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Teaching an old Robot New Tricks

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Teaching an Old Robot New Tricks

Abstract

This paper describes challenges and solutions in upgrading an industrial robot, Mitsubishi's Movemaster RV-M2, to keep up with advances in computer technology. This all-electric robot was used for about 25 years to teach undergraduate engineering students robotics concepts and applications. Originally, the robot's controller was connected via a 9-pin serial port to an Intel 8088-based PC. The PC communicated with the robot via Q-Basic programming language running under the Disk Operating System (DOS). One group of students was exposed to two phases of development, DosBox and MATLAB environments running in Windows 7 64-bit. Students' attitudes and perceptions surveys, students' self-reflections statements, and individual student interviews, strongly indicated that the old robot with an upgraded computer environment is still a capable tool in developing industrial robotics programming skills.

Introduction

Industrial robots are an integral part of many undergraduate engineering program curricula such as mechanical engineering, industrial engineering, manufacturing engineering, mechatronics, etc. However, there are some limitations in using them in undergraduate engineering labs. Namely, industrial robotic systems are relatively expensive, thus they are not replaced frequently. Even in industry, robots are expected to last a number of years. Another limitation of these robotic systems is the computer hardware and software they use. The life cycle of many computer hardware/software systems is just a few years. This means that many industrial robotic systems in undergraduate engineering labs quickly become obsolete. For example, many computer programs running under Windows 7 32-bit operating system are not compatible with Windows 7 64-bit operating system. One solution to this software obsolescence is to do nothing and keep the original robotic system with antiquated computer hardware and software. However, students are used to modern computer systems and software packages. To motivate and teach students using current engineering tools, instructors must constantly upgrade computer hardware and software.

This work addresses upgrades for an industrial robotic system and the students' reactions to these upgrades. Apart from describing the changes to the programming environment, the results of informal student interviews, students' self-reflection statements, and a short questionnaire will be analyzed and appropriate conclusions drawn.

Previous Work

In general, the importance of hands-on laboratory experiences in engineering education is emphasized in many learning theories. For example, according to "Kolb's Experiential Learning Cycle¹" students learn best if they follow a cycle (or a spiral) consisting of four steps (axes): experiencing (concrete experience), watching (reflective observation), thinking/modeling (abstract conceptualization), and applying/doing (active experimentation). Within the context of active robotic experimentation, both reflective observation and active experimentation are claimed as essential parts of the learning process. Kolb's learning cycle has been used in many engineering

education programs such as civil²⁻⁴, mechanical⁴, chemical^{2, 3, 5}, industrial⁶, aeronautical⁴, and manufacturing^{2, 3, 7} engineering.

The use of industrial robots in various undergraduate engineering and engineering technology labs is also well documented in literature. Industrial robots are used in manufacturing engineering^{8, 9}, industrial engineering¹⁰, electrical engineering technology^{11, 12}, mechanical engineering technology¹³, etc.

Curricular Context

The industrial robot described in this work is used in an undergraduate lab in a required senior-level computer-integrated manufacturing course at our university in two ABET accredited engineering programs: Bachelor of Science in Engineering with Specialization in Mechatronics (BSE-Mechatronics) and Industrial Engineering. Computer-Integrated Manufacturing (CIM) is a three credit-hour, required, one semester long course. It meets for four hours a week, where two hours are dedicated to lectures and two hours are dedicated to labs. The lab portion of the course includes digital controls, programmable logic controllers (PLCs), computer numerical controls (CNCs), robotics, and additive manufacturing (AM). The robotics lab consists of three tasks consisting of manual robot control using a teach pendant, lead-through programming, and computer programming. The manual robot control and the lead-through programming sessions deal with manipulating various small objects. The computer programming session (two weeks) involves programming the robot to write a name of the programmer on an 8 ½ by 11 inch sheet of paper. At the end of the lab, students write lab reports in which they include their working programs, their names written by the robot, sections on task challenges and solutions, and sections on self-reflections. The self-reflections sections are crucial parts of experiential learning.

To aid others in the implementation of this computer/software upgrade, a detailed description of the robot hardware and software is provided next. Some specific challenges are provided to illustrate what curriculum developers often encounter as they are creating new labs or as they are upgrading existing equipment.

Robotic Hardware

The Mitsubishi's Movemaster RV-M2 robot used in the CIM lab is shown in Figure 1. This robot was installed in 1993 and was popular since one of them was featured in the 1993 movie "Jurassic Park." The system consists of a robot, gripper, teach pendant, and a controller. The robot is a five degree of freedom (DOF), all-electric, anthropomorphic robot with an electric gripper. The manipulator's workspace is about two feet in the horizontal direction and about three feet in the vertical direction with respect to the bottom center of the robot base. This small robot has the maximum payload capacity of 4.4 lbs. This allows for a fairly small robot controller, thus the whole robotic system can fit on a desktop. The robot can be programmed and controlled by using the teach pendant and via the computer. The robot's controller communicates with a PC via an RS 232 serial port. The original PC was replaced with a Pentium-based PC. Since most of the modern PC's don't include an RS232 port, an additional card with two serial ports was installed.

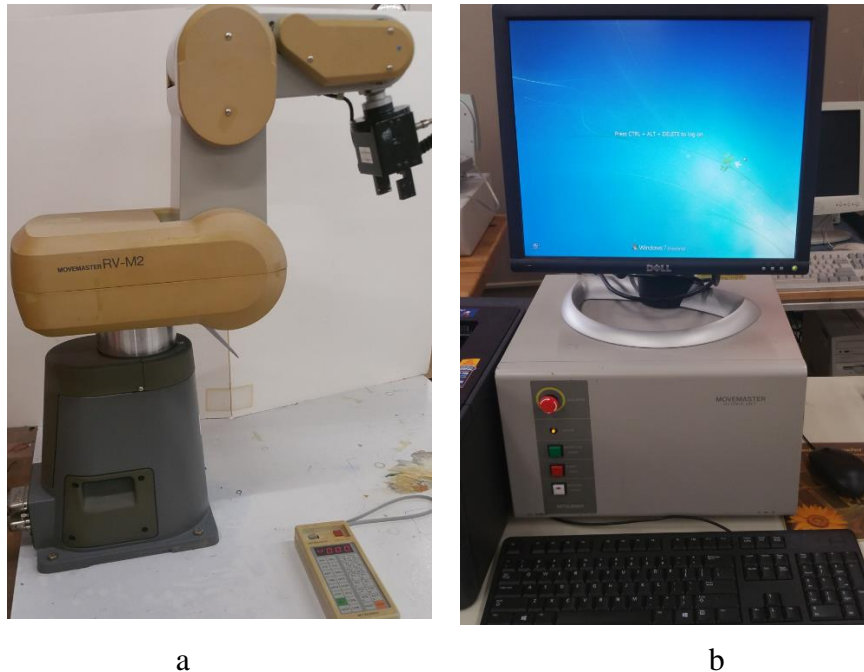


Figure 1. a) Mitsubishi's Movemaster RV-M2 Robot, b) Control Module Robot's Integrated Development Environment (IDE)

The robot's operating system consists of a 71-command instruction set. The commands include I/O commands, position/motion commands (move the robot in the world, joint, or tool coordinates), program control instructions, hand control instructions, RS232C read instructions, and miscellaneous instructions¹⁴. Originally, the operating systems was DOS running on an Intel 8088 PC. The program that was used to send the commands to the robot was Q-Basic. As the PC technology evolved, the MS Windows operating system became increasingly unfriendly to DOS applications. Also, the PC motherboard architecture advances abandoned serial ports (RS232) in favor of USB ports. The two ways to continue using the serial ports were to purchase separate serial port cards, or to use USB-to-RS232 converters (not always compatible with the robot's controller). The Command Prompt (a DOS style window) of Windows 7 32 bits was the last operating system allowing Q-Basic to run. With an inrush of Windows 7 64-bit applications, an upgrade to this system (to Windows 7 64-bit) rendered Q-Basic incompatible.

DosBox program shown in Figure 2, a wrapper, was a temporary IDE solution to this problem. Q-Basic shown in Figure 3 could still run under DosBox, but DosBox requires administrative privileges to the PC, which students were not allowed to have. So, at this stage, an instructor with administrative privileges would log into the PC, start DosBox and Q-Basic allowing students to enter their programs controlling the robot. This was not a satisfactory IDE solution because it didn't allow students to develop their programs on their own time. Also, a DOS-based programming environment had a look-and-feel of an archaic design. Students often asked, "Is this robot older than me?" In many cases, the answer was "Yes."

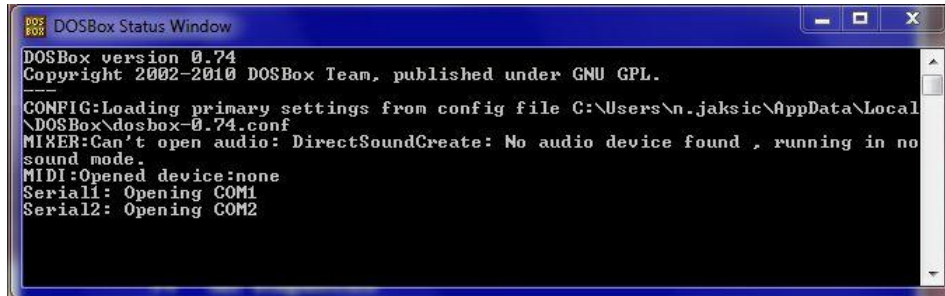


Figure 2. Screenshot of DosBox Software

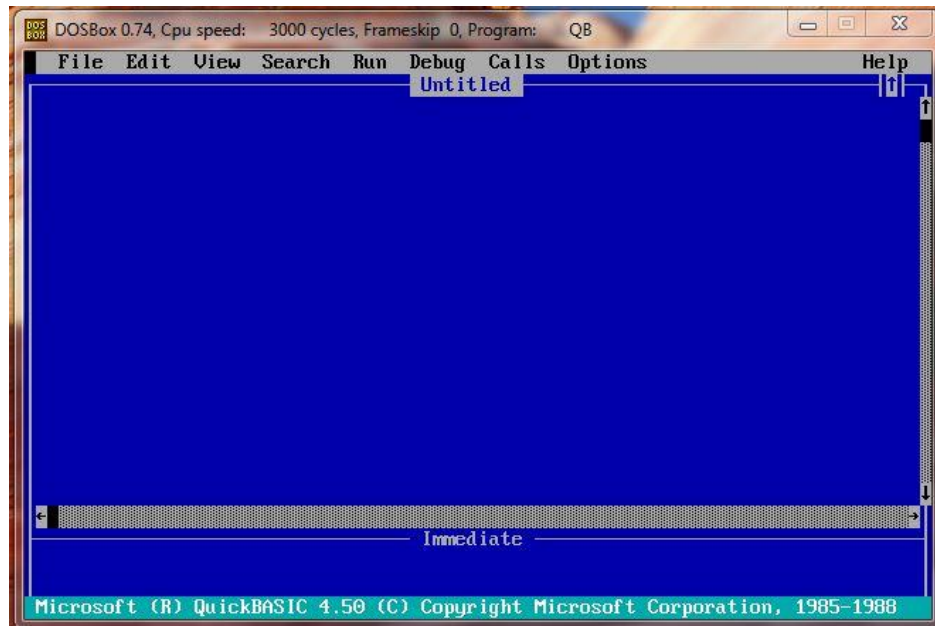


Figure 3. Screenshot of Q-Basic Environment

To solve this IDE challenge, a course instructor developed a MATLAB program capable of sending robotic commands to the robot controller. A sample program in which the robot writes the letter “A” was distributed to students and analyzed in class. Students were already familiar with the MATLAB IDE since they used it in their first-year programming course, and then reinforced their MATLAB programming skills in other subsequent engineering courses. Also, students could write their programs using the computers in many computer labs on campus. Due to the above actions and the improved accessibility to the programming environment all students were successful in completing the assigned robotic tasks. An example of the robot writing a student’s name is shown in Figure 4.

The robotic lab set followed the PLC lab set where two old Allen Bradley PLCs (SLC 100 and SLC 150) with DosBox interface were used. Students regarded these PLCs as archaic, the DOS-based graphical user interface (GUI) as unfriendly (does not use a mouse), and the whole PLC design process as somewhat inconvenient. Thus, by the end of the course, student experienced a DOS-based design environment with PLCs as well as the MATLAB IDE with the Mitsubishi’s robot.



Figure 4. Robot Writing a Name

Assessment and Evaluation of Students' Attitudes and Perceptions

Methods

Three instruments were developed and implemented to assess students' attitudes and perceptions dealing with the CIM lab in general and robotics tasks in particular: a students' attitudes and perceptions survey, students' self-reflections statements, and individual student interviews. The first instrument, a questionnaire, was administered and the results evaluated for n=17 students. There were 21 students that enrolled in the course, however, two of them were absent at the time the survey was administered, while another two students were graduate students and as such were not included in this analysis. The instrument consists of three questions rated on the Likert scale from 1 to 5, where 1 means "not at all," and 5 means "very." The 5-point Likert scale was chosen to allow students to be undecided or indifferent. The third question is somewhat biased because it is based on a couple of student complaints about the DOS-based GUI used for the PLC labs. The authors wanted to know how much of a distractor the older technology is. Also, there were three additional open-ended questions. Surveys were administered during the last class section of the semester. The score averages with standard deviations are presented in Table 1 and the entire survey is shown in Figure 5.

Table 1. Survey Results for the First Three Questions of the Survey (n = 17 students)

Num.	Question	Average	St. dev.
1	How relevant were the CIM labs to your interests as an engineer?	4.65	0.70
2	How much did you like performing different robotic tasks with the robots in the lab?	4.41	0.71
3	How much did the different computer technologies distract/impede you from the programming tasks?	2.82	1.07

Computer Technology in the Computer-Integrated Manufacturing Lab: Students' Attitudes and Perceptions Survey

In the Computer-Integrated Manufacturing (CIM) lab, you experienced a variety of computer technologies including the Disk Operating System (DOS) running the Serpent robot on an 80286 computer; the DosBox programming environment running a DOS-based PLC software for Allen Bradley SLC 150 programmable logic controller (PLC) under Windows 7 64-bit operating system, and DosBox with Q-Basic as well as MATLAB to control the lab's Movemaster RV-M2 industrial robot. During this process you learned that the DOS-based computer was easy to boot and did not require a procedure to stop it – one could simply turn off the computer by flipping a switch. Then, you learned that one can run Windows 7 non-compatible programs by going through an intermediary programming environment such as DosBox. However, the control of the serial port through DosBox was available only if the program was running with the administrator privileges (which you as individual student users didn't have). Finally, you were able to use MATLAB from your individual university accounts to operate the Movemaster RV-M2 robot. You could develop your design files for the robot on one of many computers having MATLAB installed. Also, the files saved in your account would follow you to other computers as well as to the computer controlling the robot.

I am an industrial/mechatronics engineering student.

On the scale 1 – 5 (where 1 means “not at all” and 5 means “very”) please rate the following three questions.

1. How relevant were the CIM labs to your interests as an engineer? 1 2 3 4 5
2. How much did you like performing different robotic tasks with the robots in the lab? 1 2 3 4 5
3. How much did the different computer technologies distract/impede you from the programming tasks? 1 2 3 4 5
4. Please comment on the various computer technologies used in the lab (DOS, DosBox, Win 7 with MATLAB, etc.). What is it that you liked/didn't like, appreciated, etc.?
5. What other technologies would you like to explore/experience in CIM labs?
6. Please provide any other comments on computer technologies in CIM labs.

Figure 5. CIM Lab Students' Attitudes and Perceptions Survey

Discussion

Attitudes and Perceptions Survey. Figures 6 – 8 show the distribution of student responses for the first three questions. According to Figure 6 and Table 1, students find the CIM lab highly relevant to their engineering careers. They also show a high degree of enthusiasm for working with industrial robots according to the distribution in Figure 7 and data of Table 1. Furthermore, as expected and as shown in Figure 8, it seems that a larger group of students was distracted by the antiquated DOS-based software programming environment. To probe further, quantitative responses to Questions 4 – 6 are examined.

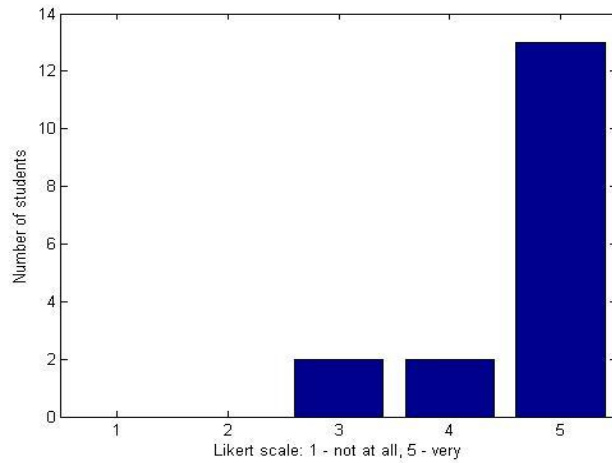


Figure 6. Responses to Question 1: How relevant were the CIM labs to your interests as an engineer?

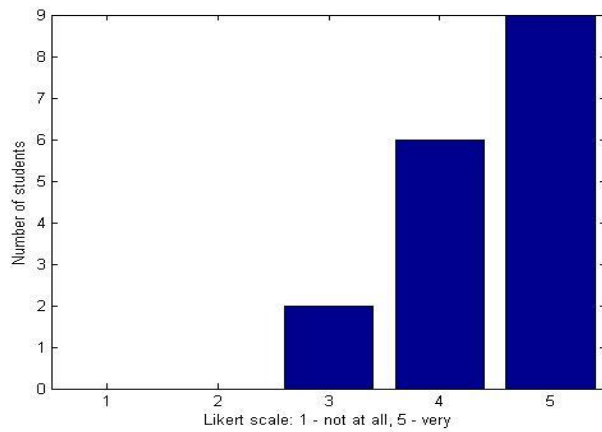


Figure 7. Responses to Question 2: How much did you like performing different robotic tasks with the robots in the lab?

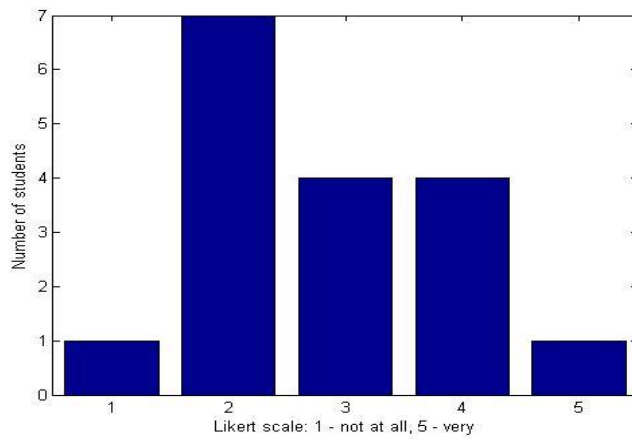


Figure 8. Responses to Question 3: How much did the different computer technologies distract/impede you from the programming tasks?

Questions 4 - 6 are open-ended questions that are designed to allow students to provide an in-depth feedback to computer technologies used in the lab. For Question 4, the comments on the computer technologies used in the lab mainly focused on two matters: familiarity and access. As expected, students appreciated the speed and simplicity of DOS, but they preferred the familiarity of Windows and MATLAB. Another group of students brought the problem of access as a major drawback of the old technology. Namely, since the University moved to Windows 7 64 bit operating system, there were no public computer labs (except for the CIM lab) that supported DosBox with administrative privileges. Also, there was only one industrial robot available for students' use. Here are some typical comments:

It would be nice if it was easier to work with the computer technologies outside of lab time.

I was just frustrated by the fact that there is only one computer that can communicate to the hardware to complete the lab. It made the overall wait much longer than it really should have been.

Question 5 is written to assess students' perceptions of modern CIM labs by asking them what they would like to experience in the lab. Students answers included statements like "spend more time on programming robots in the lab," "buy more robots," "provide more complicated robots like dexterous robots," "have image processing robotic related lab," and "teach us how to use your humanoid robots." It was surprising that a couple of students wanted more DosBox instructions.

For Question 6 (other student comments on computer technologies in the lab), most of the students reiterated that they loved the lab and even wanted to spend more time programming more complicated robotic tasks. Some of them wanted to include the robot in their senior projects, and one of them provided an advice to "make sure that industrial engineering and mechatronics students partner in all labs."

Self-reflection Statements. Students' self-reflection statements are used as another instrument in assessing and evaluating their attitudes and perceptions. While actual labs and lab reports are done in pairs, the sections on self-reflections are written individually. Self-reflections "close the loop" in completing experiential learning experience. In this case, the self-reflections revolved around three questions: what were the challenges and how I overcame them; what did I learn, and what did I like. Here, we concentrate on the third question. Some students' testimonials are provided below:

I really enjoyed this lab because I like learning how to program the robot to be able to do anything I want it to.

I loved that I was able to use Matlab code to make the robot do what I wanted.

One problem I had was that it took way too long to plot all 119 points in the cursive form of "Mike." ... It wasn't super challenging; it was just fun. It was definitely a welcome break from some of the other rigors of this program.

It was also really cool to watch the robot spell my initials successfully!

This lab was very inspiring as I was able to work with different robot arms in a very hands-on environment.

This lab was one of the most fun labs that I have experienced here at ... Its simplicity and ease of MatLab made it an enjoyable lab, and also easy to fix.

It was really entertaining to use the robot arm to stack blocks in this lab. It felt like a game rather than like school.

In their testimonials, students expressed high satisfaction with the Mitsubishi's old RV-M2 robot in both cases: when they were controlling the robot by using the teach pendant and when they were programming the robot through MATLAB.

Student Interviews. In individual student interviews, apart from comments like "Awesome lab!" students did not express problems with the age of the robot. Instead, they wanted more time and more complex robotic tasks. Some students wanted to stay after hours and program the robot.

Limitations

While many engineering departments have technology upgrade plans, many of these plans depend on departmental current and projected budgets, student enrollment, university politics, etc. Thus, the research opportunity window is often narrow when dealing with major upgrades of technology. In this case, a longitudinal study across multiple years would have been difficult since the major change in the university-wide operating system was abrupt and relatively unexpected. The comparison of the MATLAB programming environment and a DOS-based programming environment was possible because the PLC lab equipment and programming environment could not be upgraded without buying new PLCs.

The number of students ($n = 17$) in the study was somewhat small. The three distribution functions shown in Figures 6 – 8 are not Gaussian, so the qualitative analysis is fairly limited (averages and standard deviations of Table 1 are not good distribution measures). Also, since the student population is from a small regional university, the results cannot be easily applied to the students from large institutions without verifying the sufficient similarity between student populations.

Conclusions and Recommendations

In this work, a Mitsubishi's Movemaster RV-M2 industrial robot was upgraded (PC, operating system, and programming environment) to align this old robotic system with the current computer technology. From DOS and Q-Basic running on an Intel 8088 PC, computer hardware and software were adequately upgraded to a Pentium-based PC running MATLAB on Windows 7 64 bit operating system. The upgrade was possible because the PC-robot interface was using a well-established standard, RS232. From students' attitudes and perceptions surveys, students' self-reflections statements, and individual student interviews, we conclude that this 25-year old robot is still capable of helping students improve their robot programming skills. While the age of the robot did not affect students' attitudes, the use of MATLAB programming environment did, it positively impacted students' attitudes and perceptions.

In general, if the hardware and firmware of a robot are functioning well (which is often the case for robots used in education), it should not be difficult to update the IDE to the current standards. When the choice results in a familiar IDE the students can concentrate on robotic programming. In addition, as the department supports the IDE upgrades, the PC hardware changes may not influence the robot usability significantly. For ease of upgrades, when choosing a new robot, one should look for a PC-robot interface that uses well-established communication standards. An open source robot control program would also be a benefit since it may outlast the robot manufacturer's software support. Finally, the results of this study may be used as justification for lab equipment

upgrades or new equipment implementations. Future work may explore the relationship between the state of the engineering labs and students' recruitment and retention in engineering programs.

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