

AC 2008-1947: DEVELOPMENT OF AN ONLINE LABORATORY FOR COMPUTER-INTEGRATED MANUFACTURING COURSES

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Development of an Online Laboratory for Computer Integrated Manufacturing Courses

I. Introduction

This paper describes the development of an online laboratory for students in Computer-Integrated Manufacturing (CIM) courses. Computer-Integrated Manufacturing is a comprehensive topic taught in a 400 level course to senior undergraduate students, and in a 600 level online course to graduate students. Teaching computer-integrated manufacturing courses can be a challenge because of the breadth of topics spanning from manufacturing technology to electronic technology and computer technology which encompasses concepts from manufacturing processes such as modeling and milling, to manufacturing automation systems and manufacturing information management systems.

Laboratory experiences are important for technology students in the CIM courses to reinforce theories and concepts presented in class lectures. Therefore, the ability to offer hands-on lab experiences to both traditional students and online students is vital to effective learning^[1]. The development of an online laboratory will enable participation in laboratory experiences by distance students. It is also motivated by the fact that presently, as never before, the demand for access to the laboratory facilities is growing rapidly in engineering and technology programs. Being able to make the laboratory infrastructure accessible as virtual laboratories, available 24 hours a day and 7 days a week, goes far in addressing these challenges, and would also contribute to lowering the costs of operating laboratories. Additionally, online virtual laboratories will provide the opportunity for students to explore the advanced technologies applied in implementing web-based remote control/monitor solutions, so to prepare them for their future careers.

Current technology enables the remote access of equipment and instruments via the Internet. With the rapid developments of computer networks and Internet technologies along with dramatic improvements in the processing power of personal computers, online virtual laboratories are now a reality^[2]. In the early 1990's, the first remotely shared control system laboratory was proposed in the 1991 ASEE Frontiers in Education Conference. The system enables sharing of laboratory data between universities using networked workstations. Since then, a variety of remote experimentation activities have been developed in universities, such as microelectronic experiments for transistor characterization, engineering introduction experiments for circuits and devices, online experiments for control systems, and remote experiments using a scanning electron microscope^[3].

The purpose of the CIM online laboratory is to provide students lab facilities and lab activities that can be accessed locally through the campus LAN network and remotely through the Internet. This paper concentrates on the development of a web-based motor control system and a wet process control system for the online laboratory. This paper introduces the hardware integration and software applications implemented in the systems, examines the procedures for the development of mechatronic systems, demonstrates the operation of the web-based control systems, and describes the lab activities that can be developed for the online laboratory.

II. The web-based motor control system

The web-based motor control system is composed of a PC with LabVIEW software, a NI PCI-7334 motion control card inserted in the PCI bus of the computer, a MID-7602 stepper drive, a SLO-SYN stepper motor and a DLink Internet camera. The control software piloting the real process locally is a virtual instrument (VI) built in the LabVIEW environment. The VI provides an interface between a user and the control process as shown in Figure 1. The main concept of such an interface is to provide a general view of the process and facilitate full control of the operations. The motion control card provides the communication channel between the computer and the motor system. Other software running behind the interface to support the system is NI motion control and NI MAX (Measurement and Automation). NI motion control is motion driver software used to support the motion controller. NI MAX is the software used for control driver management, test management, technical data management, and providing measurement services.

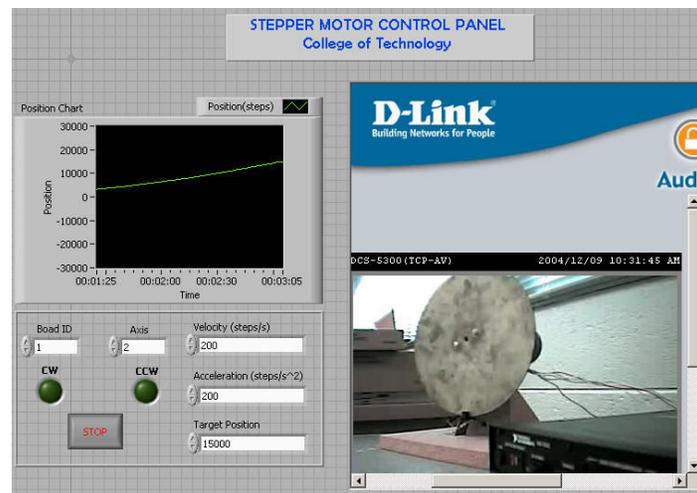


Figure 1: The control panel of the web-based motor control system

Figure 1 shows the control panel of the web-based motor control system. Students can interact in real-time with the motor control process from this control panel. On the control panel, five control parameters are required from the operator: Board ID, Axis number, velocity, acceleration, and target position. The board ID is the device ID of the motion control card assigned from MAX (Measurement & Automation) application. When multiple control cards are installed in the computer to control different systems, each system can be identified by their unique board ID. It ensures that control commands are sent to correct target devices. The axis number is the number of axis currently controlled by the operator. The control panel was designed for a one-axis movement control. When multiple motors are connected, each motor has a unique axis number. The velocity and acceleration are motion control parameters used to set the motor's velocity rate at steps per second and acceleration rate at steps² per second respectively, and they can only be positive values. The target position is the distance value for the motor movement; it can be either a positive value or a negative value. A positive value results in clockwise revolutions and a negative value results in counter-clockwise revolutions of the controlled motor. The red STOP button is used to stop the motor movement at any emergent situation. The waveform graph displays the historical record of the motor positions. A live video

was integrated in the control panel for operators to monitor the motor's movements in a real time manner. An ActiveX container was programmed and integrated into the control VI to get live video from the DLink Internet camera.

The control panel was published to the web by a web server established on the computer. Client-server architecture was constructed to make the control panel available for multiple clients. A client queue can be created for users who sent requests for control right. Only one client can actually control the system while others can monitor the control process from the control panel. The control right will be granted to the next client in the queue when it is available. The role of the client and the server can be described as below:

- The remote client can be any computer that has Internet access. The only tool that the client needs to use is a web browser. The client can browse to the webpage integrated with the control panel by entering the URL address of the web server in the browser. The client only updates the screen and gets information on the control panel, and can not make changes to VIs. Executions happen only on the server.
- The server hosts a LabVIEW web server, which publishes the VIs to the Internet. Through the LabVIEW RTE (Real Time Engine), the local server can communicate with clients, and controls the motion according to the data from the remote control panel as well as sends the current data back to the remote control panel.

The security of the control system is ensured by the management from the server side. On the server side, client requests can be granted or denied according to the IP addresses or domain names. VIs in the server can be configured to be available to or hidden from certain users.

III. The web-based wet process control system

The web-based wet process control system is composed of a PC computer, a NI compact 2000 FieldPoint controller with I/O modules, an Ethernet controller interface, an Ethernet cable, three tanks, two pumps, five discrete valves, two continuous valves, three temperature sensors, three level sensors, two pressure transmitters, and a flow rate transmitter. The physical setup of the wet process is shown below in Figure 2.

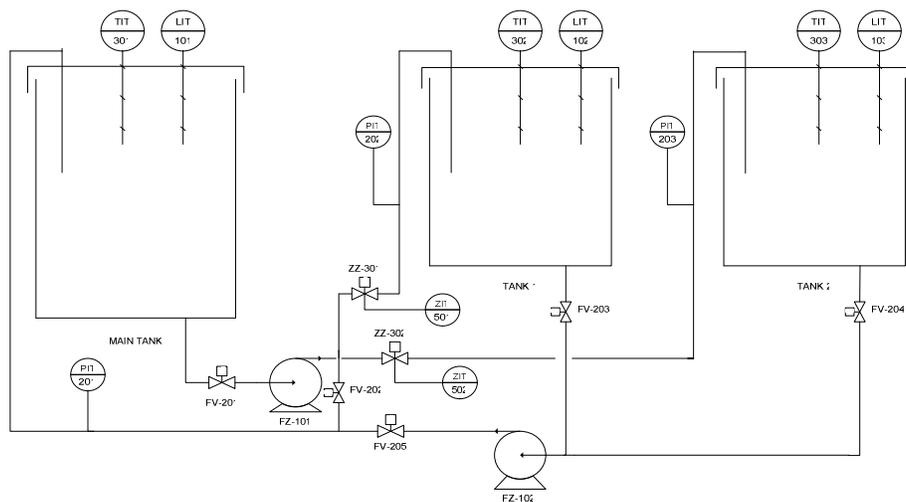


Figure 2: The physical setup of the wet process

Table 1 below provides a detailed list of the input and output devices in the physical setup of the wet process and their address assignment of corresponding control components.

Table 1.
Device list and I/O addressing of the wet process

LabVIEW Addressing	Device #	Device Description	
FP@139_102_29_56\FP-DO-400@7 (Digital Output Module)	\Channel 0	FZ-101	Pump 1
	\Channel 1	FZ-102	Pump 2
	\Channel 2	FV-201	Discrete valve 1
	\Channel 3	FV-202	Discrete valve 2
	\Channel 4	FV-203	Discrete valve 3
	\Channel 5	FV-204	Discrete valve 4
	\Channel 6	FV-205	Discrete valve 5
FP@139_102_29_56\FP-AO-200@5 (Analog Output Module)	\Channel 0	ZZ-301	Continuous control valve 1
	\Channel 1	ZZ-302	Continuous control valve 2
FP@139_102_29_56\FP-RTD-124@2 (Temperature Module)	\Channel 0	TIT-301	Temperature Sensor 1
	\Channel 1	TIT-302	Temperature Sensor 2
	\Channel 2	TIT-303	Temperature Sensor 3
FP@139_102_29_56\FP-AI-110@1 (Analog Input Module)	\Channel 2	LIT-101	Level Sensor 1
	\Channel 3	LIT-102	Level Sensor 2
	\Channel 4	LIT-103	Level Sensor 3
	\Channel 5	PIT-201	Flow Rate Transmitter
	\Channel 6	PIT-202	Pressure Sensor r 1
	\Channel 1	PIT-203	Pressure Sensor 2

A virtual interface programmed in LabVIEW provides a control panel for students to interact with the wet process through the Ethernet connection from the Ethernet controller interface (a network module on the controller) to the computer. The Ethernet communication uses an asynchronous communication architecture called event-driven communication. The network module automatically sends updates to a client when data changes. The server then caches the data from I/O modules and uses it to respond to read requests from the virtual interface. The network module scans all I/O channels with subscriptions to determine if a value have changed, comparing the current value to the cached value for each channel. If a change has occurred, the network module puts the difference between the two values in the transmit queue. The network module periodically sends and receives a time-synchronization signal so that it can adjust its clock and provide proper timestamping. When signals do not change over long periods of time, the client sends periodic re-subscribe messages to verify that the system is still online. The communication between the FP controller and I/O Modules is similar among different types of network modules. Each I/O module cycles through its internal routine of sampling all channels, digitizing the values and updating the values on the module channel registers (buffer). This cycle time is set for each module and is specified as the all channel update rate.

The virtual interface programmed for this wet process is shown in Figure 3. Controls and indicators on the interface provide the way for students to interact with the control process. A video clip was integrated into the interface for students to monitor the real process through an Internet camera. Two waveform graphics provide history data tracking of temperature and incoming pressure of each tank. The current value of tank levels, temperatures, incoming flow rate for main tank, and incoming pressure for tank 1 and tank 2 are also shown on the interface by different indicators.

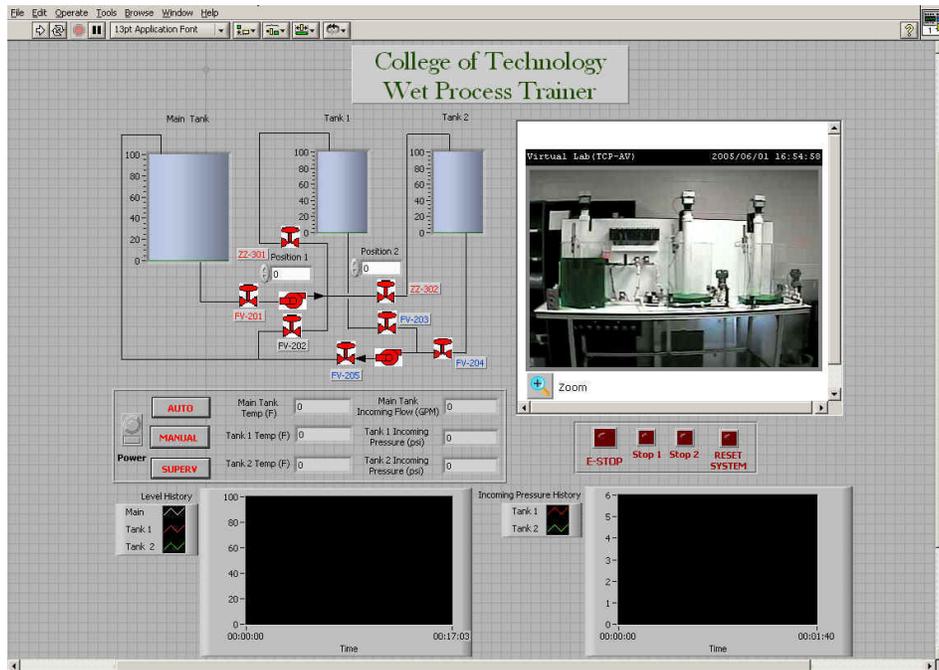


Figure 3: The interface for the web-based wet process control system

Three tank indicators represent the main tank, tank 1 and tank 2 in the physical setup of the wet process. The green line inside each tank indicates the current water level which varies from 0 to 100 percentages. The icons of valves and pumps are controls for their corresponding part in the real process. FV-201, FV-202, FV-203, FV-204, and FV-205 are controls for discrete valves. These five discrete valves and two pumps are controlled by ON/OFF Boolean signals; their status can be changed by a mouse-click on the icons. ZZ-301 and ZZ-302 represent the two continuous control valves in the real process. The status of them is controlled by the digital control below each valve symbol. The value of each digital control can be changed by clicking the arrows beside it from 0 to 100 with the increment of 10. The value of 0 represents close status of the valve, and the value of 100 represents the totally open status of the valve. The color of ZZ-301 and ZZ-302 will be changed to green color when the value of their digital control is equal or greater than 10 to indicate an ON status. Otherwise, it will be changed to red indicating an OFF status.

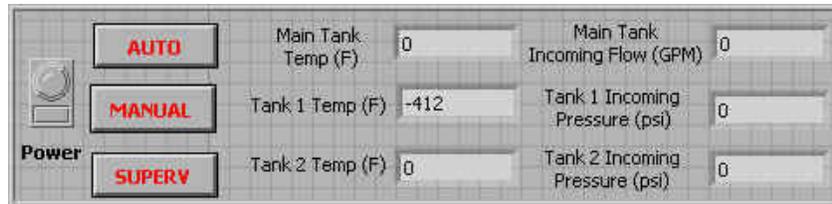


Figure 4: Mode controls and digital indicators

Figure 4 displays the part of the virtual interface with power control, mode controls and digital indicators. The power control is used to turn on/off the system, which will be in green color when the system is running. The buttons with red labels are system mode controls. This virtual interface provides three different modes for process control which include supervision mode, manual mode, and auto mode. Users can be assigned different control capabilities when different modes are enabled. In supervision mode, all the valves and pumps in the process can be controlled by users. This mode can be enabled only for maintenance and trouble-shooting purpose. In manual mode, the status change of valves and pumps will depend on both the current situation of the system and the commands from the user. For example, if the water level of the main tank is lower than 20 percent or valve FV-201 is closed, pump 1 can not be activated even if the user intends to do so by clicking on the pump symbol in the virtual interface. In auto mode, the system will control the valves and pumps automatically, depending on the water levels of each tank. The only part that users can control is the continuous control valves. Users can adjust the percentage of the continuous valves by changing the value of the digital controls. The six indicators to the right of the mode buttons are digital indicators displaying current values of tank levels, incoming flow rate, and incoming pressures.



Figure 5: Emergency Stop and Reset buttons

The virtual interface provides three emergency stop buttons and one reset button. E-Stop button will stop the whole system when pressed. Stop 1 and Stop 2 button will disable pump 1 and pump 2 respectively when pressed. Reset button is used only in auto mode to reset the system when the main tank level reaches its limits.

The web-based wet process control system was published to the web by the web server established on the PC computer. Students can access to the wet process control system from a computer with the Internet connection, control the process by interacting with the virtual interface, and monitor the real situation from the live video on the interface. Once the interface is downloaded to the client computer, right click the icon on the upper-right corner and select *request control* from the right-click menu.

IV. Lab activities developed for the online laboratory

Several lab activities have been developed and implemented in the CIM online course for graduate students as part of the required lab activities.

Lab 1: Introduction to motion control in LabVIEW

The purpose of this lab is to introduce LabVIEW graphic programming environment to students. The web-based motor control system is used to help students get familiar with LabVIEW front panel and block diagram, and explore the different functions and operations provided by LabVIEW motion control. Students will be asked to operate and monitor the motor control system through the LabVIEW interface.

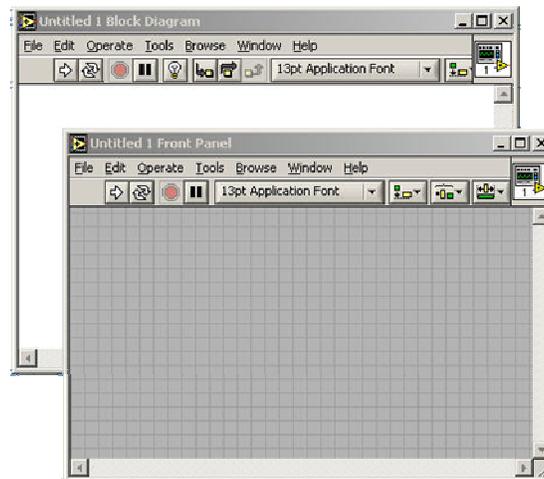


Figure 6: LabVIEW Front Panel and Block Diagram

Figure 6 shows the interface of the LabVIEW programming environment. Front panel is used to design graphic control interface, a controls palette provides various controls and indicators to be used for a control interface. The control program which runs behind the graphic interface is called block diagram which will not be displayed to end users. A function palette associated with the block diagram provides all kinds of functions and operations. Students are required to explore the major controls, indicators, functions, and operations provided by LabVIEW environment, operate and monitor the motor control system by following detail instructions through the Internet connection.

Lab 2: Programming motion control

The objectives of this lab is to help students to understand the major components in a motion control system and functions of basic motion control VIs, and gain skills in programming motion control systems. Students are required to install a LabVIEW student version on their computers, prepare a simple one-axis motor control program, send the program to the lab instructor, and test their own program for remote motor control. The board ID and the axis number are given to students for the programming. The lab instructor configures the motor and monitors the remote operations on the server.

Lab 3: Introduction to the remote process control

The objectives of this lab is to help students to understand the integration of input and output devices in a control system, examine the available devices and technologies for remote control applications, and explore the implementation of remote control applications. Students are required to operate the web process control system through the Internet connection, examine each mode available from the virtual interface, and understand the mechanism for system integration.

Lab 4: Programming for a simple process control

The objectives of this lab is to help student to gain skills in design and programming a process control system with digital input/output signals and Boolean operations. Students are required to design a process control system with valves and pumps in the wet process system, send the program to the lab instructor, and test their systems over the Internet.

Lab 5: Programming for remote measurements

The objectives of this lab is to help students understand the mechanism for retrieving analog data remotely, examine the available devices and technologies for remote data acquisition, and gain skills in developing a remote data retrieving system. Students are required to design a LabVIEW VI for remote analog data retrieving from temperature sensors, level sensors, and pressure sensors. The lab instructor provides data sheet of sensors to students and monitor their test processes on the server.

Lab 6: Design an automatic manufacturing cell for remote control and monitoring

This lab is to encourage students to apply their knowledge, skills, and experiences gained from former lectures and lab activities to design an automatic manufacturing cell for remote control and monitoring. Students are required to use sensors for measurements and use motors to simulate machine status. The machines in the manufacturing cell include 3 CNC machines, 4 industrial robots, and 1 conveyor. Based what they have learnt, students need to integrate machines and devices into a connected network, design a control interface, program the block diagram to support the control panel, assign I/O address for each device, and test their systems by controlling and monitoring the valves, sensors, and motors through the Internet connection.

V. Students feedback

We have assessed the educational value of the online laboratory through feedback from students. Our results show that most students found that these labs are very interesting, convenient to access and easy to follow. They consider the lab necessary for them to understand the concepts of mechatonic system integration, remote control, and HMI interface, and gain experiences by exploring the system through the Internet.

In addition to help students understand the concepts and principles of computer-integrated manufacturing; these lab activities provide the following main benefits.

- Hands-on experience with LabVIEW programming.
- Hands-on experience with online control and monitoring.

- Broader view on the future of industrial networking in implementing computer-integrated manufacturing.

The online laboratory currently is not available 24/7 for online students due to the security concern. However, it does provide convenient access for online students. They can schedule their lab activities in evenings and weekend days while the instructor can monitor the process through the Internet camera.

VI. Conclusion

Remote virtual laboratories over the Internet are feasible for long-distance applications. Experiences from this project show that multiple aspects must be taken into consideration to obtain adequate performance of the online laboratory. It includes a system for the connection between computers and the physical setups and a web-based networking system. In the next step of establishing more systems in the online laboratory, data acquisition, motion control, FieldPoint controllers will be integrated together for multiple systems. CNC machines, industrial robots, and a CIM cell will be available for online laboratory by the development of system integration applications and web-based human-machine interfaces.

VII. References

- [1] Gillet, D., Latchman, A.H., Salzmann, C., & Crisalle, O. D. (2003) *Hands-on laboratory experiments in flexible and distance learning*. The Journal of Engineering Education.
- [2] Chen, S.H., Chen, R., Ramakrishnan, V., Hu, S.Y., & Y. Zhang. (2002) *Development of Remote Laboratory Experimentation through Internet*. Retrieved by Mar. 10, 2006, from CMSU online library <http://cyrano.cmsu.edu:2048>.
- [3] Hutzl, W. (2001) *Creating a Virtual HVAC Laboratory for Continuing/Distance Education*. International Conference on Engineering Education.
- [4] Hua, J., & Ganz, A. (2003) *A New Model for Remote Laboratory Education Based on Next Generation Interactive Technologies*. Frontiers in Education Conference.
- [5] Salzmann, C., Latchman, H. A., Gillet, and Crisalle, O. D. (2003). *Requirements for Real-time Laboratory Experimentation over the Internet*. The Journal of Engineering Education.