the case of communication failure: is the local system able to detect communication failure and put the system in a safe state?*

Question 5.2 – *Are the communication delay critical to the system operation and does the local system check the communication delay, taking the appropriate actions?*

Question 5.3 – *What are the facilities available for the remote system reacting to failures in the local manufacturing system?*

Question 5.4 – *Does the remote nature compromise the system safeness?*

3. CIM SYSTEM AT LSA/EPUSP

3.1 Description of the System

This system to be remote accessed is a computer integrated manufacturing plant installed for research and didactic purposes at Escola Politécnica of University of São Paulo. The CIM system is composed of four stations (Figure 2): a storage station, an inspection station, a transportation station and an assembly station.

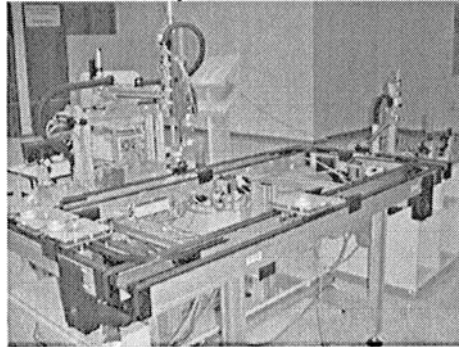


Figure 2. CIM system at LSA/ Escola Politécnica of University of São Paulo.

The purpose of the system is to assembly four components into a single product: a cylinder, an internal pine, a spring and a cover. The components are provided in different colors and must be combined according to pre-defined rules. The system is currently been used for evaluating new techniques proposed for the design of supervisory control strategies. The CIM system can operate in two configurations: a partial configuration where only the storage and inspection stations are active and a full configuration where the four stations are active.

Due to the limited space, this paper will focus on operation under the partial configuration. Basically, the storage station has a buffer of cylinders operated by a pneumatic piston. The cylinders are removed from the buffer and transported to the inspection station by a rotating arm with a vacuum vent. In the inspection station, the color of the cylinder is determined by a set of sensors, as well as its height. If the cylinder has the appropriate height it is sent to the transportation station by a pneumatic actuator, otherwise it discarded in a refuge area.

3.2 Specification of the CIM remote access system

Step 1 – Monitor or Control?

The purpose of the remote access system is to provide the user with facilities necessary to understand the system behavior, propose supervisory control strategies and test them. The user must be able to monitor the system behavior and control the execution of events in each module. This is clearly the case of developing a remote monitoring *and* control system, as the remote user must interfere in the local manufacturing system.

Step 2 – Specification of use cases and exchanged information

There are two actors: local user and remote user. The system can operate in one of the following modes: automatic, step-by-step and testing. Figure 3 details the use

cases for the partial configuration. Basically, in the automatic mode the system performs a pre-defined sequence of operations that sends a cylinder to the transportation module. This is the mode used for understanding the system behavior. In the step-by-step mode the same sequence is performed but the user fires each step, this is the mode used for collecting data about the system, such as the time for performing each operation. In the testing mode the user select the operation to be performed. This is the mode used for testing supervisory control strategies.

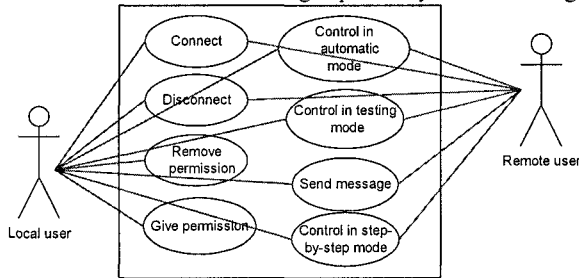


Figure 3 – Use-Case Diagram for partial configuration.

The local user has priority over the remote user. Although a remote user can always connect to the system and monitor it, he can only control the system when the local user gives permission. The local user can also remove the control of the system from the remote user. All the local and remote users connected to the system can exchange messages through a chat area – even when they do not have the control of the system.

The information to be transmitted from the local manufacturing system to the remote user is:

- if the remote user is connected or not; if he is controlling the CIM or not;
- the current state of the CIM system;
- a real-time video to understand the CIM operation and detect problems;
- text messages elaborated by the local user.

The information to be transmitted from the remote user to the local manufacturing system is:

- a request to connect or disconnect to the CIM system;
- the current mode of control chosen by the remote user;
- commands to start and interrupt the sequence of operation in the automatic mode, perform another step in the step by step mode, and perform each operation in the testing mode.
- text messages elaborated by the remote user.

Step 3 – Hardware analysis

The system architecture is illustrated in Figure 4. Each station has a PLC that controls its operation. A local PC centralizes the communication between the four stations and the Internet (remote PC). In the partial configuration the two stations are connected with the local PC by serial communication. In the case of full configuration, a Profibus network connects the four stations. The bus master is station 4. The remote access system is implemented in using generic purposes programming language (Borland C++), while communication via Internet is performed using sockets.

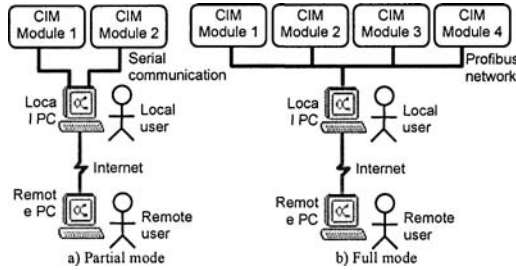


Figure 4. Configurations for remote monitoring and control.

Step 4 – Software specification

Each use-case is detailed in an UML Activity Diagram. As an example, Figure 5 presents the UML Activity Diagram for the 'control in testing mode' use-case.

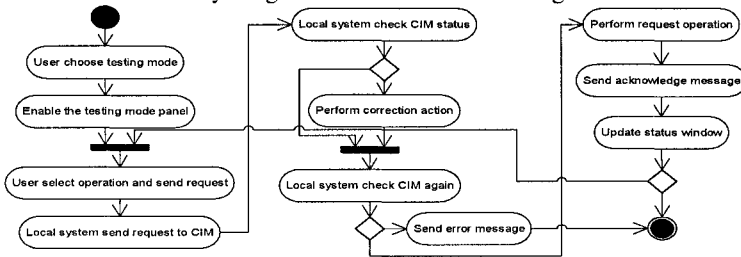


Figure 5. Activity Diagram for the use-case 'control in testing mode'.

Although multiples remote users can be connect to the CIM system at the same time, visualize the CIM evolution and exchange message; only one user at a time has the control of the CIM system. The local user chooses the remote user that has the control.

Step 5 – Requirements for remote access

The last step regards the requirements related to the remote nature of the system. The communication delay is not critical for its operation because its evolution is driven by discrete events. The following requirements are specified, among others:

- The local system must send acknowledge messages with a certain frequency in order to detect when the remote system lose the connection the local system. In this case, the local PC must warn the local user in order to give the control of the CIM system to another remote user.
- The local PC must check the current state of the CIM before requiring an operation. When the CIM is not on a safe state, an adequate correcting operation must be performed. An example is when a request to send a cylinder to the inspection module is emitted but it is already occupied by another cylinder – in this case the cylinder in the inspection module must be sent to the refuge area.
- When an operation is required but is not performed in a certain time interval, the local and remote users must be warned of the occurrence of a fault.

The requirements of Step 5 must be verified in order to validate the specification. For this purpose, a model of the remote access system and local manufacturing systems is build and analyzed using formal techniques and simulation tools.

The remote control system developed based on the specification describe in this section is current under operation. An example of the remote control system interface is presented in Figure 6.

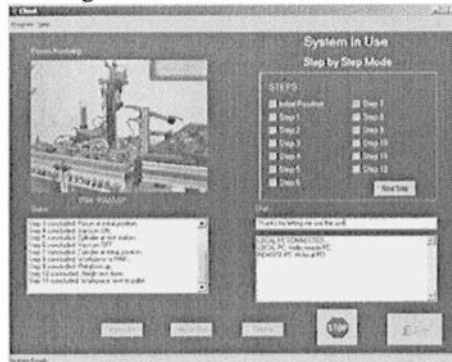


Figure 6. Interface of the remote control system.

4. CONCLUSION

This paper introduces a systematic approach for the specification of remote monitoring and control systems. In order to illustrate the approach the development of a remote monitoring and control system for a didactic assembly plant is presented. Currently, the specification method is been applied to a number of case studies with different characteristics in order to validate it.

5. ACKNOWLEDGEMENTS

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