Modular Laboratory Approach to CIM Teaching

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ABSTRACT

Traditional CIM (Computer Integrated Manufacturing) instruction usually revolves around a hard-wired CIM cell that comes complete with a CNC (Computer Numerical Control) machine tool, a robot tending the machine tool, a conveyor system with on-line sensors, a PLC (Programmable Logic Controller), computer interface, and air/power supply. While this setup can give a good demonstration of a working CIM cell, and can also be used for demonstrating certain parts of the system, the real challenge confronting CIM in industrial practice is how to put all these pieces together in the first place.

Unless a company buys into a turnkey installation prepared by a system house (consulting companies specializing in custom-order integration jobs) where the kinks in integrating disparate system components have already been worked out (though not always the case), the reality is that systems integration always comes with components that do not exactly match up, or for which fixes have to be made on the fly. Engineering students who are only exposed to an error-free system, uncomplicated by system bugs and minor incompatibilities, are not prepared to cope with these real world problems.

This paper presents the result of a NSF-ILI project to examine the alternative of teaching students how to integrate system components themselves, from the ground up, making use of basic principles and seeing first hand how everything does not always fit together nicely. A laboratory was established consisting of modular, table-top system components that can be mixed and matched to build many different computer integrated systems using a variety of configurations. The development of this lab and the outcome on student learning of CIM are described in this paper and in the presentation.

INTRODUCTION

Systems integration and control refers to the design, development, and orchestration of both the major and supporting components and functions of a system in a concerted manner. In manufacturing, the major components would be the machine tools, robots, inspection stations, etc., that are involved in the actual manufacturing process; the supporting components would be the conveyor belt, material handling robots, sensors, programmable logic controller, etc., that provide auxiliary services to the manufacturing process. The major functions would be the machining, forming, assembly, etc., that transform the raw materials into finished products; the supporting functions would be the part feeding and orienting, operation sequencing, sensing, dispatching, etc., that provide vital assistance to the completion of the manufacturing process.

The primary course related to this project is IE 384 (Industrial Process and Distribution Control Systems) which covers the supporting system components and functions. It includes topics that are essential to achieving system integration, such as microprocessor concepts, data communications, programmable logic control, sensing and data acquisition, material handling, identification systems, and database management. These topics are presented in an integrated manner such that the course culminates in the synthesis of a computer integrated manufacturing subsystem by the students. The presence of automated and computer-controlled equipment alone in a system does not constitute computer integrated manufacturing (CIM).[1] To realize the benefits of CIM, the operation of these equipment must be synchronized and coordinated, and the data used and shared by these equipment must be managed to provide timely, orderly, and consistent information for decision-making.

To a great extent, the knowledge required for CIM resides in the relationships between system components and functions, and in the implementation of these relationships in the system configuration. A *modular* hands-on laboratory that will enable the identification and implementation of such relationships has been developed. This modular approach is *unique* in its ability to provide students the opportunity to exercise their creativity in designing, developing, controlling, and testing different configurations of computer integrated systems. In the process, they will have an enhanced appreciation for the scientific principles as well as the practical problems that are involved in systems integration and control. This approach is a departure from the basic building block concept (e.g., Fisher-Teknik kits) on the one hand, and hard-wired CIM cells (e.g., Technovate, Amatrol) on the other hand.

In the basic building block concept, students are provided with the most basic components, such as gears, motors, links, diodes, etc. that can be assembled together like an erector set to build a model machine tool, robot manipulator, etc. Our department has these Fisher-Teknik kits, and our experience has shown that while they are effective in illustrating the principles of machine design and actuation, they are too low in the hierarchy of systems development to be an effective medium for learning system integration and control. For example, to demonstrate a coordinated robot pick-and-place activity between a conveyor and a machine tool, students first have to build models of the robot, conveyor, and machine tool. Often, students get frustrated by the poor reliability and precision of the mostly plastic materials that the building blocks are made of. By the time the students are ready to integrate the models, they also find out that communication between these models is difficult because such models were intended to be stand-alone. Thus, teaching systems integration and control using Fisher-Teknik kits is not an effective approach because of the distraction from the side activity of building and trouble-shooting the component models.

At the other end of the spectrum are hard-wired CIM cells, which may include a machine tool for processing, a robot manipulator for work handling, and a conveyor for transporting, all fine-tuned to neatly work together. The MU College of Engineering has two such hard-wired cells, a CIM cell from Technovate and a MH cell from Digital Equipment Corporation. Both provide a convenient tool for demonstrating the operations in a finished cell, and have become showcases for campus visitors. They are being used by manufacturing courses in IE and ME to illustrate either single machine operation, or whole system operation. While they are programmable to handle a class of products, they have fixed connections and cannot be used to demonstrate the wide variety of possible system configurations that exist in real-life production environments. Moreover, they are too fine-tuned to represent the many inconsistencies and problems often encountered in actual system integration and control such as incompatible data formats, controllers, voltage/drive levels, etc. The hard-wired cells perform well for the operations they have been configured to do. However, it is not flexible and does not serve well as a teaching tool on how to integrate a system in the first place. A modular system, on the other hand, can demonstrate integration from first principles with often encountered variables, and permit an almost unlimited number of possible configurations, bounded only by the imagination and creativity of the students.

CONCEPTUAL FRAMEWORK

The project is to establish a *modular* laboratory for teaching system integration and control, equipped with portable, table-top, high-level system components such as robot manipulators, conveyors, sensors, controllers, etc., that do not have to be individually assembled, and yet are not already hard-wired to handle only a few tasks. The system components in the laboratory are modular, allowing a variety of mix and match configurations. For example, one possible scenario (A) may be a *robot* moving a part from a *conveyor* to an *indexing table* or *carousel* where a non-contact *barcode reader* identifies a barcode on the part that will indicate the appropriate carousel bin; another scenario (B) may be a *barcode reader* identifying a bar coded part and sending information to a *microcomputer database* which then sends a signal to the *programmable logic controller* to route the part to a side *conveyor*; still another scenario (C) may be a *robot* using a tactile *probe* attached to a *data acquisition system* on a *microcomputer* to inspect deviations in part feature tolerance.

In all three scenarios, the same robot, conveyor, barcode reader, and microcomputer are used in varying capacities under different configurations. Often encountered problems in system integration and control can be introduced as part of the exercise. Many other scenarios are possible using the same modular components by creating a different configuration. Moreover, these configurations can become modules themselves in a recursive manner to form part of a bigger system. The modular laboratory is also equipped with a multimedia software component for simulating system environments on computer that would otherwise be difficult to emulate with the hardware components.

To optimize the use of resources, the modular laboratory is being shared by another course, IE372 (Integrated Production Systems) that covers computer aided design and manufacturing (CAD/CAM). This course focuses on the integration of the major manufacturing system components and functions described earlier that actually transform the raw materials into the finished products, as opposed to the supporting system components and functions covered in IE384. Some of the modules, e.g., the machine tools and inspection devices, serve a dual purpose for both course needs. Two hundred fifty students are expected to pass through the courses affected by this project over five years. These students include IE majors for whom these courses are required, and students from other disciplines (Mechanical Engineering and Industrial Education) who regularly take these courses as technical electives.

In the summer, the plan is for the laboratory to be used to sponsor workshops for junior high and high school students and teachers as part of the nation-wide effort in nurturing interest in science and engineering among America's youth.[2] With the already strong presence in the IE Department at MU of minority and women engineering students, another plan is to also conduct workshops specifically for women and minorities to help increase their representation in science and engineering.[3]

IMPLEMENTATION PLAN

IE384 includes eight essential topics (Tx) in system integration and control:

` *Microprocessors* (T1) are at the heart of automated systems today. This topic covers number systems, encoding systems, logic gates, system interrupts, functions, basic hardware, *and how these components affect system integration and control*.

` *Materials handling* (T2) covers the movement and deployment of materials in various stages of processing through the system with the help of automated devices. This topic covers the principles of material handling including the use of bowl feeders, indexing tables, conveyors, robots, *and how these components can be integrated with the primary processing operations*.

` *Data communications* (T3) is a necessary ingredient for system integration under computer control. This topic covers the principles of digital\analog data\signalling, signal conversion, data transmission and reception, serial and parallel communication, RS232-488 standards, multiplexing, *and how these components enable system integration and control*.

` *Local area networks* (T4) use data communications to provide electronic communication between dissimilar equipment in multi-vendor production environments. This topic covers the principles of networking, topologies, access methods, the MAP protocol, OSI layers, *and how these components can be used for system integration and control*.

` *Database development* (T5) is also a vital component of any computer integrated system. This topic covers the principles of database modelling, the different paradigms such as hierarchical, semantic, relational and object-oriented models, *and how these components can be used for representing the pertinent information in an integrated system*.

` *Sensing and data acquisition* (T6) handles the detection and logging of status data from processes using sensors. This topic covers the principles of sensors, probes, data logging methods, data analysis, basic hardware, *and how these components can be used for providing control feedback for system integration*.

` *Identification* (T7) methods in manufacturing provide the direct link between the physical materials and the intangible information that reside in databases. This topic covers the principles of identification methods, the associated hardware and software such as barcodes and radio frequency transmitters, *and how these components can be integrated in the system*.

` *Programmable logic control* (T8) handles the supervisory control functions in system integration. This topic covers principles of logic control, ladder logic programming, sequencing, timing, *and how these components are* *used to coordinate and orchestrate the operations in an integrated manufacturing system.*

There are eight mini-projects over a 16-week semester, one mini-project every two weeks. Each mini-project introduces a module that will be integrated into the system, following the topics presented above. The culmination is a complete integrated system, or sub-system. Owing to the modular nature of the laboratory components, the instructor can use a different system to integrate for each offering of the course. For example, in a certain semester the class may use scenario B, where a *barcode reader* identifies the part to the computer *database* which in turn sends a signal to the *programmable logic controller* to route the part to a side *conveyor*. Every two weeks, a different module will be introduced and integrated into the system. The concepts, underlying principles, and practical problems associated with each module in the context of system integration and control are discussed. The students work in groups of four, with the group turning in a report for each mini-project. Thus, the students are introduced to the module, experience how the module can be integrated into the system and the problems that can occur, learn how to work as a team, and finally learn how to express their experience in a report.

Prior to the modular laboratory, it was difficult to present the integration aspect because of the inherent limitations with the basic building blocks of the Fisher Teknik kits and the hard-wired CIM and MH cells. Then we were limited to introducing the individual concepts. Now with the modular laboratory, it is easier to communicate the modular integration of the concepts. Even the student reports reflect a greater emphasis on the integration of the module into the system. A laboratory guide for the students was developed to reflect the new modular approach.

OUTCOME OF THE PROJECT

The new modular laboratory is known as the Modular Laboratory for System Integration & Control (MLSIC). It is currently housed in a 12' x 16' foot room, but is scheduled to move to a new room this summer in conjunction with the relocation of the Department of Industrial Engineering to new facilities. The new equipment acquired under this project include:

` Data collection probe sets consisting of data acquisition probes such as timers, counters, thermocouples, transducers, tachometers, pressure and logic probes for use in collecting data for analysis. Relevant Topics: T3,T5,T6.

` Data acquisition hardware and software consisting of computer interface boards for use in data collection and associated data acquisition software. Relevant Topics: T3,T5,T6.

` 80486 microcomputers for use as workhorse processors to control devices via controller boards, collect data via data acquisition boards, and demonstrate data communications via serial/parallel or network communication boards. Relevant Topics: All.

` Non-contact barcode and radio frequency readers and associated software for use in performing automated online identification. Relevant Topics: T1,T3,T5,T7.

` Table-top SCARA robot, vacuum gripper, and simulator software for use in pick-and-place material handling and interface with various controlling and sensing devices. Relevant Topics: T1,T2,T3,T4,T5,T8.

` Table-top CNC mill, vise, and part locator as the primary processing tool in the lab. It is the only module that actually involves a manufacturing operation, while the others perform supporting functions. Relevant Topics: T1,T3,T4,T5,T6,T8.

` Table-top expandable conveyor system (1000mm) which provides part of the material handling component in designing system configurations. Relevant Topics: T1,T2,T5,T6,T8.

` Conveyor accessory set which includes vertical and horizontal gages for on-line dimension inspection, infra-red and limit switches for part sensing, and a compressor to drive the conveyor. Relevant Topics: T1,T2,T5,T6,T8.

` Table-top indexing table (400mm) which provides intermittent part feeding, and emulation of a carousel storage/retrieval device. Relevant Topics: T1,T2,T5,T6,T8.

` Table-top articulated servo robot which provides additional degrees of freedom for motions that cannot be attained by the SCARA robot. Relevant Topics: T1,T2,T3,T4,T5,T6,T8.

` Controller board interface and software which is the major interface between the microcomputers and the various modules. Relevant Topics: T1,T2,T3,T5,T8.

` Data communications hardware and software which fundamentally enable the interconnection and exchange of electronic information between the modules. Relevant Topics: All.

` Local area network modules which provide the primary mode of interfacing between heterogeneous devices in the workplace. Relevant Topics: T1,T3,T4,T5,T8.

` Multimedia presentation upgrade kit which enables graphical simulation of environments that are difficult to emulate with the physical modules. Relevant Topics: All

VALIDATION OF EFFECTIVENESS

The effectiveness of the project is continually evaluated in four different ways. First, a preliminary evaluation consisting of a survey questionnaire is administered at the beginning of the course to assess pre-existing student perception of system integration and control. Second, a survey questionnaire is administered after each mini-project exercise to assess the learning experience of the student in identifying the problem, the objective, the purpose and operation of the module that was introduced in the integration and control of the system. Third, an exit survey questionnaire is administered to assess the change in the perception of the student after having gone through the course. Correlation measures suggest the influence of the modular approach in the process of learning systems integration and control.[4] We are currently collecting data to compare the modular approach with the previous practice of using hard-wired CIM and MH cell setups. We are doing this by subjecting the students to both a modular and a hard-wired environment for the same type of systems integration activity. This comparison will hopefully bring a closure to the evaluation of the effectiveness of the modular approach. Fourth, a survey questionnaire for continuing education courses, such as the planned summer workshops for junior high and high school students, teachers, and minority groups especially women and minorities, is expected to provide a different perspective from an audience outside of the IE384 class.

DISSEMINATION OF RESULTS

The findings of this project are being presented at ASEE conferences (this national ASEE conference and the MidWest Regional ASEE conference last April), and a paper is being submitted for publication to the

Journal of Engineering Education. An instructor manual/monograph describing how to create modules and combine modules to create realistic system configurations as laboratory exercises is in preparation as part of the project. The planned summer workshops for junior high and high school students, teachers, minority and women will be another form of dissemination. We have also found that vendors of educational laboratory hardware and software are beginning to adopt the modular approach to CIM teaching by marketing high level modules as an alternative to hard-wired CIM cells.

CONCLUSION

This paper presented the experience of developing a modular laboratory for system integration and control as an alternative to either basic building block Fisher-Teknik kits or hard-wired CIM cells. We described the rationale for a modular approach, the implementation of the modular approach to the course, the equipment inventory relevant to such an endeavour, and the validation of the effectiveness of this approach to learning system integration and control.

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