AC 2009-1890: FROM HANDY BOARD TO VEX: THE EVOLUTION OF A JUNIOR-LEVEL ROBOTICS LABORATORY COURSE

Yanfei Liu, Indiana University-Purdue University, Fort Wayne

From Handy Board to VEX: Evolution of a Junior Level Robotics Laboratory Course

Abstract

A new set of autonomous robotics experiments for a junior level course is described in this paper. These experiments are based on the VEX robotics kit with the MPLAB software both of which offer more flexibility for the students to apply their mechanical and software design knowledge to build an autonomous mobile robot. The students work in groups and each group has at least one mechanical engineering major and one electrical or computer engineering major. This type of grouping ensures that students are exposed to a multi-disciplinary working experience, which is one of the desired outcomes of this course. Preliminary assessment results about the level of satisfaction that the students have about various components of the course are also presented.

Introduction

Since ancient times robotics has always been a fascinating topic and thus it can be used as a vehicle to excite young people who are interested in engineering, science and technology. The Department of Engineering at Indiana University - Purdue University Fort Wayne (IPFW) offers a junior level robotics course with a companion laboratory course. This course is required for students from three majors: computer engineering, electrical engineering, and mechanical engineering. The course content includes introduction to microcontrollers (μCs), actuators, analog and digital sensors, electronics, and programmable logic controllers. The justification to have this course in the curricula is twofold. First is to provide a basic knowledge about electromechanical systems to students since nowadays there are very few systems that can be categorized as either pure electrical system or mechanical system. Second is to help student build multidisciplinary team skills.

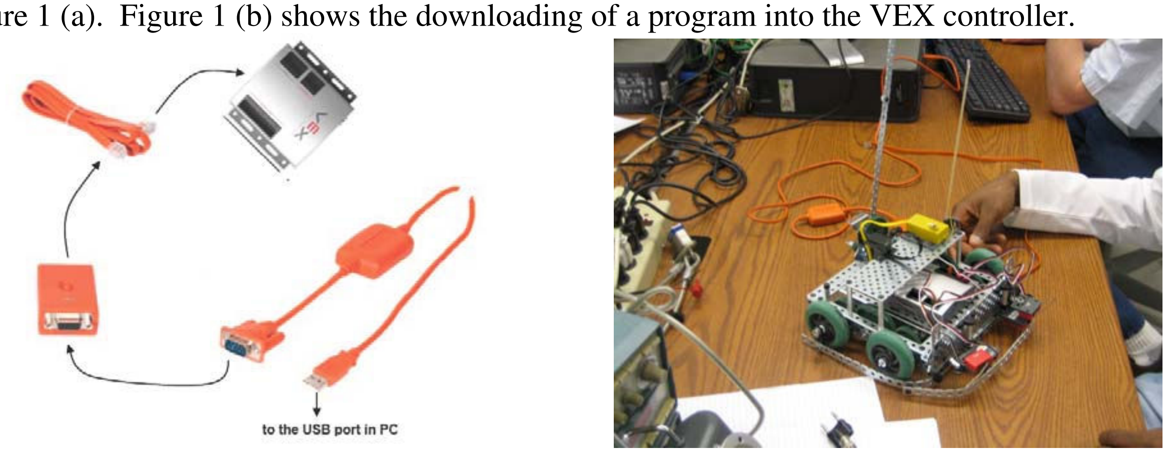
Robotics is an appropriate technical field for the integration of different engineering curricula topics and therefore it has been adopted into undergraduate studies at many universities. Manseur[1] developed a senior level course including teaching theoretical knowledge of robot manipulators, such as kinematics, dynamics, and control, as well as hands-on laboratories that build Lego robots with the MIT Handy Board[2]. Juliano and Renner[3] designed an undergraduate robotics course that emphasizes laboratory activities using two different robotics kits, LEGO Mindstorms and Parallax Boe–Bots. Beer et al.[4] described a robotics course that uses LEGO robotic kits and the MIT Handy Board for both undergraduate and graduate students. In this course, undergraduate and graduate students are asked to design and build a robot to compete in a final egg hunt contest; however, graduate students are required to finish extra writings and outside class readings. Lauwers and Nourbakhsh[5] presented an ongoing effort to design a CS Freshman curriculum using a common robotic platform. The goal of this freshman curriculum is to motivate students about computing using robots as an application area. The overall goal is to stop the steeply declining enrollment in computer science studies.

For the junior level robotics course at IPFW we constantly review the contents of the lectures and the lab equipment in order to improve its content and delivery. Until spring 2008 the robotics laboratory course used the LEGO Challenger robotic kit in combination with the Handy Board[2], a Motorola 6811-based microcontroller system, as the processing unit. While the Handy Board is a powerful tool for mobile robots applications, its software development environment, Interactive C, is rarely used by students in their later courses. Also the use of LEGO pieces fails to bring up the proper attention of college level students. It's not helpful for engineering students to apply their mechanical design knowledge into the construction of the robot by just using LEGO pieces. After evaluating many commercial robotic kits, we came to the conclusion that the VEX[6] robotic design system is a sturdier and more powerful set when compared with other robotic kits. The VEX robotic kit also offers more flexibility for students to apply their mechanical design knowledge when they build a robot. The software that comes with the kit, MPLAB IDE (Integrated Development Environment) and a C compiler, supply a true C environment. MPLAB is a popular open source development tool for embedded systems and is also used in a senior level embedded system course in our department. Hence choosing the VEX robotics kit provides students with important skills for their later design project and for their future career.

The remainder of the paper is organized as follows. First, the VEX robotics kit and the necessary software are introduced in detail. Then the four experiments and a final project are described, followed by the assessment methods and the results. The conclusions are given at the end of the paper.

VEX Robotics Kit

The VEX standard kit was selected for the laboratory experiments. This kit includes motors, gear trains, metal frames and shafts, basic sensors, controller and program modules. The VEX controller is composed of two PIC 18F8520 μCs. The sensors include two light sensors, two limit switches and two bumper switches. The programming hardware includes an USB-to-Serial Cable, a VEX programming module, and a RJ11 phone cable. For the software, a MPLAB C18 compiler for the VEX system provides a true C programming environment. The USB-to-Serial Cable, VEX programming module, and phone cable are to be connected together as shown in Figure 1 (a). Figure 1 (b) shows the downloading of a program into the VEX controller.

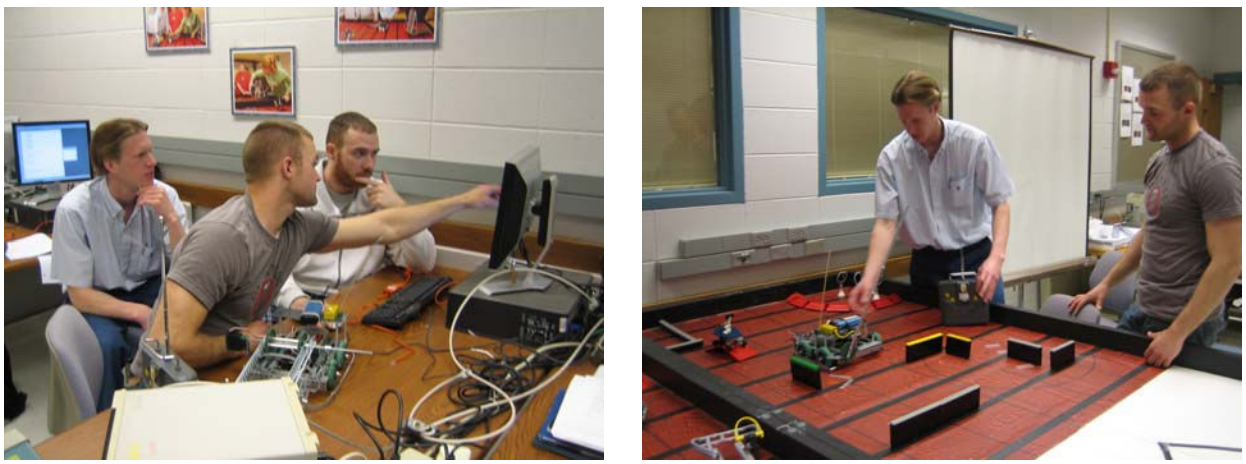


(a) Connection diagram (b) Downloading a program

Figure 1: VEX program hardware

Experiments

The laboratory work consists of four informative experiments and one final project. Each laboratory session takes 2 hours and 45 minutes. Figure 2 (a) shows one of the workstations used in the lab. The objective of the four informative experiments is to allow students become familiar with the VEX Robotics kit and the software environment. The four experiments are: Introduction to the VEX Robotics Kit (1 week), Introduction to the MPLAB IDE (1 week), Programming the robot (2 week), and Sensor interfacing (2 weeks). The final project is a robotic competition project that includes a series of challenges (7 weeks). All of the experiments and the final project are conducted in groups. At the start of the semester, the whole class is divided into groups of three students, with each group having at least one mechanical engineering student and one electrical engineering or computer engineering student. The purpose of this grouping is to ensure that students are exposed to a multi-disciplinary working environment, which is one of the desired outcomes of this course. In the following paragraphs these experiments are described in detail.



(a) A workstation (b) Robot testing

Figure 2: Students working during the lab session

Experiment 1: Introduction to the VEX robotics kit

The purpose of this laboratory is for the students to get familiar with the VEX® Robotics Kit and to be able to build a "squarebot" using the parts provided in the kit. Students in the lab start with laying out all of the parts from the kit, read the descriptions of the parts in the instructional manual, and identify and sort the parts. The VEX instructional manual provides step by step instructions to build a "squarebot." Figure 3 shows a picture of a squarebot built by the students.

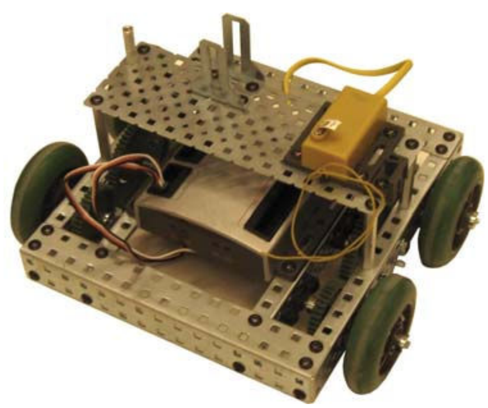


Figure 3: The squarebot

Experiment 2: Introduction to the MPLAB® IDE

This laboratory introduces students to the MPLAB® IDE and how to write simple PIC assembly language programs. MPLAB® IDE is a free-source development software for the PIC microcontroller, which is the microcontroller that the VEX robotics kit uses. MPLAB allows users to use either PIC assembly language or C language to program the chip. In the lecture, students are exposed to the basic PIC assembly instructions, such as MOV, ADD, INC, DEC and basic directives to construct an assembly program. Then in the laboratory students use the simulator provided with MPLAB to simulate the execution of the assembly program, monitoring the specific memory locations and registers used in their code to ensure a good understanding of the PIC assembly instructions.

Experiment 3: Program your robot using MPLAB® IDE

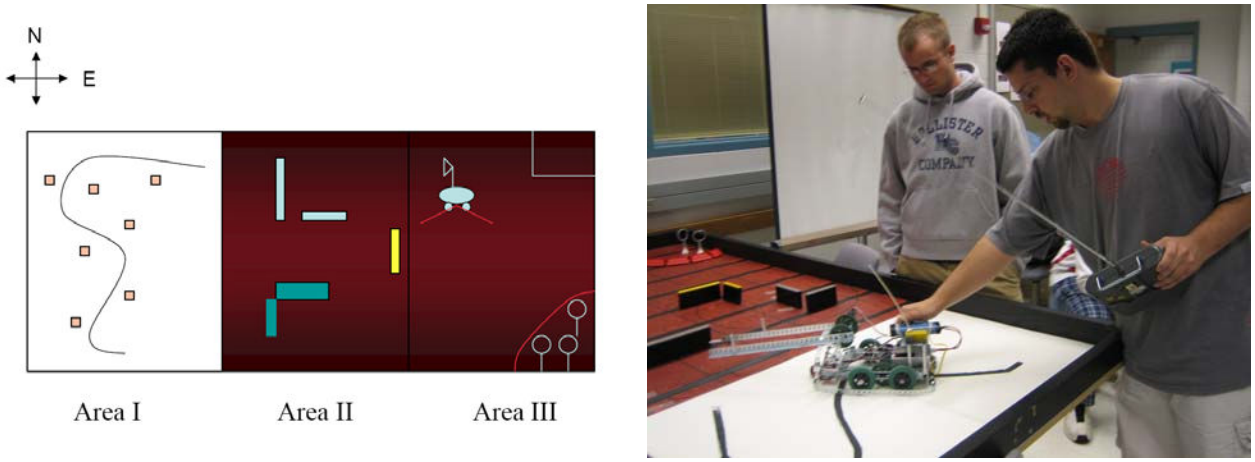
This experiment is about how to program the robot in C language using MPLAB® IDE. The assignment is to program the robot so it can travel along the perimeter of a 1mx1m square. The activities in this experiment involves learning how to open a programming workspace, build the program and download the HEX file to the VEX controller using the MPLAB® IDE, Microchip C18 compiler and the IFI downloader. In this experiment students download a default code from the VEX website[6] as a start to program the robots in autonomous mode. Students use time delays to hold the running of the motor to accomplish the assignment.

Experiment 4: Utilizing Sensors in VEX Robots

The purpose of this experiment is to learn how to program a robot to read in data from analog sensors, the light sensor and digital sensors, limit switches and bumper switches. Using the light sensor, students have to program their robot so that it can follow a black line on a piece of white paper under the normal room lighting. Using the digital sensors, students need to program their robot so that it is able to navigate itself within a contained area.

Final project

The objective of the final project is to allow students to use all the skills and knowledge learned in previous experiments to construct and program a robot to accomplish well-defined missions within a specific scenario. Each team must construct and program a robot to follow a trail (while sweeping dust out of the way) in area I (shown in Figure 4). Then the robot must navigate itself to go through the maze in area II, free a rover, and move three ice cores to the area on the northeast corner in area III. Figure 4 shows the map of the challenge field and an actual picture of the field. The whole project takes 7 weeks to finish. Students need to turn in two progress reports and a final report. In these reports students describe their design, the building of the robot and the evaluation of their design after the competition.



(a) Challenge field map (b) Actual field setup

Figure 4: Challenge Field Map

Implementation Challenges

The proposed experiments have been implemented in the junior level robotics course since the spring of 2008. The implementation challenges are the following. Although VEX robotics kit provides the option of programming in a real C environment under MPLAB, the programming has to be based on the VEX Starter Code[7] provided by the VEX robotic design system website. The starter code downloaded from the website without any modification allows the robot to be driven by human operators using the radio control link (shown in Figure 4 (b)). The code can switch to autonomous mode by using a signal from one of the channels in the radio control link. Students can program under specific places within the code to allow the robot to operate in autonomous mode. Because students do not have the option to start a program from scratch, the debugging of the program becomes somehow difficult. In experiment 4 where the robot tracks a black line on a piece of white paper placed on the floor under normal room lighting, students have difficulties due to the fact that the sensor value on black and white are not separated enough. Therefore, the robots' performance is not steady. Students need to mount extra lighting on the robot to ensure that the enough margin is generated between the sensor inputs for black and while surfaces.

Course Assessment

This new developed course, both the lecture and the laboratory, was first implemented in the spring of 2008. A survey was conducted with respect to both lecture contents and laboratory experiments for the spring and fall of 2008. The number of students in different majors who took the survey is listed in Table 1. The number of students in both electrical engineering and computer engineering kept almost the same while the number of students on mechanical engineering increased by quite a few, which showed a big impact in the results. Since the course is a multidisciplinary course, the major concern in the lecture component is whether all the students from different majors learn useful material. Students' assessment before the full implementation of this junior level course consistently complained about that the lecture contents were mostly electrical engineering material (see Appendix I for details), which was one of the reasons that this course was updated. In the survey two Likert scaled questions[8] were asked. The students were asked to rate the questions from 1 to 5. There were a total of 14 students taking the survey. The course was again offered in the fall of 2008. A total of 23 students took the course. The same survey was conducted at the end of the semester. 18 students participated in the survey. Table 2 lists the questions and the average scores for each individual question. The results showed that students from the spring semester were mostly satisfied with the lecture contents; however students from the fall semester had more concerns. It should be noted that the number of EE, CmpE students who took the survey were the same for both semesters, however the number of ME students changed from six to ten. Most of the written comments expressed the concern that the contents cover more EE materials then ME, which has always been a challenge for this course. The author is currently teaching the course this semester and adding more ME contents to balance. The same survey will be conducted in the end of this semester to seek for feedback.

Table 1: Number of students in different majors participating in the survey

Type of survey	**Number of students**							
	Spring 2008				**Fall 2008**			
	CmpE	**EE**	**ME**	**Total**	**CmpE**	**EE**	**ME**	**Total**
Lecture	3	5	6	**14**	3	5	10	**18**
Laboratory	3	5	4	**12**	4	3	12	**19**

* CmpE – Computer Engineering, EE – Electrical Engineering, ME – Mechanical Engineering

Table 2: Average scores of the lecture survey questions.

Questions	**Average Scores**	
	Spring 2008	**Fall 2008**
1. Were the contents covered in this course evenly balanced among the fields of Electrical Engineering, Computer Engineering and Mechanical Engineering? If not, please elaborate.	4.0	2.3
2. Were the contents from other disciplines rather than your major taught clearly enough to learn? If not, please elaborate.	4.3	2.6

Another survey about the switch from Handy board to VEX robotics kit was also conducted at the end of the spring 2008 semester. Before the course upgrade students complained about the inconsistent behavior of the Handy board (see Appendix II for details). A set of Likert scaled questions listed in Table 3 were asked. The students were asked to rate the questions from 1 to 5. There were a total of 12 students taking the survey. The same survey was also conducted at the end of fall 2008 semester. 19 students took the survey. Table 3 lists the questions and the average scores for each individual question. Results showed that students were satisfied with the VEX robotics kit and MPLAB in general. However students gave lower scores for Questions 1 & 2 compared with other questions. From the written comments, we notice that students raised concerns that there were not enough smaller parts such as brackets for complex design and a larger variety of sensors would be preferred. The reason for this situation is that we started with the VEX standard kit which lacks a good variety of the parts. More parts, including small brackets, optical encoders were purchased during the summer of 2008 to address these concerns. The author is constantly collecting students' feedback to keep improving the course.

Table 3: Average scores of the laboratory survey questions.

Questions	Average scores	
	Spring 2008	Fall 2008
1. Does the VEX® Robotics Kit offer enough sufficiency to build what you want to deliver? If not, are there any specific parts you would like us to add on?	3.0	3.1
2. Are the sensors provided in the Kit enough for you to complete the missions? If not, what kind of sensors you would suggest us to add?	3.2	3.2
3. Do you find the VEX® Robotics Kit easy to work with?	3.7	3.7
4. Do you find MPLAB® powerful enough and yet manageable to work with? If not, what are the things you dislike about MPLAB®?	3.5	3.3
5. Do you find MPLAB® user friendly? If not, explain your concerns in specific aspects.	3.8	3.2
6. Does ENGR 221 – C language and other program languages you learned prepare you well to program in MPLAB®? If not, what kind of knowledge do you think you lack?	4.2	3.6
7. To what extent did the lab instructions help you?	4.1	4.1

Discussions and Conclusions

This paper describes the efforts of using the VEX robotics kit in the laboratory experiments of a junior level robotics course and upgrading the lecture contents. This paper also summarizes two student surveys that were conducted to assess both the lectures content and their laboratory experience. The results of students' survey on the lecture contents showed satisfaction compared with the students' comments (in Appendix I and II) before the course was upgraded. The results of students' survey on laboratory experience showed positive feedbacks in working with the VEX robotic kits and the MPLAB programming environment. However, students raised concerns that the VEX robotic kits did not offer enough sufficiency to build their designed system (Question 1 in Table 3). The author is constantly improving the course content and the laboratory using students' feedback. More VEX parts were added to the kits during the summer of 2008 based on students' feedback. The score for Question 1 in the survey in the fall of 2008 shows a small improvement. More parts are planned to be added during the summer of 2009.

Acknowledgement

This work was supported by 2007 Summer Instructional Development Grant from Indiana University – Purdue University Fort Wayne Center for the Enhancement of Learning and Teaching (CELT). The author would like to thank Gail Rathbun for all her help in this project.

Bibliography

1. R. Manseur, "Development of an Undergraduate Robotics Course," *ASEE/IEEE Frontiers in Education Conference*, Nov. 1997, Pittsburgh, PA.
2. The MIT Handyboard webpage, http://www.handyboard.com/, last accessed January 2009.
3. B.A. Juliano and R.S. Renner, "An Undergraduate Course in Robotics and Machine Intelligence," in *AAAI Spring Symposium on Robotics and Robot Venues*, March 2007, Stanford, CA.

4. R. D. Beer, H. J. Chiel, and R. F. Drushel, “Using Autonomous Robotics to Teach Science and Engineering,” *Communications of the ACM*, 42(6), pg. 85-92, June 1999.
5. T. Lauwers and I. Nourbakhsh, “ Iterative Design of a Robot-Centered Curriculum for Introduction to Computer Science,” Proceedings of AAAI Spring Symposium on Using AI to Motivate Greater Participation in Computer Science, Stanford, CA, March 26-28, 2008
6. VEX Robotics Design Systems, http://www.vexlabs.com/, last accessed March 2009
7. VEX Robotics Design Systems Support and Downloads, http://www.vexrobotics.com/vex-robotics-downloads.shtml, last accessed Marcch 2009
8. Likert, Rensis *(1932), "A Technique for the Measurement of Attitudes", Archives of Psychology* **140**: pp. 1-55

Appendix I: Previous student comments on the lectures content

Comments ENGR 280 (ECE/ME 280)*
Spring 2006

Outcome 1: An understanding of MC68HC11 microcontrollers

- Difficult
- Class is heavy based on prior classes in the EE major that ME's do not have

Course Evaluation for ECE/ME 280
Spring 2006

Question 1: What do you like least about this course?

- Being a class that is needed for MEs, I wish this class would have more ME related material. About the only ME related material in this course is gear trains.
- Book, mostly EE material.
- The mechanical stuff without taking any of it, kind of brutal.
- The ideas are basics for EE students and completely new for ME students.

Question 2: What would you suggest to improve this course?

- More ME material.
- Class is too in-depth and covers classes EEs haven't even taken.
- Electrical Engineering students should be given a chance to take ME classed rather than this course. I would suggest this class to be an elective rather than required.
- Cover less topics or not go so in-depth. Too many topics are covered. The material could be more balanced between ME topics and EE topics.

Appendix II: Previous student comments on the laboratory content

Comments Lab Evaluation ECE/ME 281*

Question 1: Is the lab well equipped? If not, what do you think is missing?

- Lego pieces were missing
- Better Handy Boards
- Longer phone cords would allow program changes from the play board
- We were forced to work with only one type of sensor, which was very unreliable

Question 2: Is the lab equipment functional? If not, please elaborate.

- Handy Board is inconsistent
- Handy Boards
- Handy Board is very inconsistent
- The Handy Boards could be more reliable
- Most of the sensors worked fine

* ECE/ME 280 and ECE/ME 281 were the robotics lecture course and laboratory course before they were upgraded to junior level courses. Another reason to have the course at the junior level is to allow them to complete courses in statistics, dynamics, and differential equations before taking the robotics course.