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# Wireless Network Control For Internet Manufacturing

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## Abstract

The control of a manufacturing process can be carried out in a wireless networked environment. This allows for realistic real time control and simulation. This can be achieved through the declarative definition of Computer Integrated Manufacturing (CIM) components, the standardisation of CIM interfaces and the object-orientated approach to model development and data management. Control for Internet manufacturing can produce an efficient and effective solution for CIM processes. This approach allows a remote user to monitor and control CIM processes in real time over the Internet. A mechatronic design approach has been applied to the development of a CIM Internet control system, to optimise the overall function of a CIM system.

The research described in this paper addresses the topics of advanced manufacturing technologies, specifically Computer Integrated Manufacturing and Modular Mechatronics. The primary concern is the development of an Internet controlled manufacturing environment, which utilises wireless network technology.

## 1 Introduction

Multimedia works well in the computerised manufacturing environment, because it is cost-effective, convenient and the results can be measured [Rahman et.al.]. There is a need for enterprise integration, because modern manufacturing operations are more decentralised in nature. This may be achieved using multimedia capable computer wireless networks, especially in the process of integrating various functional areas such as marketing, design and planning, production and distribution within the enterprise [Potgieter et.al.]. To succeed, the Internet-based multimedia products have to be based on standard products. These include transceivers, network interface cards, gateways, small servers, sensors and controllers, and a widely accepted operating system.

Some functional areas of manufacturing have been considered for Internet uses. These include Computer Integrated Manufacturing (CIM), Flexible Manufacturing Systems (FMS), Computer Aided Design (CAD), Automated Storage and Retrieval Systems (AS/RS), and Robot control and scheduling. The modular design approach simplifies the manufacturing, control and implementation of an Internet-based manufacturing process. The traditionally separate functions of research and development, design, production, assembly, inspection, and quality control are linked in Computer Integrated Manufacturing processes. Integration requires that quantitative relationships among product designs, materials, manufacturing processes and equipment capabilities, and related activities be well understood [Kalpakjian et.al.]. The effectiveness of a CIM system depends on the presence of some large-scale, integrated communications system involving computers, machines, and their controls. Each component of the CIM system, when broken down into its most simplistic components, must be seen as an actuator. A microprocessor-controlled actuator within a CIM cell consists of sensors, motors and linear/rotary actuators capable of position feedback and speed control. All these CIM cell components are connected to a PC-based controller that connects via a wireless communication system to a host controller as in Figure 1.

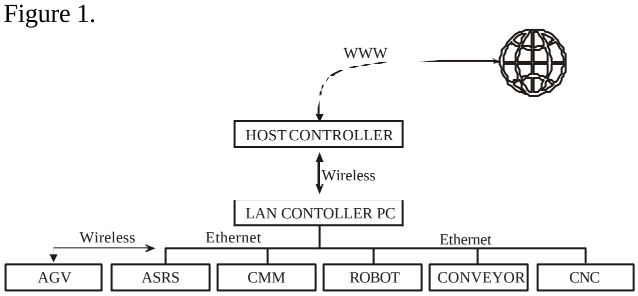



Figure 1: CIM Architecture [Potgieter]

On a primary level, these CIM components are controlled using modular mechatronic principles [Potgieter et.al]. Mechatronics encapsulate the integration of electronics, control engineering and mechanical engineering, where there is a trend towards the development of modular actuating systems. The approach of the modular design technique is to start the design process at the software and electronic control stage with initial disregard for the actuating system. This design approach allows for the development of standardised control systems for the entire CIM system.

## 2 Internet Manufacturing Technologies

Information technology (IT) is now becoming a new challenge for the designer. IT provides information for the manufacturing engineer, and recently knowledge management systems have been developed to provide greater assistance [Counsell et.al.]. IT software tools have been developed which provide designers with a usable methodology for requirements capture, conceptual design and control.

Web-based manufacturing is a concept that has captured the interest of researchers and developers. The World Wide Web is used as the infrastructure for teleoperation. Manual closed-loop control, where the human operator forms part of the control loop is the earliest and most studied form of teleoperation [Taylor et.al.]. At its simplest, communication is through mechanical linkages and feedback is by direct viewing.

If there is significant time delay in communication, instability occurs and manual closed-loop control is no longer suitable. One technique that can improve operator performance and avoid instability problems is a shared or supervisory control scheme, where the control of the robot or device is shared between a local control loop and the human operator. World Wide Web teleoperation is a concept that involves the control of the remote device from within an Internet application. It requires a supervisory control scheme to avoid instability and makes the manufacturing environment available to vast numbers of people, thus opening a new range of applications.

## 3 Modular Mechatronic Systems

The research employs a design methodology referred to as, *Modular Mechatronics*, which optimises the development of the Internet-based manufacturing environment [Potgieter et.al]. The modular mechatronic design methodology is a rapid system development tool integrating system building blocks comprising established mechatronic principles and systems. The Internet-based CIM control system presented in this research was developed using the modular mechatronic rapid system development tool and therefore provided a practical design strategy for modern mechatronic systems.

Manufacturing is a complex system composed of many diverse physical and human elements, some of which are difficult to predict and control [Kalpakjian et.al.]. Ideally, a manufacturing system should be represented by mathematical and physical models, which shows the nature and extent of interdependence of variables involved. In a manufacturing system, a change or disturbance anywhere in the system requires that it make a system wide adjustment in order to continue functioning efficiently. The demand for a product may fluctuate randomly and rapidly, because of its style, size, or production volume. Modelling such a complex system can be difficult due to a lack of comprehensive or reliable data on many of the variables involved. The standardisation of the design and control methodology simplifies the manufacturing systems and minimises the system complexity.

[Honekamp et.al.] proposes a modular design approach that requires the functional decomposition of the project into mechatronic functional modules and implementing the hierarchical structuring of the mechatronic functional modules to develop mechatronic systems. The base level of the mechatronic functional modules is defined to be an encapsulated mechatronic system comprising of a supporting structure, actuator/sensor groups and controller elements.

The modular mechatronic design approach allows the project definition to be decomposed into independent sub-tasks according to the individual mechatronic functionality of each module. These sub-tasks define the mechatronic functional modules and therefore represent encapsulated mechatronic systems.

The success of the modular mechatronic design methodology is dependant on the computer-based integration of the various functional mechatronic modules. The responsibilities of the computer-based controller can be organised in multiple levels, ranging from low-level control through supervision to general system management [Isermann]. Figure 2 shows the functional modular mechatronic sub-tasks required by the Internet-based PUMA industrial robot and integrated conveyer control system presented in this paper.

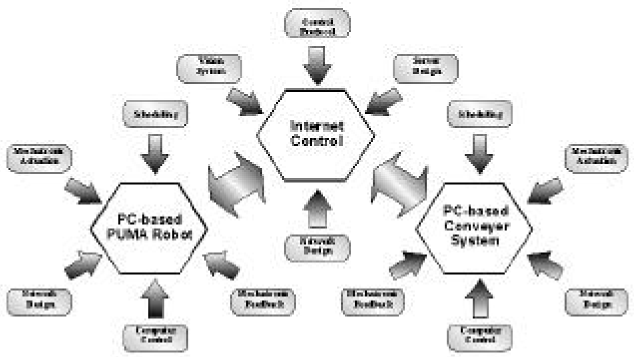



Figure 2: The functional modular mechatronic sub-tasks required by the Internet-based CIM control system. Note how functional mechatronic modules are shared between systems.

The integration of the modular mechatronics systems in a software domain is achieved by the development of algorithms that control the coordinated interaction of the individual sub-tasks. The modular mechatronic rapid system development tool should therefore be able to ensure the rapid development of flexible Internet-based manufacturing technologies.

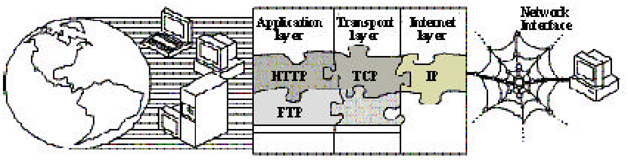
Modular mechatronic systems can be applied to a variety of automated manufacturing operations. These operations can be further extended by including information processing functions and utilising an extensive network of interactive computers. The communication between the individual computers can now be established using wireless network technology. This allows for the freedom of movement of computers within a defined area of transmission, thus enhancing the modular Mechatronic design approach of the CIM Cell.

Computer Integrated Manufacturing is both a methodology and a goal, rather than an assemblage of equipment and computers. Implementation of CIM in existing plants may begin with modules in various phases of operation. This provides an ideal platform for the implementation of the modular mechatronic design methodology.

## 4 The CIM teleoperation system

Internet technology provides the platform for the development of an integrated wireless network environment. This can be used for diversified applications of different manufacturing systems. To be successful in real-world applications, Internet controlled machines require a high degree of autonomy and local intelligence to deal with the restricted bandwidth and arbitrary transmission delays of the Internet [Hu et.al.].

With the rapid development of the Internet, more intelligent devices and systems have been developed. The Internet provides a cheap and readily available communication channel for teleoperation. There are still many problems that need to be resolved before successful real-world applications can be achieved. One way to overcome these problems is to remove the closed-loop control of the human operator and provide a high degree




of machine intelligence for the uncertainties in real-world applications. As researchers, it is essential to find the correct balance between human and machine interaction. Also an intuitive user interface is required for inexperienced people that control machinery over the Internet. Figure 3 shows the protocol layers used during Internet information transfer.

Figure 3: Internet protocols during information transfer.

CIM components must not only be controlled, but also monitored. The solution of this research problem consisted of two parts. The first part covered getting information about the process being monitored. The process was naturally active during this time. The second part represented visualisation of the process on the Internet providing actual information through the World Wide Web.

The continuous and steady image stream feedback from the CIM cell was necessary for the Internet user to control the CIM components. Moreover, the image quality was good enough to provide as much information as possible about the CIM cell for teleoperation.

The front-end imaging system of the *visual feedback module* consisted of three modules, the image sensor, the image acquisition and interface card and the computer processor. The visual feedback module consisted of four overhead cameras monitoring the CIM cell.

The Camera selector Client controller controlled the camera selection and the Host Server controlled the image capture process. Each camera signal was relayed by cable to the camera selector circuit.

Once the appropriate view was selected, the single camera view signal was then captured using a FlashPoint$^{3D}$ frame grabber. The FlashPoint$^{3D}$ frame grabber card was an AGP board that transferred images significantly faster than more conventional formats. The visual feedback module used Server push technology, where the video was made up from a stream of still images, and sent by a Java program to a Java applet via a socket, and interpreted by the applet in JPEG format.

The FlashPoint$^{3D}$ frame grabber, captured a still image every 250 milliseconds and saved this image to the image directory of the Web page on the image Server. The Java applet was imbedded in the Image Server Web page. The Java applet allowed the image to be updated at 4 frames per second. The size of the still image was 15Kb, which was easily transmitted to the Client machine, without causing network congestion. Figure 4 shows the live video feed Web page.

The communication between the various CIM Clients and CIM Host was achieved using a wireless TCP/IP communications protocol. The system used low-level control commands to instruct the various CIM controllers to perform a task. The CIM controllers then relied on primary machine intelligence to perform the task. This control structure eliminated Intemet lag problems associated with the control of machines over vast network distances. The standardisation of Mechatronic components simplified the control and monitoring of the various CIM components.

The CIM Host controller communicated with the CIM Clients using one WinSock controller for each Client. To connect to a WinSock controller required an IP address and a port. On the CIM Host controller the IP address was fixed, each Client was connected to a different Port number. Simply adding more Winsock Controls allows for more Clients to connect to the Host controller, which provided the system with modularity. If the connecting client tried to connect using a conflicting port number, the Host controller forcefully rejected the connection.

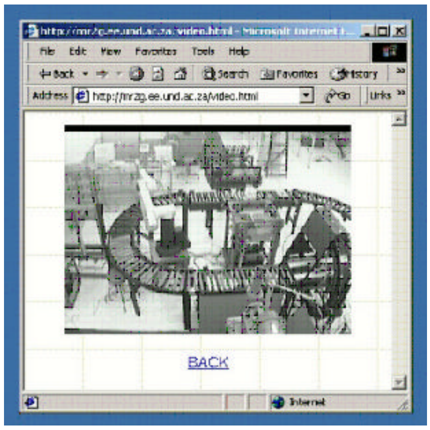



Figure 4: The live video feed Web page.

A PUMA industrial robot, CIM conveyer system and an automated visual inspection system were computer-based technologies that were controlled. These apparatus incorporated mechatronic actuators, feedback devices and network hardware. This equipment for the CIM system was controlled remotely using the supervisory control strategy. The primary controllers contained the machine logic to efficiently execute the supervisory control commands from the remote Web Client.

The CIM Host Controller (Server) received the supervisory control signals from the remote Web Client and relayed the appropriate control signals to the CIM controllers. The Host Controller transmitted the control information across the entire CIM network, but only the appropriate CIM components received and used the information. The CIM controller's set-up, allows the conveyer Client and robot Client to only communicate with the Host Controller. The Host Controller receives the feedback commands and processed the information according to a pre-programmed algorithm. Table 1 shows the control commands used to control the conveyer system.

| Command Number | CIM Host - Conveyer Client | Conveyer Client - CIM Host |
|---|---|---|
| 1 | ClientCON-START | |
| 2 | ClientCON-AGVAVIS | |
| 3 | ClientCON-AVISAGV | |
| 4 | ClientCON-AGVROBOT | |
| 5 | ClientCON-ROBOTAGV | |
| 6 | ClientCON-AVISROBOT | |
| 7 | ClientCON-ROBOTAVIS | |
| 8 | ClientCON-EXIT | |
| 9 | | HostCON-AGV |
| 10 | | HostCON-ROBOT |
| 11 | | HostCON-AVIS |
| 12 | | HostCON-RUN |
| 13 | | HostCON-EXIT |

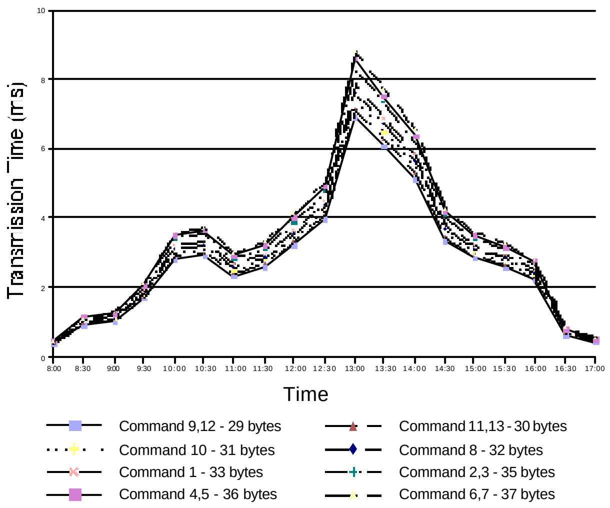



Table 1: The control commands for the PC-based conveyer system.

The transmission time performance for each command between the CIM Host and Camera Selector Client is plotted in Figure 5.

Figure 5: Graph of the transmission times between the CIM Host and the Conveyer Client.

Figure 5 shows the longest transmission time interval is 8.847 milliseconds, for a 37 byte data packet at 13:00 hours. The Conveyer Client received the command to start a material handling routine from the CIM Host in less than 9 milliseconds from transmission. During off-peak times, 17:00 hours, this value dropped below 600 microseconds.

## Conclusion

The Internet-based control system has been developed in a controlled laboratory environment, with very low electronic noise. Future research will be undertaken establish the significance of interference of these wireless communication networks within an established manufacturing environment. The CIM control strategy was developed as a PC-based technology using the *modular mechatronic* design methodology. It represents an original and meaningful contribution to the fields of Internet manufacturing technologies, wireless networks and modular mechatronic computer integrated manufacturing.

The CIM conveyer system and PUMA robot were implemented as computer-based technologies. The advanced control algorithms required to sequence and coordinate the interaction of the CIM components to perform the standard routines were developed and coded in Microsoft Visual Basic 6 (VB6). The Web client graphical user interface (GUI) was developed using a combination of VBScript, HTML and JAVA. The functional capabilities of the developed Internet control structure introduced a high level of flexibility for product development and manufacturing.

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