AC 2011-2759: RESTRUCTURING THE ROBOTICS LABORATORY AND ENHANCING THE ROBOTICS CURRICULUM AT RIT

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Restructuring the Robotics Laboratory and Enhancing the Robotics Curriculum at RIT

Abstract

The Manufacturing and Mechanical Engineering Technology department at the Rochester Institute of Technology has been involved in an ongoing effort to improve its junior/senior/graduate level Robotics in Manufacturing laboratory and curriculum. The previous laboratory provided interesting challenges for the students to be able to get into the laboratory space and effectively use the equipment. The new laboratory exercises incorporate research of selected robotics topics, new laboratory equipment, part/process design, and process improvement. The curriculum restructuring involves the integration of previous laboratory exercises with new exercises on existing equipment and the new equipment using manufacturing philosophies such as lean, agile, and 5S. The paper will describe the new laboratory curriculum and how the manufacturing systems techniques were utilized to realize significant beneficial restructuring.

Background and Motivation

A robotics course as a technical elective and a required course provide upper-level engineering technology students with an interesting class experience within their desired curriculum at Rochester Institute of Technology. Allowing students to gain applied knowledge of some of the current robotics equipment is in the interest of the university and it students. Previous students have worked diligently on maintaining the robotic equipment. However, the students did not have a focus of cleaning the work space or developing a static work area for future students. In the summer of 2009, it was determined by one of the co-authors of this effort that a clearly defined plan had to be initiated to improve the overall condition of the robotics laboratory. In the summer students are not using the laboratory for coursework so there was an opportunity. Part of the continuous improvement process included actually upgrading the laboratory space, equipment, and curriculum (in the form of updating the experiments the students would be performing). In essence, the physical laboratory and the Robotics in Computer Integrated Manufacturing (CIM) course curriculum required restructuring to enhance the student learning experience. The course consists of one class section and one laboratory section. The focus of this effort was to restructure the laboratory section and improve the laboratory area and equipment which had not been previously improved [1].

Teaching Philosophy

The Robotics in CIM course serves as an introduction to robotics and programming systems primarily for engineering technology students and as a technical for elective for the university. However, the course includes other elements such as teamwork and written and oral communication. The written and oral communication aspects of the course are typically required for the lecture portion of the course. The teamwork portion of the course is typically required in the laboratory experiments in the course. Teamwork was also updated to become part of the lecture portion of the course. Safety, programming, and logic are the main focus in teaching students proper use of robotic equipment. The course and laboratory are to provide preliminary knowledge and real-time application of logical programming. This knowledge and application can aid the student in understanding many of the robotic applications in industry.

Laboratory Resources

As previously mentioned, the course has a dedicated laboratory of which is accessible to students with card-access to the room. The laboratory contains 2 AdeptOne industrial-sized robots, an Intellitek Eshed ER-4u training robot, an Adept Cobra 600 robot, 2 Adept Cobra 800 robots, a Fanuc LR Mate 200iC robotic training cell, a Cognex vision center with dedicated computer, and Intellitek proLight Machining Center cell.

Laboratory Improvements

In general, many of the laboratory improvements fall under the domain of continual process improvement. The continuous process improvement effort utilized concepts from 5S Improvement, Lean, Agile, Facilities Planning, and Reconfigurable Manufacturing.

5S Improvement and Lean

In its most fundamental form, as defined by Womack, Jones, & Roos, lean is the elimination of waste [3]. To make efficient use of the laboratory space, some of the robots that did not function properly were removed. Also, items that were stored in the laboratory area were removed. Two separate large industrial AdeptOne robots were removed from the laboratory. One smaller Adept Cobra 550 robot was also removed. This removal of equipment allowed for increased capacity and the ability for the laboratory equipment to be reconfigured in an “optimal” manner.

5S is an approach that provides a framework to create a neat and clean work environment [2]. The typically steps are sort, set in order, shine, standardize, and sustain. The methodology behind 5S was utilized to make the laboratory a good workplace as defined by Juran [2]. Old and obsolete equipment was organized and placed on wooden pallets for removal from the room. Tables and chairs were organized and sorted. Equipment required cleaning, dusting, and organization. Although it may appear that these activities were simple, time and care was spent in the organization. Benefits of such an undertaking included prevention of possible accidents, elimination of time searching for tooling, and prevention of possible defects arising in the equipment. Physical cleaning operations required multiple passes with detergents for proper cleaning.

A large sub-project requiring approximately one month of time was the complete refinishing of the laboratory tables and benches. Each table required sanding, filling of holes, multiple coats of wood stain, and about 5 polyurethane coatings to be applied by hand for proper presentation of the laboratory. Each table/workbench required individual attention so that dust and wood particles did not enter the area where polyurethane was setting. The benefits of a clean and neat workplace (in this case, a laboratory) were realized.

Agile: Electrical Improvements and Reconfiguration

Many of the robotic equipment in the laboratory require the use of a three-phase 208-240V electrical system. A few of these receptacles were located in a certain area that was inconvenient for making efficient use of the laboratory space. The installation of new receptacles was required for our industrial robotic equipment. Two electrical receptacles were moved from the South wall to the North wall and West wall for use with three-phase 208-240V equipment. All required receptacles were three-phase NEMA L15-20 equipment and the required three-phase NEMA L15-20 plugs were properly installed for equipment mating with the L15-20 receptacles. The majority of the three-phase industrial cable and plugs were available at a local electrical wholesale supply store. All electrical changes and upgrades were done with specific regard to New York State Electrical Codes. The electrical changes allowed for the laboratory space to become agile in its configuration. In its simplest form, as defined by the Iacocca Institute in 1991 in a report entitled 21st Century Manufacturing Enterprise Strategy, agile is the ability to adapt to changing conditions. Eliminating the obstacles created by the electrical system, allows the users of the laboratory to be able to reconfigure the area based upon utilization needs.

Facility Planning

It should be noted that facility planning techniques were examined to aid in eliminating unwanted materials and determining the most optimal configurations of the laboratory space dependent upon what the students may be required to execute in the experiments and projects.

Curriculum

The laboratory section of Robotics in CIM course is divided into 9 laboratories and a vision system demonstration. The students were required to attend laboratory as per their schedule for the entire 10-week quarter. There were approximately three students in groups working together on each laboratory. The groups were expected to complete the required deliverables outside of their laboratory period and required to perform the necessary laboratory exercises within their particular lab section. The newly developed laboratory schedule is illustrated in Table 1.

Table 1. Laboratory Schedule

Lab #	Description
1	Safety Overview
2	Eshed Pick & Place
3	Adept Pick & Place Golf Balls
4	Adept Feeders Using Sub-programming
5	Adept Feeders Using Sub-programming & Sensors
6	Gripper Design
7	Adept Feeders Moving Through a User Prompt
8	Adept Pick & Place Aluminum Cylinders with(out) Chamfers
9	Eshed Color Sense
10	Vision Systems and Demonstration

The improvements done to enhance the laboratory curriculum were based upon the experience of the graduate student and centered on organizing laboratories to build upon each other and to expose students to as many different varieties of logical programming in robotics as possible. More importantly, the curriculum was enhanced to expose students to more real-world applications of robotics than was present prior to the updates of which they may be exposed to upon graduation and reception of employment in the manufacturing arena. The use of sensors and other types of media that are utilized in conjunction with robotics are experimented upon. This includes the necessary logic behind how the sensors communicate with the robotics to complete a task that may be present in modern manufacturing.

Many of the laboratory assignments were previously written. However, they were difficult to fully comprehend and caused a great deal of confusion with the students. They also were scheduled in an order that did not build upon the previous laboratory exercise. The laboratories were re-written to clearly identify requirements and were subsequently put into practice with the students using a professional outline and a standardized formatting structure. Also, in each instance, a laboratory assignment was created to be completed outside of the laboratory period and the answer key was also created for the instructor to easily grade each aspect of the laboratory that was to be submitted by the students in their respective groups.
Supplemental programming material and presentation material have also been introduced as a means to show the students proper coding and documentation of the programming code required to operate the robots in the laboratory. This improves their overall knowledge of the code and grading techniques used to evaluate the code they have created. Since many of the students had not been exposed to programming robotics, an introduction to proper programming techniques was instituted to enable the student clearly follow the logic of their programs as well as other programs presented to them in the future.

Safety Overview

This particular laboratory assignment was to be completed by each individual student as a very important beginning assignment in the course. Safety is a very important factor in the robotics laboratory. It is possible that a student could become severely injured if not aware of the strength and mobility of the robotics equipment.

Eshed Pick & Place

The students were required to use the proper programming code and logic to move various colored blocks over an invisible wall. The color of the block did not matter, however this introductory laboratory used the Intellitek Eshed ER-4u robot with gripper functionality to familiarize students with a standard pick and place operation. This laboratory serves as an introduction to the type of logic that the students would be learning and understanding throughout the course.

Adept Pick & Place Golf Balls

The students were required to use the AdeptOne industrial-sized robot to perform the simple task of moving golf balls oriented in a grid to another grid nearby. The AdeptOne end-of-arm tooling is a vacuum solenoid with a vacuum cup attached for proper grip of each golf ball. This laboratory introduces students to a different type of programming then previously utilized and allows them to prepare for programming code used in future laboratory assignments. The programming code used in this laboratory is V/V+ for Adept robotic controllers.

Adept Feeders Using Sub-programming

The students were required to move golf balls from a grid and drop into 3 different PVC tubes which are pitched so that a golf ball will roll from one end to the other. This introduces the students to programming “loops” in their V/V+ coding schemes.

Adept Feeders Using Sub-programming and Sensors

The students were required to move the golf balls from a grid and into 3 different PVC tubes. Instead of the use of “looping” techniques in their code, they were also required to use the AdeptOne robotic input and output codes to make use of fiber optic sensors installed at the termination point of each of the PVC tubes. When a golf ball exists at the end of one of the tubes, the student is required to write code to move it to the next tube and finally back onto the original grid from where it originally departed from.

Gripper Design

The purpose of this particular laboratory exercise is to introduce and familiarize students with detailed gripper design and the engineering behind how grippers interact with parts on a production line. All robotic applications require the use of end-of-arm tooling to perform operations on various types of material and products. The students were required to design a gripper that can easily pick up an aluminum extrusion. Using an appropriate solid modeling software (such as Solidworks, which is the primary software tool used in classrooms at Rochester Institute of Technology), the proper calculations for gripper mass, extrusion mass, friction, forces from the gripper, and acceleration were required as deliverables in a report-style format from the students. Students were also required to create fully-dimensioned and labeled engineering drawings to support their software model as deliverables within their group report.

Adept Feeders Moving Through a User Prompt

The students used the identical setup as in §5.3, §5.4, and §5.5, however in this laboratory experiment they were required to create a user prompt on the terminal screen to work through moving the golf balls from the grid, through the PVC tubes and back to the grid. The user prompt must be clear enough for the instructor or outside person to be able to execute the program free of defects. The purpose of this laboratory assignment is to familiarize students with multiple different avenues in which they are able to print information to the screen. It also familiarizes students with the ability to place a prompt on the terminal screen so that a user may interact with the robotic equipment similarly to how this may occur in a manufacturing application.

Pick & Place Aluminum Cylinders with(out) Chamfers

In this laboratory assignment, the students were required to use the AdeptOne robot with the identical vacuum solenoid and vacuum gripper to pick and place small aluminum cylinders from one 3x4 grid to another 3x4 grid in sequence. The grid is designed to have chamfers in some areas and sharp edges in other areas. Similarly, the staging holes for each of the cylinders is sized ranging from near exact to the size of the aluminum cylinder up to a size that allows some space for the aluminum cylinder to be placed "sloppily" into the staging area.

The purpose of this laboratory assignment is to show students that when you remove a part from a loosely oriented area and try to fit it into a tight space, which it could be, it is almost impossible for success. Also, this laboratory assignment shows students that the use of chamfers in staging areas allows parts to be easily centered in the scope of the gripper confines so that it may be more easily placed.

Eshed Color Sense Lab

Sensors, which are becoming more important in the industrial world today, are used extensively in the robotics laboratory. The use of the Keyence RGB Digital Fiberoptic CZ-K1(P) Sensor was used by the students in this laboratory assignment. One major problem with the last iteration of labs was the fact that the sensor was not correctly wired to the Eshed controller, thus making it extremely difficult for the students to use this sensor. Upon further inspection and research, the connection problem was identified and corrected and the proper controller adjustments were made so that the sensor will now sense red, yellow and blue when installed in the current fixture being used. As future work to be completed, setup is required to allow the sensor to clearly differentiate between blue and green because the colors are very similar in color in the current setup.

Vision Systems and Demonstration

This laboratory is typically scheduled in the last week of classes. It is used primarily as a demonstration of the basic capabilities of a vision system and the software involved in processing images acquired. The vision system being used in the laboratory is a Cognex Insight 5000 series (color CCD) camera coupled with the Cognex Insight software system. The purpose of this laboratory assignment is to expose the students to a well-respected vision system that may be used in manufacturing. A laboratory report was not required for this laboratory assignment because of the timeframe available which allowed the students to delve into the vision system as far as curiosity allowed without a formal report.

Supplemental Programming Material

Because most of the students do not have a background in programming robotics, the purpose of the supplemental programming documentation is to visually allow the students to review proper coding. It also acts as an aid to allow students to document their code for use in the future. This material was given as a presentation using Microsoft PowerPoint during the normal lecture time. The students were all given copies of each slide of the presentation so that they may follow along with the instructor and to make their own notes. After the presentation, the students were then required to properly document their code for every laboratory assignment thereafter.

Conclusion

The primary goal of this course is to introduce mechanical engineering technology and manufacturing engineering technology students to the field of robotics and how they apply to real-world applications. Lectures alone are not sufficient in providing the correct level of learning that each student needs to fully understand the complexities of each individual robot and how programming languages differ. Recently, it was noticed that the laboratory itself was in need of restructuring and the laboratory curriculum improved to reflect the updates. With the recent updates to the laboratory and the laboratory curriculum, the students, in theory, should perform better in the classroom and in the laboratory. This complete redesign of the classroom itself has also influenced the soundness and professionalism of the student reports. Because the assignments were clearly laid out in logical and coherent order, the students were more able to objectify their deliverables which made grading their reports easier. Standardization throughout the entirety of the laboratory assignment sheets was a must.

A recent (October 2010) ABET accreditation site visit, noted that the Robotics Laboratory was "…too small for the current class size…" and initially ranked it as an ABET "Concern". Without the recent restructuring of the Robotics Laboratory, the "Concern" would have been undoubtedly ranked as a "Weakness", which is more severe and would require definitive corrective action before the next ABET visit. While the laboratory space is indeed small, the restructuring has enabled operational efficacy gains, student professionalism in lab procedures and a more favorable ABET evaluation. Space negotiations are an ongoing activity as the lab is enhanced and, it is far easier to negotiate additional space for an orderly laboratory.

Future Considerations

Additional refinement to the laboratory classroom and curriculum is planned for the immediate future. This aids in the adaptability and the agile nature of the laboratory. Many of the laboratory assignments will need further revision for upcoming quarters. Currently in progress for improvement are two, 2 foot by 4 foot, plywood boards with sensors mounted to them. They are being redesigned to take up less space. A laboratory assignment for the sensor boards is also being developed, as it was removed from the curriculum due to extremely poor design. Similarly, the classroom itself will need adjustment as time goes on. The new Fanuc will also be introduced in an updated version of the curriculum. Keeping track of all variables in the laboratory is a difficult task.

References

1. Brunese, P. A., Greene, C. M., & Elam, M. E, 2007, "Restructuring the Manufacturing Systems Laboratory Curriculum at The University of Alabama," Proc. of the 2007 International Engineering Research Conference, June 7-8, Orlando, Florida.
2. Gryna, F., Chua, R., & Defeo, J., 2007, Juran's Quality Planning & Analysis for Enterprise Quality, Engineering, 5th Edition, McGraw Hill, New York.
3. Womack, J., Jones, D., & Roos, D., 1991, The Machine That Changed The World, Harper Perennial, New York.

Appendix 1

Figure 1: View of Laboratory

Appendix 2

ESHED PICK AND PLACE
LABORATORY 2

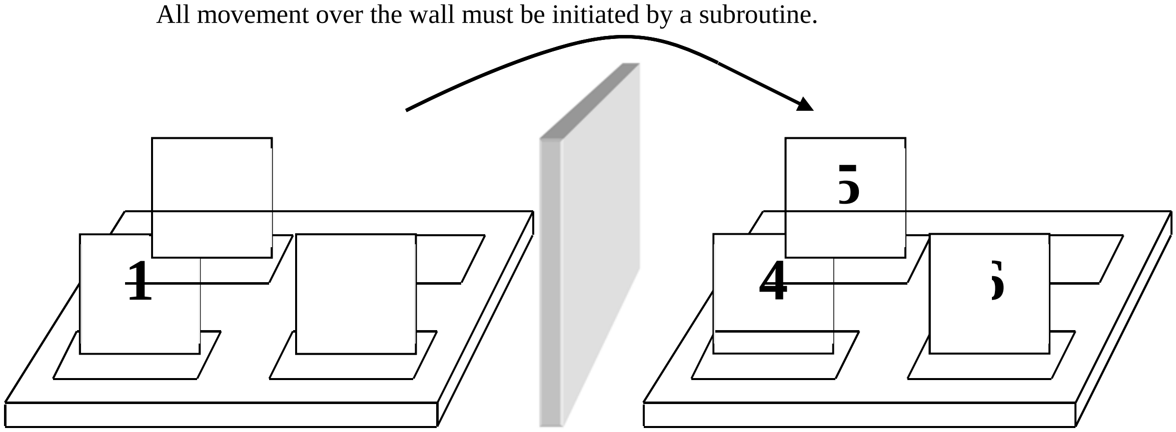
Due Date: Next lab session.
Hand in lab write-up including pre-lab and a copy of the Program created.

Objective: Develop skills in the area of robot programming and operation.
Use and understand the purpose of **approach points** and **subroutines**.

Scenario: Use the Eshed robot to pick up three blocks and place them on the other side of the wall as shown below.

Required: Program an approach point directly above each block, such that the motion of the robot is almost entirely in the Z direction (vertical).

All movement over the wall must be initiated by a subroutine.



There are blocks placed in positions 1, 2, and 3.

Move: Block 1 to Position 6,
Block 2 to Position 4,
Block 3 to Position 5.
The blocks should not touch another block or obstruction during motion.