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Using Cost-Saving Hard Automation Laboratory Projects in Manufacturing Education

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Abstract

This paper discusses the benefits of incorporating hard automation-oriented projects in manufacturing laboratories. This approach enables academic programs with limited funding to provide a valuable hands-on experience in factory automation to students while they are in school, rather than leaving it to be learned in the workplace. Two examples of laboratory projects involving high and low degrees of hard automation activities are presented. The hardware designed and built by the students as well as the associated costs are discussed.

Introduction

Engineering technology (ET) and industrial technology (IT) programs are facing the challenging task of educating competent students in many aspects of manufacturing including factory automation. A hands-on educational approach has been an effective tool to gain such competency in ET and IT programs. Many of these programs offer laboratory-oriented manufacturing courses with the mission of providing students with practical experience in automation and its application in integration of production systems. A common laboratory facility in ET and IT programs includes computer-integrated manufacturing which may be referred to as CIM lab or robotics lab [1,2,3]. CIM/robotics laboratories are typically equipped with educational, and in many instances, commercial grade machine tools and instruments. At the undergraduate level, the laboratory is primarily used for soft automation education. That is, teaching how to program computer-controlled equipment such as computer numerical control (CNC) machines, robots, and programmable logic controllers (PLC). However, a soft automation approach should be coupled with a hard automation learning approach if a full spectrum of factory automation education is desirable.

Hard automation is a full or near full scale development of an actual automated manufacturing and/or assembly workcell using capital equipment such as CNC machines and robots, components that are fabricated by students, and a variety of standard parts such as pneumatic cylinders and sensory devices. The use of hard automation-oriented projects in manufacturing education benefits students in the sense that a) it provides them with a detailed practical knowledge of how to develop a real world factory automation project "built from scratch", and b) they learn how to manage various phases of a project construction from the "ground up," including equipment installation, integration, and troubleshooting phases. Thus, students are exposed to subtle problems with numerous difficulties and uncertainties and are forced to exercise their problem solving skills.

While most CIM/robotics courses provide soft automation training, the extent to which the hard automation-oriented projects are implemented varies from one school to another. Several factors such as limited financial resources, lack of faculty expertise, and time constraints affect the degree of inclusion of hard automation projects in CIM/robotics courses. However, such limitation should not deter the ET and IT departments from pursing such value-adding educational activities considering the facts that: a) a hard automation project can be constructed using low cost standard parts and built-in-house components which are more affordable alternatives to the ready-to-use devices bought from the market, and b) many ET and IT programs are already equipped with laboratory equipment such as conventional machine tools and fluid power, which facilitate fabrication of various customized components in-house. To this end, the remainder of the paper describes the resources required to implement hard automation laboratory projects using two student projects. The educational values as well as the costs of the projects are also discussed. The first project was part of a CIM capstone course (ITD 592) offered to manufacturing/electromechanical ET and IT students at Murray State University. The second project was inspired by the work done on the first project and developed informally by a group of students.

The project context

Generally the technical content in hard automation laboratory projects is significant and involves fabrication and integration of a number of mechanical and electro-mechanical devices. As a result, the students enrolled in ITD 592 must have basic knowledge and skills in at least one of the following technologies:

(a) Metal machining processes; including the ability to use manual and CNC machine tools. Most students in the class have already taken at least one course in machine tools processes.
(b) Fluid power technology; including the ability to assemble basic pneumatic circuits and understand the functions and capabilities of various pneumatic components. All students in the program are required to take a fluid power class during the second or third year of study.
(c) Electronics and PLCs; including the ability to build basic electrical circuits and basic understanding of programmable logic controllers. All students are required to take a basic electrical systems course during the first or second year of their study. Some students may have already taken a course related to PLC.
(d) CAD and CAM Programming; including the basic skill in using CAD software and programming CNC machines. All students are required to take at least one CAD class before senior year. Some students may have already taken a CNC programming class.

Due to the nature of the project work the semester is divided into two periods: the first six weeks are lecture oriented and the last nine weeks are very project intensive. The topics included in this capstone course are intended to:

(1) familiarize students with the concept of integrated manufacturing systems and cells;
(2) help those students with deficiencies in key topics such as PLC and electronic circuits
(3) familiarize students with new topics such as robotics, sensor technology, and communication networks

At the outset of the semester students submit a proposal indicating the expected steps and activities to complete the project. The objective of a typical factory automation laboratory project would be: plan, design, and build an integrated assembly/machining cell. In addition to normal teaching functions, the faculty work as consultants and provide logistical support as the project progresses. The faculty also provide a general guideline for implementing the project as follows:

1. Project planning stage
   - Generating product ideas: brainstorming by entire class
   - Product idea selection
   - Group leader (system integrator) selection
   - Set up a tentative schedule of tasks, task titles, personnel, and time required for each task
   - Formation of teams: e.g. product & cell development team, PLC and robotic team
2. Designing stage
   - Design for assembly evaluation (concurrent engineering)
   - Material and manufacturing process(s) selection
   - Cell layout
   - Detailed drawings of product
   - Assembly operation design
   - Fixture and pallet design
3. Building stage
   - Fabricating fixtures, pallet, and mechanical hardware
   - Cell formation and physical arrangement of equipment
   - Electrical interfacing
4. Control software programming stage
   - Robot, PLC and CNC programming
5. Operational testing and presentation of results

Figure (1) shows typical resources required in developing a factory automation project within an academic laboratory environment.

Project Evaluation

The project is graded based on a set of criteria. The criteria typically include project functionality and project presentation, accompanied by demonstration of operations. Comprehensive documentation consisting of all engineering drawings and programs is also required. Moreover, to make grading of group projects fair, each student evaluates the contribution of other students to the project in terms of teamworking, creativity, and problem solving.

Laboratory projects

The following two student projects represent examples of projects with low and high degrees of hard automation content respectively.

A) Automated yo-yo manufacturing and assembly project: The purpose of the project was to design and build a functional integrated machining and assembly cell completely under computer control. The object to be produced was a yo-yo toy, composed of two halves of the yo-yo and a connecting pin. This system was intended to be an example of an industrial automated manufacturing cell (see Figure 2).

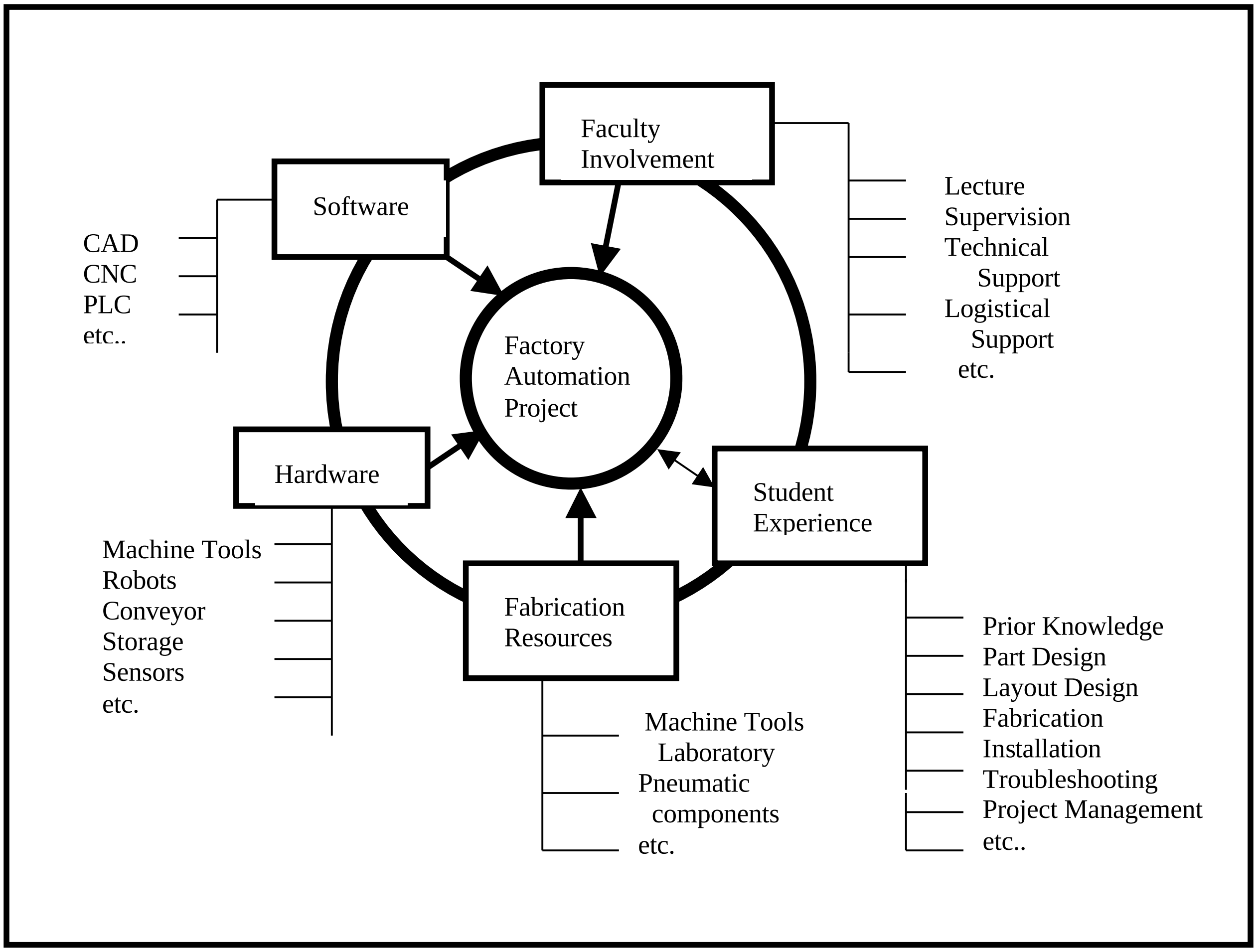

Figure 1. Framework of factory automation projects in school laboratory

Manufacturing & Assembly Planning and Design

Based on the number of students, the class was divided into three teams. The composition of each team was designed according to the students' skill, previous coursework, and interests. The functions of each team were as follows:

1) CAD/CAM Team: This team was responsible for a yo-yo design and programming the CNC machine for engraving a logo into the face of the yo-yo. This team was also responsible for the integration of the CNC machine into the assembly workcell.
2) Assembly Team: This team was responsible for designing and fabrication of the assembly station in order to successfully assemble the yo-yo in a accurate and repeatable manner.
3) Robotics Team: This team was responsible for the robotics operations of the manufacturing cell.

Extent of Hard Automation

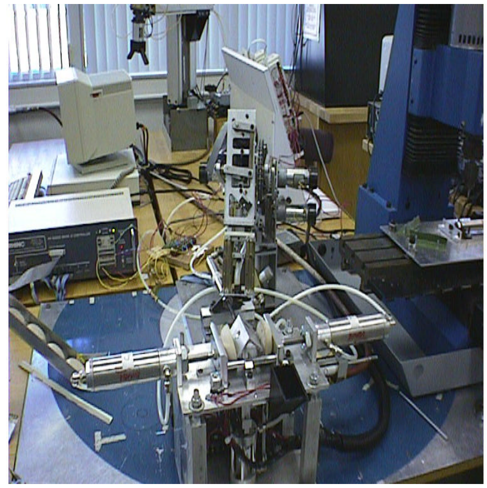

Figure 2. Yo-yo assembly module

The major hardware already available for the project consisted of a table-top CNC milling machine, a 5-axis Rhino robot, and an A-B programmable logic controller.

The major hardware designed and fabricated by the students was the yo-yo assembly module (see Figure 2) which was by far the most complex part of the project. This was a unique challenge that was presented to expose students to hard automation. The assembly module was totally built from scratch with available materials in the machine tools laboratory. The module consists of several structural components made by students using manual machine tools. Moreover, a number of standard components including four pneumatic cylinders, four proximity sensors, nine relay switches, and a seven-valve manifold assembly were used in integrating the workcell. With numerous main and auxiliary devices used in the workcell structure, the difficulty rested with how to synchronize the motion of various pieces of hardware and program the sequence of activities within the cell. A great deal of interaction and teamworking was required to make the workcell operate correctly.

The major educational aspects of this project were (a) the design of an assembly workstation and turning it into a functional device; (b) understanding the concept of factory automation through the integration of hardware and software into a functional automated workcell; and (c) the utilization of modern engineering tools such as CAD and CNC.

B) Automated yo-yo retrieval and assembly project: This project was based upon the aforementioned yo-yo project. A team of students decided to participate in the annual student robotic challenge sponsored by Society of Manufacturing Engineers and in a competition sponsored by the Fluid Power Education Foundation. One of the requirements imposed by FPEF was that the majority of hardware must be built from generic components and custom made parts. Therefore the students had to replace the table-top robot with a pair of simple linear slides controlled by pneumatic cylinders to perform pick- and-place functions.

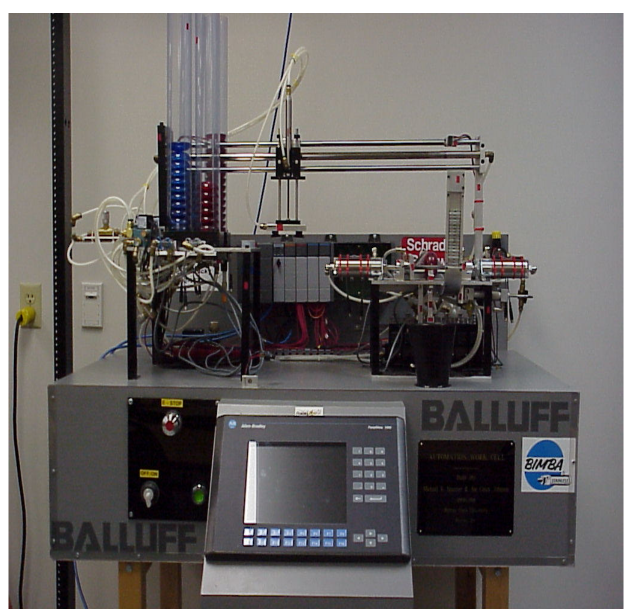

Fig. 3. Yo-yo retrieval and assembly cell

The team also decided to reduce the size of the workcell to a portable size. Thus the removal function was eliminated and the CNC milling machine was removed from the cell. As a result the scope of the cell's objective was redefined as automated retrieval and assembly of pre-fabricated yo-yo pieces (see figure 3). The new arrangement posed quite a challenge for the team since considerable customized hardware needed to be fabricated, installed, and tested by the students in a short period of time.

Extent of Hard Automation

Considering the new design requirements the team decided that the following functions needed to be incorporated into the assembly cell:

(a) Storage facility: Four vertical storage containers made of transparent plastic for holding two different colors of yo-yo halves. This facility stores sufficient stock to feed the assembly operation for a relatively long period of time (see Figure 4).

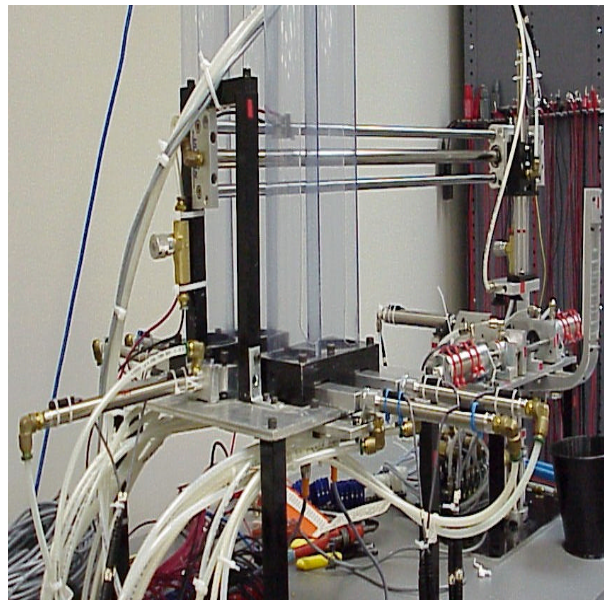

Figure 4. Storage and retrieval module

(b) Retrieval facility: At the bottom of each storage column a double-ended pneumatic cylinder extends and pushes two yo-yo halves forward simultaneously. Subsequently, the retrieved parts are pushed toward pick-up position by another cylinder.

(c) Pick-and-place function : A two-axis linear slide is activated to pick up the yo-yo halves using a pair of suction cups. This mechanism, which is based on the new technology of rodless cylinders, transports the parts to the assembly station two feet away then drops them into the fixture. Two sensors on each axis are used for accurate sequencing of the operation (see Figure 5).

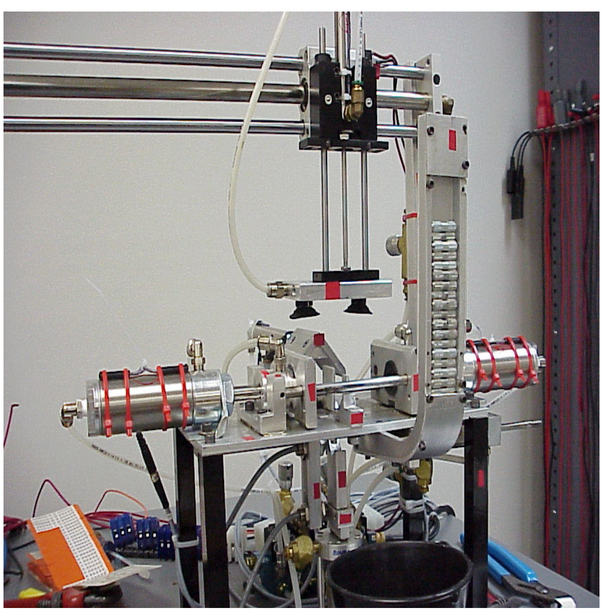

Figure 5. Transport and assembly facilities

(d) Pin storage and positioning: A storage facility made of a number of customized metal and plastic parts holds aluminum pins for assembly of yo-yo halves. A pin is pushed toward the assembly station under the force of gravity and then is pushed out and lifted up sequentially by two cylinders into assembly position.

(e) Assembling yo-yo halves: Two cylinders compress the yo-yo's halves with the center pin in between. Finally, the finished yo-yo is ejected into a storage bin using another cylinder (see Figure 5).

The cell has worked very well in demonstrations both inside and outside the laboratory. The major educational values of this project were similar to the previous project. Additionally, it exposed the students to the design, fabrication, and installation of an assembly system in a more complex computer-controlled environment.

Cost Consideration

A common limiting factor in setting up automated and integrated manufacturing cells in school laboratories is the high cost of hardware. Typically, two types of hardware are used in structure of the cells: a) major hardware, such as CNC machines and robots; and b) minor hardware, including standard and custom-made parts. The higher utilization of type (a) hardware in a project normally translates into a lower level of hard automation activities since more ready-to-use capital equipment with high costs are involved in the project. Conversely, the higher utilization of type (b) hardware means a higher level of hard automation activities in a project since more customized components are used in construction of the cell. Therefore, it is fair to say that type (b) projects are less costly than type (a) projects. As can be seen from the description of the two projects discussed earlier, the first project is a more type (a)-oriented project, while the second project is mainly type (b)-oriented. As a result, the major cost of implementing the second project is from purchasing relatively low-cost standard mechanical and /or electromechanical components and fabricating customized parts by the students. The examination of components used in the two projects revealed the following cost saving opportunities:

- A two-linear-axis actuator vs. a 5-axis robot
  Many ET and IT departments are unable to justify the purchase of industrial robots (at least $25,000). A desktop educational robot similar to the one used in the first project costs about $5,000. A two-linear- axis actuator that was used in the second project is capable of performing simple pick and place functions and was obtained for just about $500.
- Hardware fabrication
  More than 50 different metallic and plastic components were fabricated manually by the students using machine tools in the department's laboratories. The cost of these components was negligible since the materials were mainly scrap pieces.
- Electromechanical components
  Several pneumatically powered cylinders were used in both projects. These cylinders were obtained for about $100 total. The cost of components, including eight proximity sensors, several solenoid valves, vacuum pumps, fittings, and plastic tubing cost, was about $300.An Allen-Bradley MicroLogix PLC was already available for the project. However, it can be purchased for $600.

The total cost of the second project was less than $1,000 which was minimal considering the educational outcome discussed in this paper. Moreover, the project won the second place award of the 1999 SME Robotics Challenge and the first place award of the FPEP.

Conclusion

Based on the two projects described above, use of hard automation projects as part of the formal and informal curriculum seems to be a good approach to (1) providing students good training in factory automation in an academic environment, and (2) easing funding problems of laboratory projects depending on the extent of application of hard automation.

Although the approach to teaching capstone computer-integrated manufacturing courses described here requires that individual faculty members have considerable practical experience in various areas, similar results are achievable by teamworking among expert faculty within a department.

A typical hard automation laboratory project may demand a great deal of physical and logistical effort by the students as well as the faculty. However, most students appreciate the value of the education they are getting which is attested to by positive feedback from our students who indicated a clear sense of pride, ownership, and confidence over the project they designed and fabricated.

Bibliography

[1] Sheng-Jen Hsieh, "Integration of Manufacturing System Design Across Curricula" SME proceedings on Manufacturing Education for the 21st Century, Vol. V, 1998, pp. 243-246.

[2] L. King, M. Hoag , "Students Teach What They Learn to Learn Better What They Were Taught," SME proceedings on Manufacturing Education for the 21st Century, Vol. V, 1998, pp. 329-334.

[3] Abe Zeid, "A Laboratory Oriented Course in Manufacturing Systems and Techniques," SME proceedings on Manufacturing Education for the 21st Century, Vol. V, 1998, pp. 287-290.

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