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A Manufacturing Laboratory for Integrated Hands-on Applications

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Abstract

Since 1980's, Computer Integrated Manufacturing (CIM) has dramatically changed the way of manufacturing in all industries as well as the way manufacturing courses are taught. Among many worldwide CIM programs offered at various universities, some are more application oriented, some focus more on the business aspects, and some put more emphasis on the information technology behind the CIM concept. Over the last decade, CIM had evolved into a newer concept, namely Computer Integrated Enterprise (CIE), due to the advancements in the area of information technology and its applications in e-business. Nevertheless, there is still a gap between the shop floor and the upper level functions, such as enterprise resource planning. This paper focuses on the automated manufacturing systems and production aspects of CIE under the umbrella term of *Integrated Manufacturing* with emphasis on integration and reconfigurability of laboratory equipment to provide the most effective environment for hands-on applications.

The paper introduces the basic features and capabilities of a laboratory, Integrated Systems Facility (ISF) (http://www.umr.edu/~isf/), which was established with the goal of improving manufacturing system related courses at the Engineering Management Department at the University of Missouri – Rolla (UMR). It highlights several teaching and research aspects of this initiative. Courses that have been determined by considering various learning styles in order to encourage life-long learning within the scope of integrated manufacturing concept and their laboratory requirements are discussed. A sample project is described in order to highlight the overall approach.

Introduction

The rapid growth of information technologies that has provided public access to a vast assembly of educational resources and learning opportunities has transformed the capacity of higher education to deliver educational and training programs to learners of different age groups. Increased enrollment of adult learners who demand an education using these new information technology tools has been observed over the last few years. With this new demand, universities are changing their programs and restructuring their academic policies to accommodate these new audiences. As computer technologies continue to decline in cost, information technology tools and their applications on the Internet provide invaluable opportunities for educators and learners. The Advisory Committee, under the auspices of the Education and Human Resources (EHR) Directorate of the National Science Foundation (NSF), stated that as a goal[1]:

> *"All students have access to supportive, excellent undergraduate education in science, mathematics, engineering, and technology, and all students learn these subjects by direct experience with the methods and processes of inquiry"*

They further report the fact that the use of new technology is exploding in all aspects of life to such a degree that fewer jobs are available to those without technical preparation. The Advisory Committee states that despite the observation that America's basic research in science, mathematics, engineering and technology (SME&T) is world-class, its education still is not. The Committee highlights the need to effectively use modern technology to gain more productive and rewarding undergraduate SME&T education in terms of its long-lasting results, effectiveness and excitement for both students and faculty. In accordance with this view, Holton[2] emphasizes that undergraduate SME&T education in America is still producing a few highly-qualified graduates while leaving most of its students "homeless in the universe".

Underlining the importance of hands-on practicing in the framework of learning, the 1993 report of the Wingspread Group on Higher Education[3] states that classroom learning must be accompanied by "knowledge derived from first-hand experience". Similarly, Seymour and Hewitt[4] note the poor quality of the educational experience due to "too much dull lecturing" and poor academic advising certainly does not provide all students access to supportive excellent experiences. This fact coupled with inadequate and insufficient laboratory facilities becomes the major reason for under-qualified and under-employed graduates. In the report of the Advisory Committee[1], the importance of hands-on practice is presented through the words of Prof. Eugene Galanter (Director, Psycho-physics Laboratory, Columbia University):

> *"Insofar as every science depends on data for both theory and application; laboratory or field data collection experience is an absolute necessity. Adding up numbers from a textbook example is not the same as recording those numbers or qualitative observations based on one's effort. When students "own" their data, the experience becomes a personal event, rather than a contrived exercise."*

In 1997, the Society of Manufacturing Engineers introduced the so-called Manufacturing Education Plan[5] building on a platform of performance activities that supports manufacturing education. In their report, it is stated that the attendees strongly indicated a need for hands-on experience as an important aspect of the education of the manufacturing engineers. Among the gaps identified in current curricula, the lack of exposure to manufacturing principles placed in the top five areas. The Manufacturing Education Plan highlights the importance of teaching these principles through both experience and formal lecturing.

The desired educational curriculum resulting from the research described in this proposal can be briefly outlined in connection with the four keywords[1] in the "vision" stated by the NSF Advisory Committee:

all - Every student must have the opportunity for hands-on experience related to manufacturing-oriented processes and experiments through laboratory practices.
supportive - The laboratory practice must encourage and nurture students in manufacturing engineering subjects that, for the majority of students seem remote, theoretical and abstract in the case of solely in-class lectures.
excellent - Superb educational experiences must be provided for every student through a high quality laboratory environment.
inquiry - Every student must be involved in some way in scientific inquiry through improved course contents in connection with the hands-on experience at the laboratory level.

Computer Integrated Manufacturing: An Overview

The phrase "Computer Integrated Manufacturing (CIM)" was coined by J. Harrington Jr. in 1973[6]. In his book, he notes that highly fragmented manufacturing operations lead to localized optimization, thus an integrated approach to the enterprise is essential. Since then, the concept has grown to be a very large area that involves many complex aspects of computer-supported manufacturing. Today, there are various different CIM definitions in the literature. For example, the Computer and Automation Systems Association (CASA) of the Society of Manufacturing Engineers (SME) defines CIM as the integration of the total manufacturing enterprise through the use of integrated systems and data communications coupled with new managerial philosophies that improve organizational and personnel efficiency. This means that CIM is beyond the concept of only computer-aided design (CAD) and computer-aided manufacturing (CAM). The common agreement among those various definitions is that CIM involves the total integration of all elements in a manufacturing enterprise through the use of computers [7-9].

CIM is concerned with providing computer assistance, control, and high level integration at all levels of the manufacturing industries, by linking islands of automation into a distributed processing system. CIM is based on strict hierarchical information flow structures, which aims at total automation. However, with the latest developments in computer technology supported by major advances in electronics and informatics, the introduction of CIM in such heterogeneous environments becomes very difficult and insufficient as regards the need for successful integration of various hardware and software tools. Holonic Manufacturing (HM) aims to overcome these problems by providing autonomy and effective human integration at lower levels of the structural hierarchy, which allows direct interaction of workers on the shop floor with equipment and cells as decision makers[10-13]. Considering the decentralized structure of Holonic Manufacturing Systems (HMS), the shop floor personnel must be given the maximum possible scope and responsibility for decision making in detailed planning[14]. Surprisingly for many people, although the "factory of the future" is characterized as a philosophy encompassing the integration of projected future technologies to manufacture products in a "peopless" and "paperless" environment[15], this concept of an unmanned factory is opposed by ideas of a re-emergence of the human factor in production[16]. Today, an appropriate blend of hard-automation and humans is essential in order to respond to customer demands in a timely and cost-effective way. The rest of the paper refers to this concept as "*Integrated Manufacturing*".

Integrated Manufacturing and Engineering Education

In the 70's, CAD/CAM revolution took place in industry. It began with the development of computer-aided drafting (CAd) software tools that made engineers realize that the potential of the computer existed to expand the horizons of "drafting" to the area of design, namely Computer Aided Design (CAD). Once the drawing information was digitally stored in the computer, it became a simple matter to use this information to generate a code that could control numerically controlled machines. That was when Computer-Aided Manufacturing (CAM) came into play. In the 80's, Design-for-Manufacturing (DFM) concept began to receive significant attention and the concepts of CIM were introduced to expand the limits of both CAD and CAM[13]. Due to its multi-disciplinary nature, CIM requires state-of-the-art computer technology, networking skills, and manufacturing control methods[17]. However, there was a lack of engineers and technicians who could implement and maintain the CIM system at that time[7,18,19].

Meanwhile, it was indicated in the survey of Merchant[20] that as of January 1985 the official agency for accreditation of all engineering programs, the Accreditation Board for Engineering and Technology (ABET), had granted accreditation to only two four-year and one postgraduate manufacturing engineering programs. By having realized this problem, four segments of the technical and industrial community, The Federal Government, Technical Professional Societies, Industrial Corporations and Academic Institutions, started initiatives for manufacturing engineering education[19].

As a result, many universities had established their own curricula supported by manufacturing facilities to teach CIM related concepts and technologies. It was indicated in the survey of McCluckie[21] that there were over 100 manufacturing programs teaching CIM topics in 1988. Despite the fruitfulness of CIM programs in the late 80's, CIM concept itself has grown so large during the 90's that today it covers a larger number of new topics such as manufacturing resource planning, product development management, supply chain management, e-commerce, enterprise resource planning, virtual enterprise formation, and integration of various new information technology tools for factory floor communication and manufacturing system control.

Therefore, many universities started to modify their CIM programs to cover more contemporary topics in those newly emerging areas. Proliferation of these new areas has had a positive impact in many ways but has also created islands of applications, which are very difficult to fully integrate. Today, people are looking at a bigger picture and heading towards integrating various enterprises and forming "virtual" enterprises, while there is still a gap between enterprise resource planning systems and shop floor management tools[22]. From this standpoint, the major issue in order to reap the maximum advantage of these technologies is integration. The common feature of system integration is that it requires coordination among physically or logically distinct and sometimes complex processes, component units, and subsystems[23].

Manufacturing Systems-related Courses at Engineering Management Department

There are four courses taught by Dr. Saygin in the Engineering Management Department at UMR. The scope of these courses and the applications within each course is schematically depicted in Figure 1.

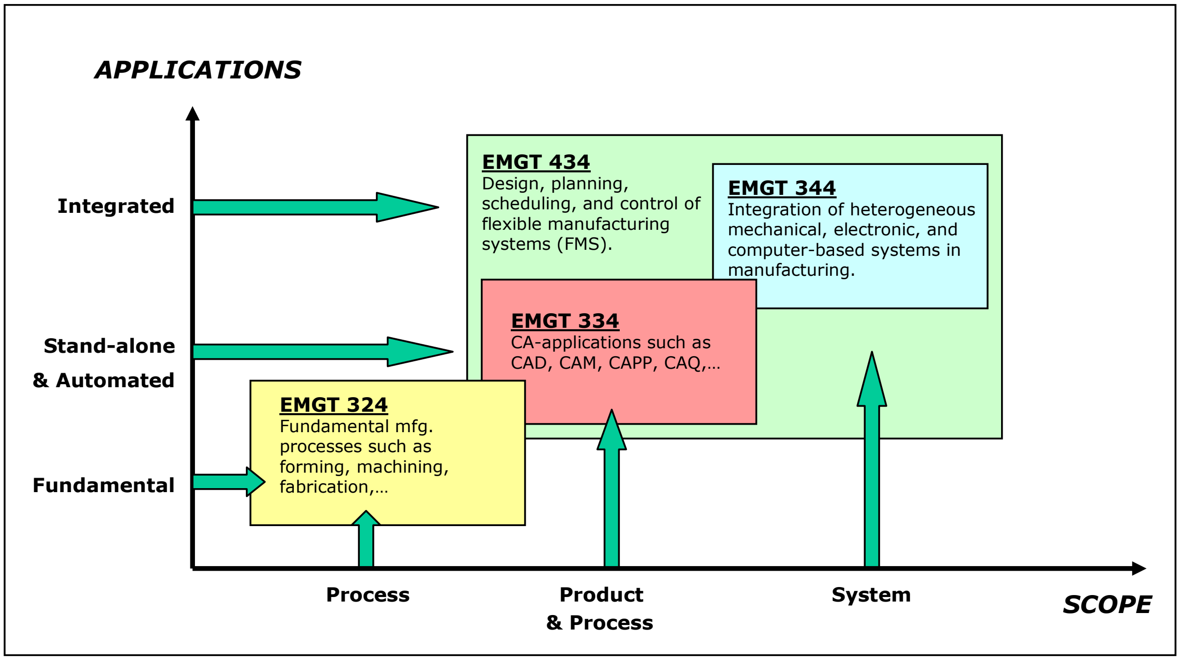

Figure 1. Applications and Scope of Courses

EMGT 324, Fundamentals of Manufacturing: This course provides students with an understanding of basic manufacturing processes and equipment used in the forming, machining, and fabrication of products. The course consists of lectures, demos, and hands-on laboratory experiments. The laboratory work includes turning, milling, drilling, bending, and various quality control experiments (*Course Website: http://web.umr.edu/~saygin/teaching/324/*).

EMGT 334, Computer Integrated Manufacturing Systems: This course is designed to address the key integration issues in manufacturing with the goal of providing the future engineers with a thorough understanding of CIM. An in-depth and integrated coverage of computer aided design, computer aided process planning, computer aided manufacturing, production planning and scheduling, manufacturing system control, and shop floor control topics as well as the integration among them are presented. The laboratory work, which complements the topics covered in class, provides hands-on practice in the areas of (1) product design (AutoCAD), (2) process planning and NC code generation (MasterCAM), (3) CNC machining, (4) programmable logic control (PLC) programming (RSLogix 5 and 500), (5) robot programming (IBM 7547 model robot), and (6) PC–based control. The first three exercises are tied together to aid the concept of concurrent manufacturing. Students design parts to be machined on a CNC mill. Thus, they need to understand the capabilities of the CNC mill, as well as raw material and cutting tool limitations, in order to successfully machine the part. The last three exercises are focused on equipment control and development of control logic for them either on a PC or PLC. The course also aims to go beyond the traditional understanding of CIM by highlighting the importance of several other topics such as holonic manufacturing, enterprise integration as well as the future trends in integrated manufacturing systems. A variety of semester project options are available, ranging from literature surveys to software development to hardware integration. (*Course Website: http://web.umr.edu/~saygin/teaching/334/*).

EMGT 344, Interdisciplinary Problems in Manufacturing Automation: This course highlights the major automation-related interdisciplinary problems within the scope of manufacturing systems. Based on the principles studied in EMGT 334, this course introduces the technical aspects concerned with the integration of heterogeneous mechanical, electronic, and computer-based systems in manufacturing. This course blends the study of mechanical engineering technology, electrical engineering technology, and computer technology. The goal is to tie these areas together to enhance the students' understanding of integration and automation in manufacturing systems. The term project, which constitutes the major part of the course, requires design and development of a physical system. Project topics are interdisciplinary in nature, involving manufacturing engineering, mechanical engineering, electrical engineering, and integration of various computer hardware and software. Students in teams of two or three are given a vague project description in the beginning of the semester, such as designing a rotary storage and retrieval system, which primarily includes a robot and a barcode reader. Project teams first develop a conceptual model with various alternative components. They discuss their designs and the integration issues with the instructor, teaching assistant, and the ISF electronics engineer. After the conceptual design stage is completed, they manufacture the components of their system and assemble them. The project continues with the development of a control system, either PC or PLC-based, to operate the system (*Course Website: http://web.umr.edu/~saygin/teaching/344/*).

EMGT 434, Advanced Manufacturing Systems Integration: This course focuses on the major integration issues related with the automated manufacturing systems. It introduces a focused theme on advanced hardware and software integration concerned with the design, planning, scheduling, and control of Flexible Manufacturing Systems (FMS). The laboratory work includes NC part programming, PC-based control, Robot programming, PLC programming, and systems analysis using simulation. The laboratory topics are tied together in an application-oriented manner on an FMS to enhance the students' understanding of integration and automation in manufacturing systems. The course aims to provide students with an understanding of the key concepts of manufacturing systems integration including information flow in manufacturing enterprises, organization of integrated manufacturing systems with focus of flexible manufacturing cells and systems, fixed automation techniques, part tracking and identification, and shop floor control. At the end of this course, the students acquire some of the skills required for effective design and operation of modern manufacturing systems including team work, interconnecting various intelligent devices in a manufacturing system, writing control software for machine tool, robots, storage/retrieval systems, and shop floor management. Systems-level applications and experiments encourage students to reorganize knowledge and discover the connections among different concepts taught in previous courses (*Course Website: http://web.umr.edu/~saygin/teaching/434/*).

Curriculum Development

The contents of the courses described above have been determined by considering the Perry Model[24] and the Kolb Learning Style Model[25] to encourage life-long learning within the scope of integrated manufacturing concept.

In the Perry Model, the first level is *Dualism*, where the students view teachers as absolute authorities. At this level they expect the teacher to give them the facts, and they believe that there are only right or wrong solutions to problems. As students mature to the next level, *Multiplicity*, they still heavily rely on authorities, but they acknowledge legitimate uncertainty. At this level, they become aware of the fact that for certain problems there is no just a single solution and for such cases one answer can be as good as the other. The third level is *Contextual Relativism*. At this level, learners accept that they are legitimate sources of knowledge. They realize that authorities help but learners themselves are the active decision makers. The fourth level is *Commitment with Relativism*. At this level, students synthesize solutions to the consequences of making the commitment, and they realize that the perfect or ultimate solution does not exist but they are committed to struggle with the process and to continually improve.

In the Kolb Learning Style Model, four learning modes exist: (1) *Abstract Conceptualization* (learning based on *explaining* concepts), (2) *Reflective Observation* (based on *examining* the events, operations, etc. rather than actively participating), (3) *Concrete Experience* (based on actively *experiencing* with an event, operation, etc.), and (4) *Active Experimentation* (learning by getting involved in an event, interacting with it, and affecting the outcomes).

The learning styles versus intellectual growth, within the context of integrated manufacturing, of the four courses summarized above are shown in Figure 2. Due to its contents and the composition of the class, students in EMGT 324 are anticipated to mature from the first level, Dualism, to Multiplicity, via lectures (Abstract Conceptualization), laboratory demonstrations and videotapes (Reflective Observation), and hands-on laboratory experiments (Concrete Experience).

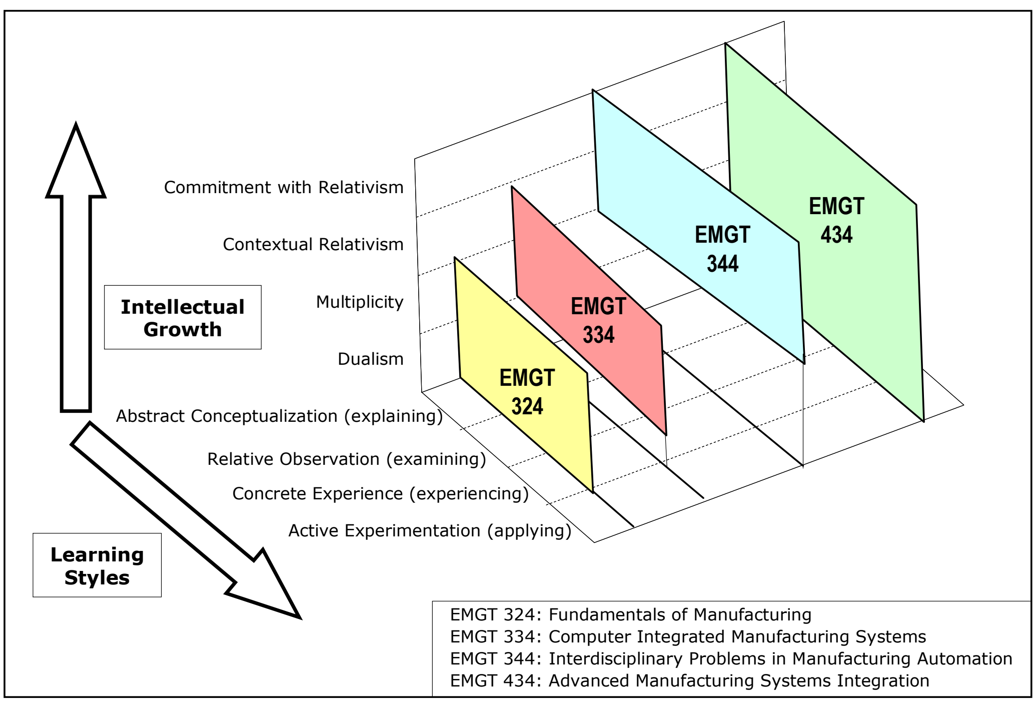

Figure 2. Intellectual Growth and Learning Styles: A Manufacturing Systems Perspective

In EMGT 334, it is expected that the students will mature from Multiplicity to Contextual Relativism. This course covers CIM concepts and since there are no strict boundaries as to what CIM is, the students learn that there are various alternative solutions to many of the CIM-related problems. In addition, they realize that CIM is a continuously evolving subject and that they are legitimate sources of knowledge in order to solve related problems. Similar to EMGT 324, EMGT 334 includes lectures (Abstract Conceptualization), laboratory demonstrations and videotapes (Reflective Observation), and hands-on laboratory experiments (Concrete Experience), this time with emphasis on computer-aided methods and software tools.

EMGT 344 aims to provide a learning environment where students can mature from Contextual Relativism to Commitment with Relativism. The course involves lectures (Abstract Conceptualization), laboratory demonstrations and videotapes (Reflective Observation), hands-on laboratory experiments (Concrete Experience), and semester projects related to system design and development (Active Experimentation). From the standpoint of these projects, the major difference EMGT 334 and EMGT 344 is the scope and the implementation of the projects. In EMGT 344, the project teams create physical models from scratch thus Active Experimentation is of major focus. Finally, EMGT 434 has the broadest coverage of all learning styles and intellectual growth levels due to its relatively integrated, advanced content and specific focus on FMS compared with the other three courses.

Integrated Systems Facility

With the intent to improve the existing manufacturing system related courses, an integrated laboratory environment development project has been launched at the Engineering Management Department in June 2000. The Integrated Systems Facility (ISF) has been developed to provide an integrated laboratory environment with the objective of supporting manufacturing systems related teaching and research activities for undergraduate and graduate level courses in the manufacturing engineering emphasis area of the department. ISF is a state-of-the-art 5,000 square feet facility, housing several manufacturing cells and systems as shown in Figure 3. How the various elements of ISF fit together with the courses is presented in Table 1.

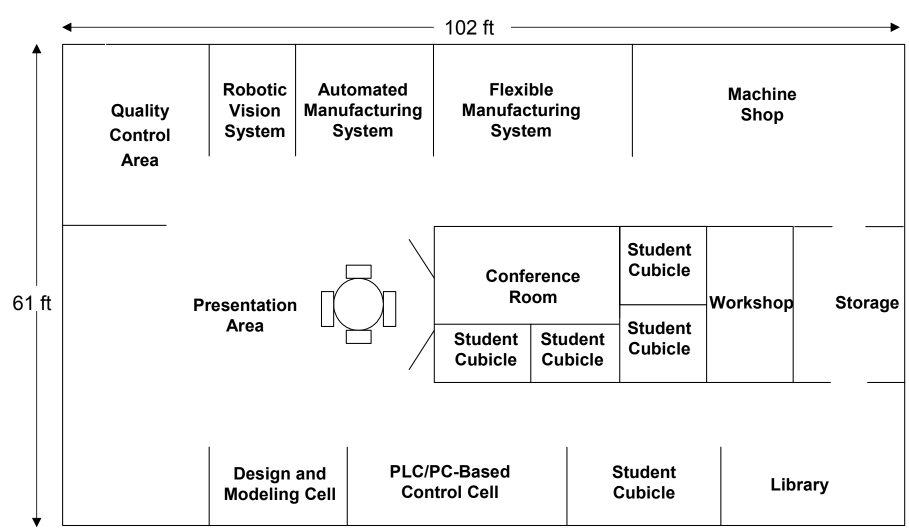

Figure 3. ISF Layout

Table 1. Lab Areas in ISF and Courses

Lab Areas* → / ↓Courses		Design and Modeling Cell	PLC/PC-Based Control Cell	Quality Control Area	Robotic Vision System	Automated Manufacturing Cell	Flexible Manufacturing System	Machine Shop
EMGT 324	***Lab Requirements***			✓				✓
	Content Emphasis	Scope is on manufacturing processes and quality control & assurance. Turning and milling operations are covered in Machine Shop, while basic quality control applications are carried out in the Quality Control Area.						
	Prerequisite	None						
	Level	Undergraduate and Graduate						
EMGT 334	***Lab Requirements***	✓	✓			✓		
	Content Emphasis	The course covers the fundamental computer-aided activities, starting from design through shop floor control. Design and Modeling Cell provides software tools for product design and NC part programming. Automated Manufacturing Cell supports implementation of NC codes on CNC machine tools. PLC/PC-based Control Area is equipped with various industrial controllers to provide programming and testing of control models. Hierarchical versus heterarchical control schemes, holonic manufacturing systems, real-time decision making are among the topics covered in the lab.						
	Prerequisite	None						
	Level	Undergraduate and Graduate						
EMGT 344	***Lab Requirements***	✓	✓		✓			✓
	Content Emphasis	The focus is on automated production system design, including its controller. Robotic Vision System is used, in the beginning of the semester to demonstrate how automated production systems operate. The Robotic system has a neural network based feature recognition system and a PC-based controller. Machine Shop is utilized during fabrication of components of the automated system. PLC/PC-based control area is utilized for designing the controller. Design and Modeling Cell is used during software code generation to implement the controller. Networking, sensor-based decision making, integrated system design topics are discussed in the lab.						
	Prerequisite	EMGT 334						
	Level	Undergraduate and Graduate						
EMGT 434	***Lab Requirements***	✓					✓	
	Content Emphasis	Students are exposed to the complexity of decision making in the areas of design, planning , scheduling, and control of flexible manufacturing systems (FMSs). Using the simulation packages ARENA and ProModel in Design and Modeling Cell, students develop hypothetical FMSs and test and evaluate various operational control rules and conduct statistical analysis. In Flexible Manufacturing System, students learn how to program each equipment and control the overall system. Impact of dispatching rules, their implementation in cell controllers, auction-based job allocation, and stochastic nature of automated manufacturing systems are covered in the lab.						
	Prerequisite	EMGT 334						
	Level	Undergraduate and Graduate						

* See Figure 3.

A Sample Project: Automated Manufacturing Cell

The technical goal of this project is to develop and integrate hardware and software modules in order to have a fully functional automated manufacturing cell, which consists of a robot, a mill, and a lathe. The learning objectives of the project can be summarized as follows:

- Demonstrate an understanding of what constitutes an automated manufacturing cell.
- Understand the process of gaining information about hardware and software components in order to design an efficient cell.
- Demonstrate the ability to propose alternative designs for an automated manufacturing cell.

- Demonstrate the ability to integrate hardware and software so that the cell operates as a "system".
- Demonstrate the ability to technically analyze a manufacturing cell and quantify its performance in terms of production rate and idle time.
- Understand the process of "seamless" information flow from product design to device control.

The project scope provides a framework for students (1) to understand computer-aided design, computer-aided process planning, NC part programming, production planning and scheduling, real-time control, networking, sensor-based decision making, and simulation-based control topics, which are the building blocks of integrated manufacturing systems, and (2) to develop software modules that execute the necessary functions in each topic so that production data flows seamlessly. The concept of automated manufacturing cell is not new, but the process of going through its design, development, and execution phases provide invaluable experience for students since the overall process demonstrates the inevitable gap between theory and practice and the necessary strategies to bridge it.

The project started in Fall 2003 in the course EMGT 334 with the objective of developing a new layout that consisted of Dyna Mill, Dyna Lathe, and Mitsubishi Movemaster robot. The old layout is shown in Figure 4.

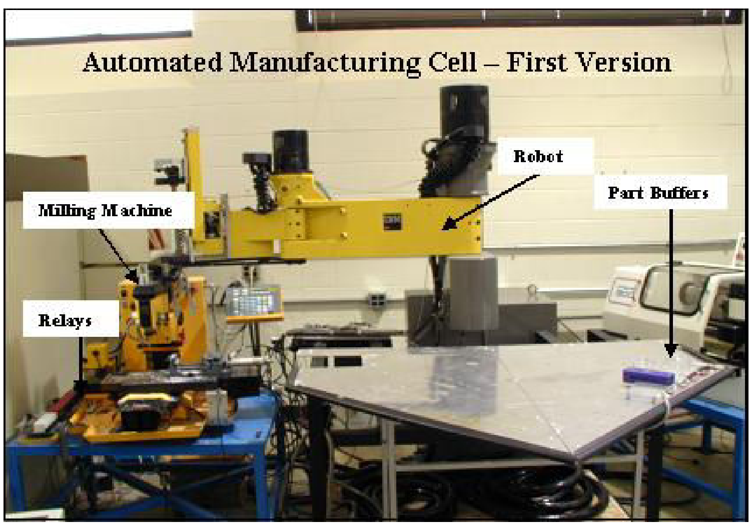

Figure 4. Old Layout

Phase 1 (Sept-Dec 03): The two machine tools have been located side by side. The old Mercury robot has been removed from its slideway as in Figure 5. The Mitsubishi Movemaster robot, which was formerly mounted on the Festo Assembly Station, has been moved onto its new slideway after machining a new base, as shown in Figure 6. The final layout of the automated cell is shown in Figure 7.

Figure 5. Removal of the old mercury Robot from its base

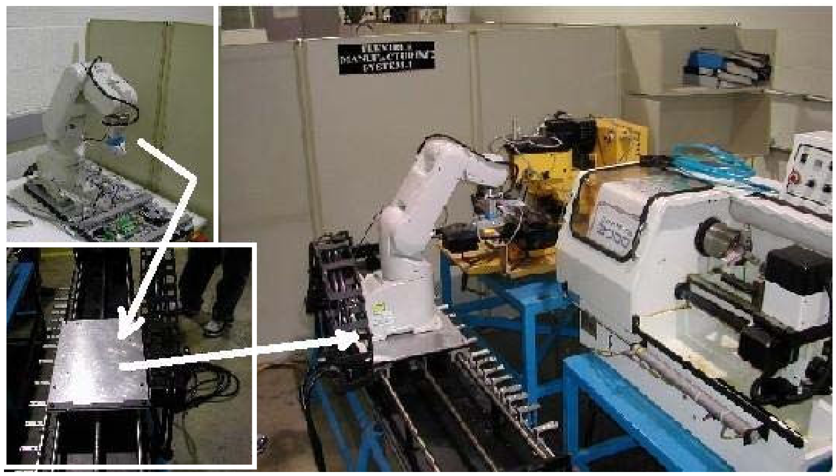

Figure 6. Mitsubishi Robot mounted on the slideway

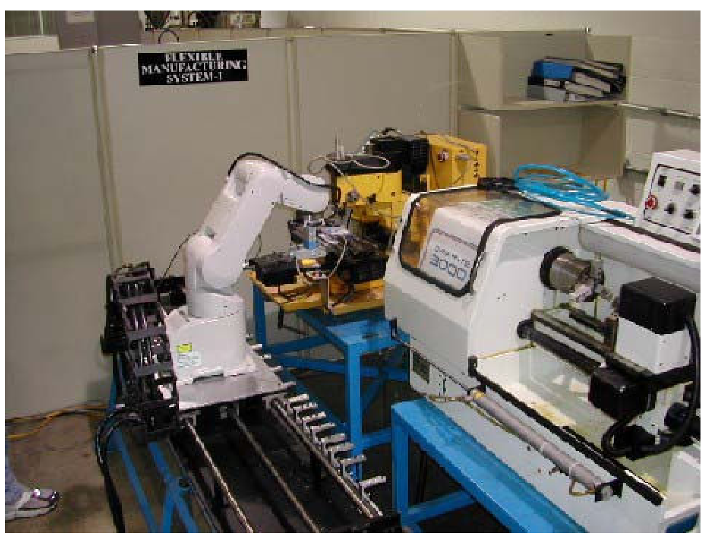

Figure 7. New Layout

The project team has completed wiring in order for the three equipment to communicate effectively. An initial testing, using COSIMIR®, has been carried out right before the end of the semester in December 2003 as shown in Figure 8.

Figure 8. Initial Testing

Phase 2 (Jan-May 04): The goal of this phase is to demonstrate an integrated flow of product data, NC/Robot programs, and real-time control in the course EMGT 344. The automated cell will perform unattended operations, produce different part types in any given order, and be capable of basic production planning functions. The envisioned system architecture, as shown in Figure 9, is currently under development.

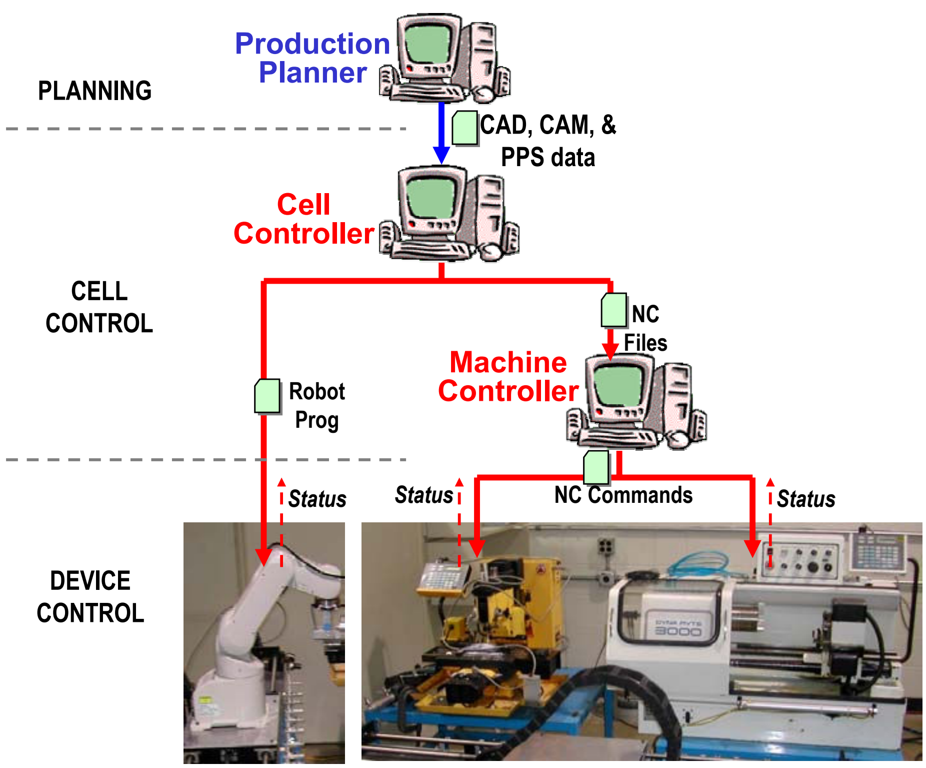

Figure 9. System Architecture

Following software platforms will be used in order to implement the architecture shown above:

- COSIMIR for cell control and simulation (Cell Controller)
- AutoCAD for product design (Production Planner)
- MasterCAM for NC part programming (Production Planner)
- Visual Basic modules for scheduling (Production Planner)
- Visual Basic modules for control (Machine Controller)

In Winter 2004, the students will be given the following training before starting the project:

- COSIMIR
- AutoCAD
- MasterCAM
- Visual Basic
- Scheduling algorithms
- Machine shop practice
- Communications & Networking
- Safety
- Project Management

Conclusion

A typical automated manufacturing laboratory includes an integrated manufacturing system, such as a flexible manufacturing system, with upper level planning functions such as various CAD/CAM packages. Such environments are effective in teaching the existing capability of the system and related concepts but lack flexibility if one wants to make changes in software configuration, control logic, physical layout, or even install an additional module to the system. In such laboratories, the focus is teaching how to operate existing manufacturing systems, which usually include same brand equipment set up by the manufacturer. The approach in ISF on the other hand is on teaching "systems integration". In ISF, Students learn how to integrate different brand equipment together with software in order to design higher level systems. In this way, students are exposed to the challenges of integrated systems design, which makes ISF unique among its peers.

The lack of "real flexibility", as described above, has been the fundamental motivation behind the transformation of the old Computer Integrated Manufacturing laboratory into the new Integrated Systems Facility. Since its renovation, the primary goal in ISF has been to provide an effective learning environment for students in which they can experience design and implementation of new integrated systems and develop control modules to operate them. Effectiveness in such a laboratory environment can be provided by three factors:

(1) Reconfigurability of manufacturing systems: The reconfigurability in ISF is provided by a set of modular components. Modularity allows for easy modeling of automation systems of different complexity and facilitates creation of new systems and redesign of existing systems with new functionality in a cost-effective and time-efficient way. Data acquisition cards, sensors, PCs, and PLCs are the hardware modules. Commercially available application software such as AutoCAD and MasterCAM, and software development packages such a Visual Basic® are the software modules.

(2) Multi-disciplinary laboratory staff: The multidisciplinary nature of applications in ISF requires different expertise in an integrated fashion in the areas of manufacturing, mechanical, electrical, and computer engineering. Thus, the human component is very crucial. ISF has a full time electrical engineer, several PhD and MS students with different backgrounds on its staff.

(3) Modular courseware to facilitate progressive learning: The courses described in this paper involve lectures (Abstract Conceptualization), laboratory demonstrations and videotapes (Reflective Observation), hands-on laboratory experiments (Concrete Experience), and semester projects related to system design and development (Active Experimentation).

Modular configuration not only represents the current trend towards implementing integrated manufacturing, but also facilitates learning in a progressive way; where students can start with a relatively small-scale application and can step-by-step expand the application scope under the supervision of ISF staff.

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