AC 2010-1492: INTEGRATION AND IMPROVEMENT OF A ROBOTICS LABORATORY IN AN INDUSTRIAL ENGINEERING CURRICULUM

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Integration and Improvement of a Robotics Laboratory in an Industrial Engineering Curriculum

Abstract

Robotics is the study of robots and their design, manufacture and application to various systems. The impact and benefits of robotics in education at all levels have been broadly addressed and documented by many researchers and educators. Several institutions (including Carnegie Mellon) have developed a robotics program which has provided an extensive background for students wanting to study and conduct research in this arena of engineering. When coupled with hands-on laboratory modules, robotics provides a vast source of opportunities to use original ideas and analytical skills for the solution of concrete problems in the areas of manufacturing systems, programming, logistics and others. As an attractive educational tool, robotics contributes to the increase in students' interest for Science, Technology, Engineering and Math (STEM) concepts.

Through this Course, Curriculum and Lab Improvement (CCLI) grant project sponsored by the National Science Foundation an updated Industrial Robotics and Automated Manufacturing (IRAM) Laboratory will be developed at Morgan State University. The IRAM Laboratory will provide an improvement in the current facility and combine the integration of additional courses with a hands-on laboratory approach into the Industrial engineering undergraduate curriculum. These subject areas include: advanced material handling systems, robotics and automation, computer-aided manufacturing, and flexible manufacturing systems. With the use of various hardware and software systems, students will be able to integrate course projects (using the IRAM Lab) with other pre-requisite courses allowing for a transition from the use of traditional manufacturing methodologies (i.e., manual) to modern computer-controlled ones.

This CCLI project focuses on strengthening the engineering workforce by allowing engineering students to learn how to use software to model and determine solutions for various manufacturing scenarios, and to engage in realistic applications of flexible manufacturing systems with the use of newly developed laboratory modules. It is also aimed to provide students with experience in understanding and implementing robotics principles from key research literature; to offer students hands-on practice with real problems; and to give students confidence in their ability to develop group work expertise. It will also increase the number and readiness of engineering students entering into the labor force and graduate education programs.

Introduction

Robotics is a technology that is concerned with the study of industrial and/or mobile robots. The official definition as provided by the Robotics Industries Association[1] states that a robot is a reprogrammable, multifunctional manipulator designed to move materials, parts, tools, or special devices through variable programmed motions for the performance of a variety of tasks. In addition, these mechanical devices are commonly used and operated automatically to perform routine work for human beings. With the use of robotics, it is possible to minimize the time it takes to complete repetitive tasks (e.g., spot welding, spray painting, assembly operations, lifting, machine loading and unloading, etc.) which could also translate into cost savings for a given industry. In addition, tasks which are not suitable for humans such as deep sea excavation, space exploration, bomb diffusion or hazardous waste removal, could be simplified with the use of robotics.

Automation is a technology that is concerned with the use of mechanical, electronic, and computer-based systems in operation and control of production[2]. Large, complex systems with components such as conveyors, computer-numerically controlled (CNC) machine workstations, automated guided vehicles (AGVs), and robots make up an automated system. Industrial automation can be classified in to three classes: (1) fixed automation, (2) programmable automation, and (3) flexible automation. With fixed automation, specially designed equipment is utilized to produce a single product only. Programmable automation uses equipment to make batches of products at a time. Once a single batch is finished, the equipment can be reprogrammed to make another batch of products. On the other hand, flexible automation allows for the manufacture of different parts to be made at the same time within the same manufacturing system.

By combining the two technologies of robotics and automation, an efficient, automatically operated system can be formed to perform an infinite number of tasks and operations, especially those concerned with the manufacture and assembly of parts or products. A properly equipped system will allow for the automated production of various parts/products in a flexible manufacturing environment using computer-controlled methods (e.g., CNC milling, CNC turning, CNC drilling, automatic part storage and retrieval, etc.).

At Morgan State University, the Robotics and Automation course provides an impetus for allowing students to learn the basic concepts of the organization and operation of microcomputer-based manipulators (i.e., robots). Assignments and lab projects considering kinematics, dynamics, manipulation, trajectory planning, and programming are key elements for the students utilizing the Industrial Robotics and Automated Manufacturing (IRAM) Laboratory. The incorporation of an updated laboratory will provide a platform for students to experience the actual integration and utilization of mid-sized industrial robots and automated equipment. This project will allow for the update of the IRAM Laboratory by creating a flexible manufacturing system. This new improved system will allow for various machines to be integrated and utilized for the manufacture of customized parts, and allow for the design of computer-integrated manufacturing (CIM) scenarios. This manufacturing laboratory improvement will enhance student learning by introducing several new courses, and promote research in Industrial Engineering (IE).

Literature Review

Included in the literature are several different applications of the use of robotics education in undergraduate curriculums. Wolfer and George presented how Indiana University South Bend has deployed autonomous robots in their computer organization course to facilitate introducing computer science students to the basics of logic, embedded systems, and assembly language[3]. They observed that robots help to provide effective, real-time feedback on program operation and their adopted projects help to illustrate the viability of a robot-enhanced environment for assembly language programming. Anderson and Baltes overviewed a mixed reality approach that meet some pursued teaching criteria, and describe its use in an advanced undergraduate course at the University of Manitoba[4]. They noted that teaching robotics to undergraduate students requires a course framework that allows students to learn about robotics in stages and provide students with motivating applications which could be used for competition. Mataric briefly surveyed his experiences of using robotics as an educational tool at the University of Southern California[5]. He considers robotics a growing field that has the potential to significantly impact the nature of engineering and science education at all levels, from K-12 to graduate school. He concluded that his undergraduate Introduction to Robotics course (including a regular lecture and a lab) provide true inspiration for students, while serving as a good retention and showcase tool for the university.

Duke *et al.* described Introduction to Mobile Robot Programming, a new robotics course offered to undergraduates at early stages of their coursework at Carnegie Mellon University, Qatar Campus[6]. They described the course details and related their experiences and observations. This course is said to leverage robotics as a platform to teach analytical skills, and to give students early exposure to teamwork and large-scale projects. It culminates in students building all the major components to solve a nontrivial task on real hardware. They concluded that the course has been well received by students, most of whom find interactions with robots and competition with their peers to be good motivators to explore and invent. Blank *et al.* explored Pyro, a tool that they have used extensively at their institutions (Bryn Mawr College, Sarah Lawrence College and Swarthmore College) to enable advanced artificial intelligence (AI) and robotics projects[7]. Pyro allows the integration of evolutionary algorithms, neural networks, and robotics as each is represented by an object with well-defined interfaces. The authors stated that several key features make Pyro especially useful for implementing student projects. They concluded that for enabling students to attempt ambitious robotics projects within an academic semester, it is essential that they are provided with a high-level framework for communicating with physical robots and simulations as well as for constructing robot control architectures.

Manseur discussed in his paper several issues related to the recent development of an undergraduate robotics course at the University of West Florida[8]. The course combines lectures on classical robotics with robot building techniques. The course culminates in a class competition where teams of students compete with robotic devices of their design. The competition offers an opportunity to apply the knowledge gained and to contrast different design philosophies. He concluded that students' response to the course was overwhelmingly favorable, in a way that many students requested that the class to be offered again. Students also considered that course to be a good preparation and field of study for the degree program capstone design course requirement.

In their work, Hamrita *et al*. described efforts at the University of Georgia to make micro-controllers, embedded systems, and robotics education available to undergraduate and graduate students from a wide range of scientific disciplines including computer science, biological engineering, agricultural engineering, physics, and forest resources[9]. The authors stated that before teaching the Introduction to Robotics course as a regular course in the curriculum it was first tested as a trial independent study course for graduate students. Since then, the course has become a regular fixture in the fall semester offerings. Interest in the course is very strong among students from several departments outside of computer science as well as within the department. Word of the robotics activities has attracted local and regional news coverage and requests for visits from many area middle and high schools. They concluded that feedback from students who have taken these courses has been excellent.

Miller *et al*. described Beyond Botball[10], an engineering outreach program that comes from the Botball program, an educational robotics program for Middle and High School students offered each year by the KISS Institute for Practical Robotics (KIPR). Beyond Botball is defined as a Botball style of competition that provides Botball alumni and other adults the opportunity to continue to participate in a competition based on this kind of robotics. An open Beyond Botball tournament is held every year in conjunction with the National Conference for Educational Robotics (NCER), a student oriented conference held annually since 2002. Teams entering the Beyond Botball Tournament are strongly encouraged to submit papers describing their robots to the conference. Papers on other related research topics are also accepted. They concluded that the chance to interact with dozens of groups that have addressed similar issues in robot design and construction is a very valuable experience for aspiring engineers.

Methodology & Goals

Research suggests the need for restructuring of the undergraduate engineering curriculum in order to better prepare students for engineering practice[11]. Not only is industry driven companies requiring the traditional math and science background of engineers, but they are also requesting that their engineers be capable of problem solving, analysis, management, and leadership. Opportunities for industrial engineers will stretch further than the traditional manufacturing areas that it was originally founded upon. Eskandari *et al*. states that future IE graduates should have courses and learning experiences that develop their knowledge base, skill set, and work experiences in the area of non-traditional industries (e.g., information technology, healthcare, service-related, and engineering management)[12]. Thus, courses that suggest and/or promote and address these types of learning will become necessary in the undergraduate curriculum. The IRAM Laboratory and the courses associated with this lab will deliver these types of learning objectives by exposing undergraduate students to various robotic and computer-controlled applications. These learning objectives will be accomplished by implementing the following goals.

Goal 1: Enhance student learning by providing exposure to the utilization of manufacturing resources

The laboratory facility will be utilized by students enrolled in the following two existing undergraduate manufacturing courses: (1) Industrial Robotics and Automation and (2) Advanced Material Handling Systems. An array of assignments and projects will be assigned and facilitated to allow a framework of design that can be researched and presented in these subject areas.

In the Industrial Robotics and Automation course, students are exposed to topics including (a) robot geometry; (b) robot motion and drive systems; (c) motion control, performance specifications, and precision of movement; (d) robot tooling, sensors and sensing capability; (e) designing for automation process stabilization; and (f) control systems and industrial logic. These topics deal with the study, programmability, and general function of robots and machines. The IRAM Laboratory will provide a facility for student learning in the Advanced Material

Handling Systems course. Students are exposed to topics including (a) concepts of unit loads; (b) automated guided vehicle systems; (c) robotic applications to material handling; (d) conveyors; and (e) process control of material handling systems (MHS) using programmable logic controllers. Thus, the IRAM Laboratory will be an additional asset for enhancing the IE curriculum to promote student learning.

In addition to the above mentioned courses, the IRAM Laboratory will foster the development of several new courses in the IE Department. The first course entitled Computer-Aided Manufacturing will cover topics such as (a) Computer-Aided Design and Manufacturing; (b) Design for Manufacturing and Automation; (c) Group Technology; (d) Computer-Aided Process Planning; and (e) NC/CNC Programming. These topics will bring a new learning experience for the students. With the use of the IRAM Laboratory and knowledge of process planning, students will be able to program the system to identify the material used to manufacture a product and the routing each material must take through the MHS to be processed. Also, when combined with prior programming skills, the students will learn how to convert computer-aided process plans into NC programming code. This will allow for automatic transfer of CAM data to perform milling processes on the CNC milling machines. These applications are possible by updating the IRAM Laboratory from a programmable unit to a flexible automated system.

Flexible Manufacturing Systems is another new course that will be introduced with the improvement of the IRAM Laboratory. Students will learn topics including (a) FMS design, installation, and implementation; (b) manufacturing cells; (c) Just-In-Time (JIT) manufacturing; (d) processing and quality assurance equipment and systems; (e) system software support; (f) FMS computer hardware and software; and (g) network communications and programming. With this knowledge, students will learn how to design and simulate a variety of automation systems using 3D graphics. The developed layouts can then be used with process planning to track the status of a system in real time. Figure 1 shows all of the courses which will utilize the IRAM Laboratory and how they relate to future student senior design research projects.

Goal 2: Assessing the educational impact with mini-module laboratory projects for problem solving

The equipment utilized in the IRAM Laboratory combined with the OpenCIM software (which accompanies the equipment) will enable the IE Department to teach how CIM is applied to business, engineering, and factory floor elements and the links between them. The software provides an open software architecture that allows users to easily incorporate other applications and obtain data for statistical analysis.

In order to assess the educational impact, the lab modules will allow for hands-on experiences for students. They will also serve as a diagnostic tool to evaluate students' performance and understanding of the materials learned from the various topics.

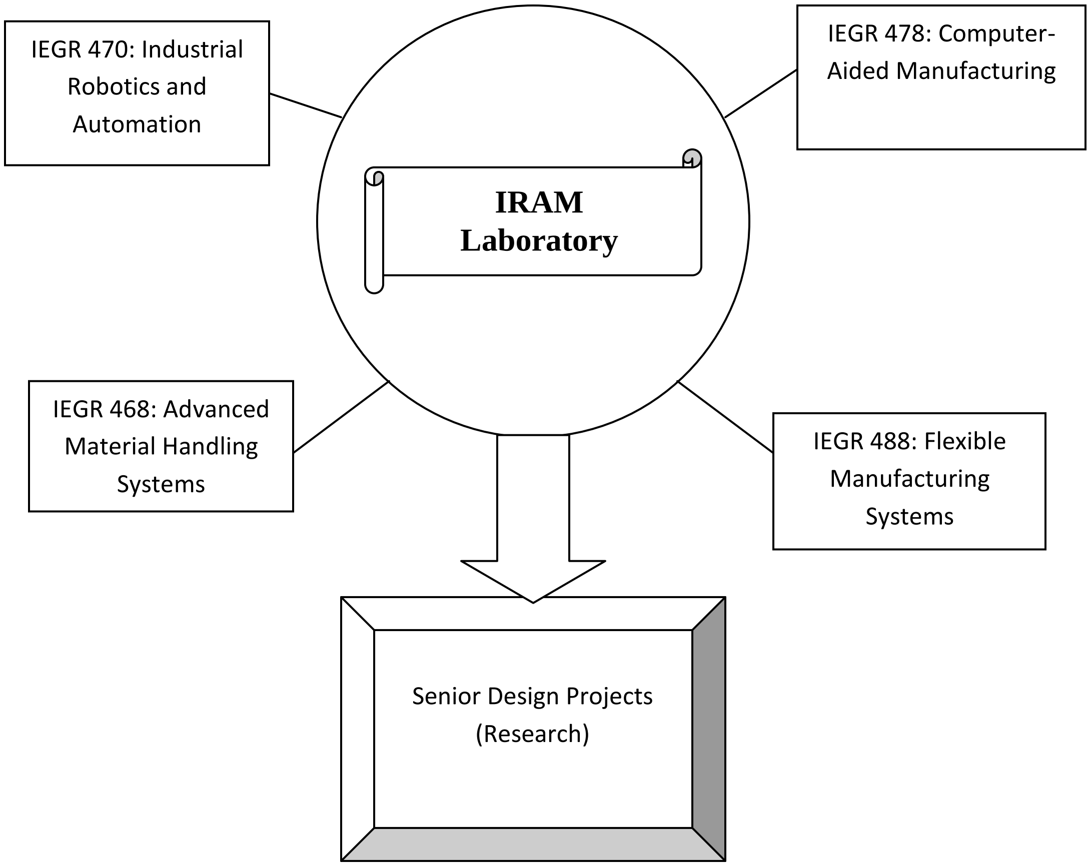

Figure 1. Courses which will utilize the IRAM Laboratory

Some of the modules/topics that will be taught in these courses include the following:

- Material Handling, Storage and Feeding
- Automated Manufacturing and Fabrication
- CNC Machining
- Identification, Detection and Tracking
- Quality Control
- Inventory Control
- Simulation, and
- Scheduling

To determine the degree in which IE students become effective users of the hardware and software utilized in the courses, performance tests will also be conducted. Metrics used to assess and analyze the results will include time required to complete the tests, number and type of errors encountered on the tests and lab modules, laboratory completion time and lab presentations. Also, students will be asked to complete a survey at the end of each course to determine the education impact that the course had on their overall understanding of flexible manufacturing systems. This will allow for an assessment of the overall impact and value that the IRAM Laboratory has on student learning in the IE program. Furthermore, data will be collected regarding how students collaborate in groupings on laboratory assignments.

Goal 3: Updating and improving the IRAM Laboratory with modern equipment allowing for the creation and dissemination of educational materials.

The initial layout of the IRAM Laboratory consists of an Automated Storage/Retrieval System (AS/RS), a six-axis jointed arm robot on a linear slide-base track, a CNC milling machine, a CNC turning center, and a Quality Control/Assembly Station. Figure 2 shows the entire IRAM Lab layout. In this newly updated facility, parts and products will be designed, stored, transported, manufactured, assembled, and inspected. Parts are designed one of three computer workstations using CAD/CAM software. These workstations are networked with all of the other machines and robots in the lab. The part design information is transferred to the CNC machine, and the process plans (which detail the routes that the parts must follow) allows for the network to distribute the information to the machines and robots to control the process. Raw materials are retrieved from the AS/RS and transported to the CNC milling machine. Here, a robot can pick and place the parts at the start and finish stages of the milling process. Once this manufacturing process is completed, parts are transferred to the turning center and/or QC inspection station via the robot while traveling along the linear slide-base track. Parts are assembled at the assembly station and then finally transported back to the AS/RS for warehouse storage. This entire process emulates what happens in a real-world industrial environment within a single manufacturing laboratory; thus, making this system flexible and efficient.

With a real-world industrial environment, students will be able to conduct projects and complete research tasks incorporating different design aspects. Students will be given the opportunity to work on relevant undergraduate research opportunities with current faculty members after completing some of the existing or proposed courses. Examples of some of these projects include: (1) utilizing the CNC mill to design parts which meet specific quality control specifications, (2) determining the optimal tolerances of manufactured parts using the assembly and quality control station, (3) utilizing the entire flexible manufacturing cell to meet due date demands of customer orders, or (4) studying repeatability and accuracy issues while utilizing the HP3 robot. In addition, the IRAM Laboratory will enable additional topic areas to be researched and presented for final capstone senior design projects. From those projects, more significant research will be possible for dissemination through the following channels: (1) contributions of the methodologies and processes to education and research journals to add to the common body of knowledge, (2) outreach visits to K-12 schools to promote careers in engineering and robotic applications and (3) presentations at conferences to share research findings.

Goal 4: Engaging and retaining under-represented students in the area of Industrial Engineering to promote a diverse workforce and graduate research education.

This project will have a significant and broad impact, as engineering students will participate in several courses which would utilize the newly updated laboratory. The number of under-represented students (women and minorities) will be increased due to the interest that will be stimulated from successfully completing the courses which utilize the IRAM Lab.

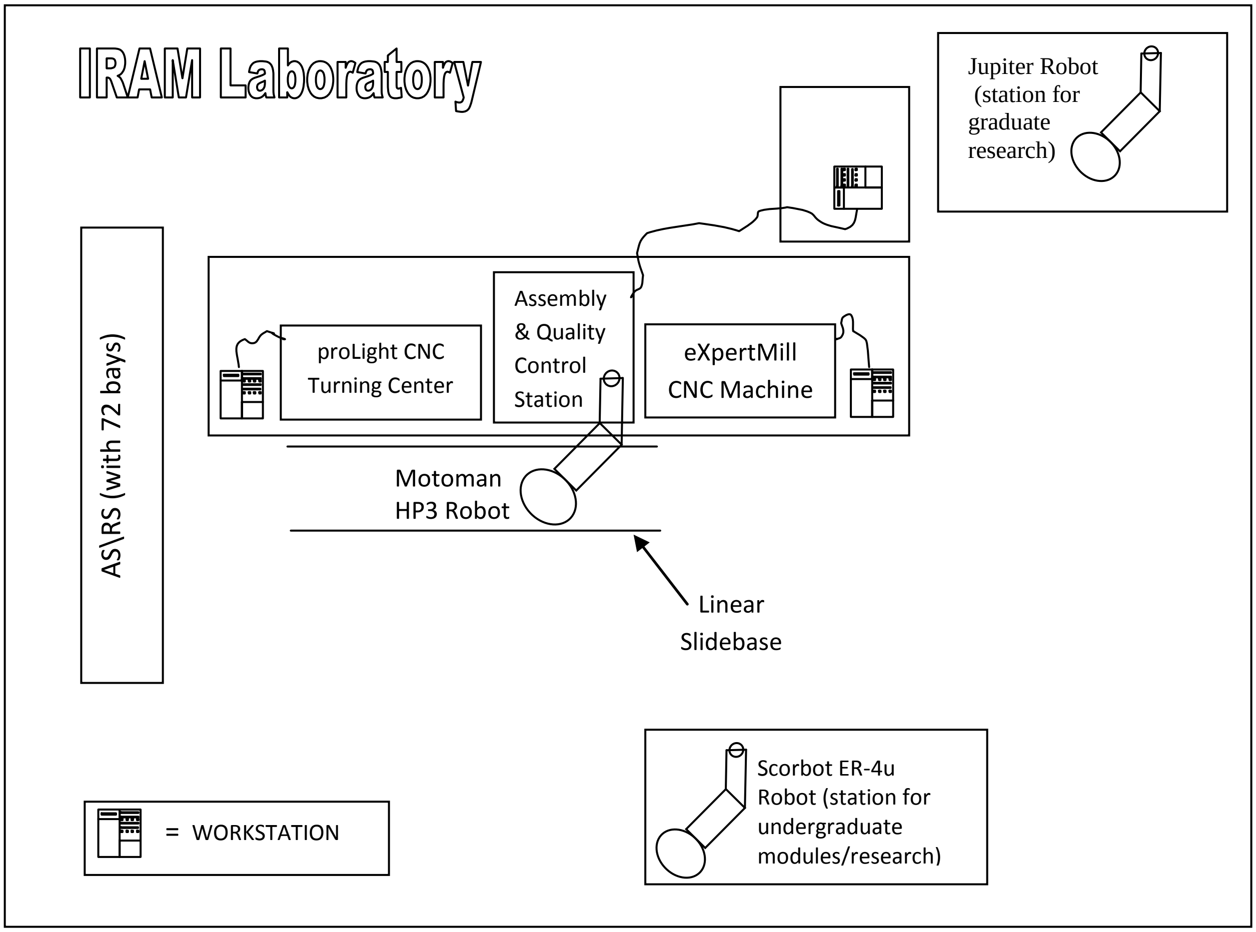

Figure 2. Layout of the IRAM Laboratory

The knowledge gained from the use of this laboratory will provide a framework for students entering into the workforce. Manufacturing industries in the U.S. can be enhanced and become more competitive in the global arena of engineering by engaging and employing highly trained graduates in engineering. Ultimately, students will increase their skills to be competent in the field of engineering, to solve problems and have the opportunities to make significant contributions that will benefit manufacturing industries. Mackie states, "Career opportunities for those willing to pursue such are plentiful in STEM. Our government needs new workers in science, technology, engineering and math to provide services for its people, protect the country and its resources."[13] Using Robotics and Automation is just one tool to help outreach to the K-12 students. Once the K-12 students are introduced to these areas, they will enroll in our programs across the U.S. and help to meet the national goal of continuing to increase the number of students entering STEM fields.

Discussion

During the fall 2009 semester, the first course (Advanced Material Handling Systems) was taught. This course was mostly theoretical because the laboratory was still being assembled. Seven students enrolled in the course, but due to financial issues, the final enrollment number was six. All six students were successful in passing the course. There were three main objectives of this course: (1) To utilize acquired math & engineering skills to evaluate & solve

MHS problems with existing algorithms, procedures, and solution methodologies; (2) To find optimal/near-optimal solutions when solving cost-related MHS problems; (3) To apply computer programming skills in the development of design problems in MHS applications.

In December 2009, the construction of the new IRAM Laboratory assembly was completed. The facility layout and planning of the laboratory was overseen by the director of the laboratory and testing of the robots and equipment was performed. Training was also supplied by Intelitek as to be certain of proper instruction in the software and robotic performance measures. The first IE course that will utilize the IRAM Laboratory is the Industrial Robotics and Automation course which began in January 2010. The initial enrollment in the course was 14 students, but due to finances, the remaining number of students equals eleven. Three of these 11 students were also enrolled in the previously taught Advanced Materials Handling Systems course. During prior offerings for the Industrial Robotics and Automation course there were five students enrolled during the spring 2007 semester and three students enrolled during spring 2008 semester. Table 1 indicates this course enrollment data. With the current enrollment, more students will receive the skills and knowledge to promote a diverse workplace and enroll in graduate education in the field of engineering.

Table 1: Course enrollment data

Course	**Spring 07**	**Spring 08**	**Spring 09**	**Fall 09**	**Spring 10**
IEGR 470	5	3	NA	NA	11
IEGR 468	NA	NA	NA	6	NA

Enrollment in the industrial engineering department sharply increased during the fall 2009 semester with a total of 34 new freshman students. Various outreach projects involving the director of the IRAM Laboratory and current robotic research students were initiated and promoted to include several K-12 schools. Also, the director engaged in several speaking engagements to incoming engineering students regarding robotics and industrial engineering. These external events aided in the acquisition of a substantial number of these new freshman students for the department. Figure 3 shows 2008-2010 enrollment trends of all majors across the entire university. It is noted that the sharp increase in IE freshman during the fall 2009 semester follows the same pattern as the university trend for freshman in all majors as compared to the steady state trend for upper class students (e.g., sophomores, juniors, and seniors). With this increased enrollment, it is likely that more students will be exposed to and enrolled in the courses supported by this project in the near future.

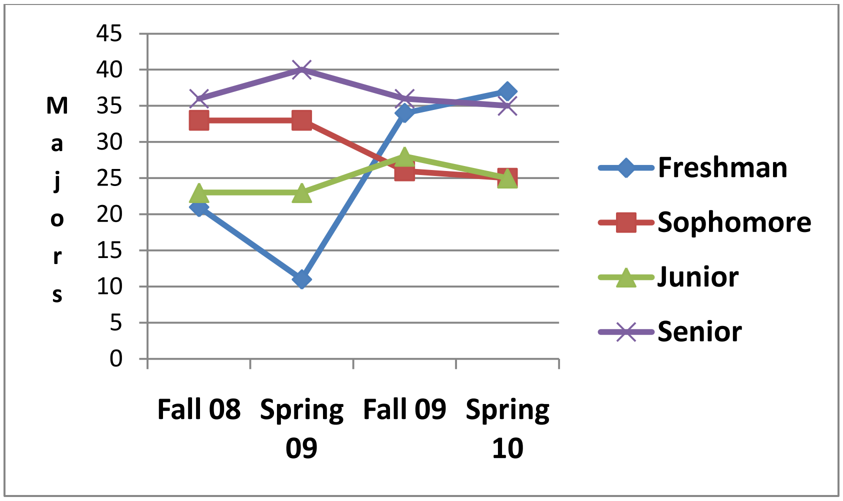

Figure 3. Enrollment trends 2008-2010

Conclusions

The intellectual merit of this project lies in developing an updated laboratory at Morgan State University that combines teaching with a hands-on integration approach. Subject areas including process planning, network communications, scheduling, and robotic programming techniques will be covered using various hardware and software systems. In addition, related course projects will tie in with other existing pre-requisite courses/projects and allow for students to transition from the use of traditional manufacturing methodologies which were performed manually to modern manufacturing methodologies which automated and computer-controlled. The focus of the project will be on strengthening the engineering workforce: (1) engineering students will learn to use software (e.g., OpenCIM software, CNC Motion for Milling and Turning, and spectraCAD/spectraCAM for computer-aided design and manufacturing) to model and determine solutions for various manufacturing scenarios, and (2) engineering students will engage in realistic applications of their flexible manufacturing projects with the use of newly developed laboratory modules.

This project will contribute to the Science, Technology, Engineering and Mathematics (STEM) education knowledge base. The project will help build the STEM education community by expanding the engineering skill set which was developed in the lower-level undergraduate courses by enriching the learning experience through enhanced learning methodologies and techniques. The project will have a broad impact on STEM education in engineering by increasing the number of under-represented students who engage in robotics research. This will provide exposure to other broader learning sources and perspectives as well as research opportunities, while promoting further interest and excitement in the field of industrial engineering. Ultimately, the enhanced learning, exposure and enthusiasm of being able to solve “real world” problems with the use of advanced robotic and automated manufacturing techniques within the industrial engineering discipline will contribute to the national benefit of discovery in the field of engineering.

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