AC 2008-795: FIRST-YEAR REAL WORLD COMPETITION TO MOTIVATE STUDENTS

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Abstract

First-year students in Purdue University's Mechanical Engineering Technology program are normally advised to take courses in English, Speech, Mathematics, Physics and MET classes in materials, and analytical and computational methods. While the materials class offers interesting elements with various types of material testing, the analytical and computational methods class is basically a mathematics review class combined with an introduction to spreadsheet analysis. There is nothing much in the first two semesters of the MET program to create excitement in first-year students, and this presents something of a retention challenge for the program.

In order to provide a real-world experience and an enjoyable competition to motivate students, the MET department at Purdue University in Columbus, Indiana partnered with a local company, MotoTron (www.mototron.com), to present the Mechatronics Career Discovery Challenge. Mechatronics combines mechanical, electrical, and software design to produce complex machines. This particular challenge involves writing the software to program a vehicle to navigate a course using a global positioning system (GPS) sensor.

MotoTron representatives provided specific training with Matlab and their own custom-designed software to accomplish the challenge. The vehicle is approximately 4 foot by 2 foot with 4 tires controlled by a steering actuator, a thrust motor, a brake solenoid, and a GPS sensor. Also on the vehicle are heading, yaw rate, and wheel speed sensors to be used for data acquisition.

Students are grouped into teams of 2 or 3 for the competition. Also invited to the competition are teams from the local high schools and the local community college. Teams are grouped into high school and college divisions. There are two 7-hour days of training using the Purdue University computers and lab facilities several weeks in advance of the competition.

Additionally, teams are required to submit their controller software to a design review prior to the competition. After the competition, teams are also required to make a performance presentation, summarizing their data acquisition and performance of the vehicle. The paper details the training, the competition and the results of design reviews and performance presentations.

Introduction

Retention of college students and particularly freshmen students is a universal concern among institutions of higher education. Typical retention rates of freshmen who go on to take sophomore-level courses are in the 60 -70 % range while the overall five year retention and graduation rate has been reported at 37%.[1] Institutions have implemented many potential solutions to address this problem. At Southern Illinois University in Carbondale, the College of Engineering has adopted an "Introduction to Engineering Course" that is required of all freshmen majoring in engineering. The course is described as a "lecture-laboratory course" that "allows students to work with hands-on projects that will teach the usefulness of mathematics and basic engineering concepts." Another goal is to have students "better understand how fundamental principles of science and engineering are useful in the profession." An additional dimension of the work at SIU-C is to have students perform basic math computations with data collected during hands-on exercises to illustrate the importance of mathematics. To complement the basic math computations, Matlab is also introduced to assist in analyzing the collected data.[1]

At Old Dominion University, the Engineering Fundamentals Division of the Batten College of Engineering and Technology has instituted a two-course sequence designed to provide "an authentic engineering design experience." Included in these courses is a "hands-on, team-oriented introduction to engineering." This was in response to the finding that "Attrition may also be triggered by lack of student interest in, or enthusiasm for, the type of academic learning experience that characterizes the traditional engineering curriculum."[2] Students may become disillusioned during their first year as they slog through prerequisites and program requirements that are unrelated to their major area of study. This situation may be made worse if students are required to do remediation in math or English, which happens often at Purdue University in Columbus. While retention may not be the issue for these students, they may be looking for some reinforcement that they chose the correct field of study.

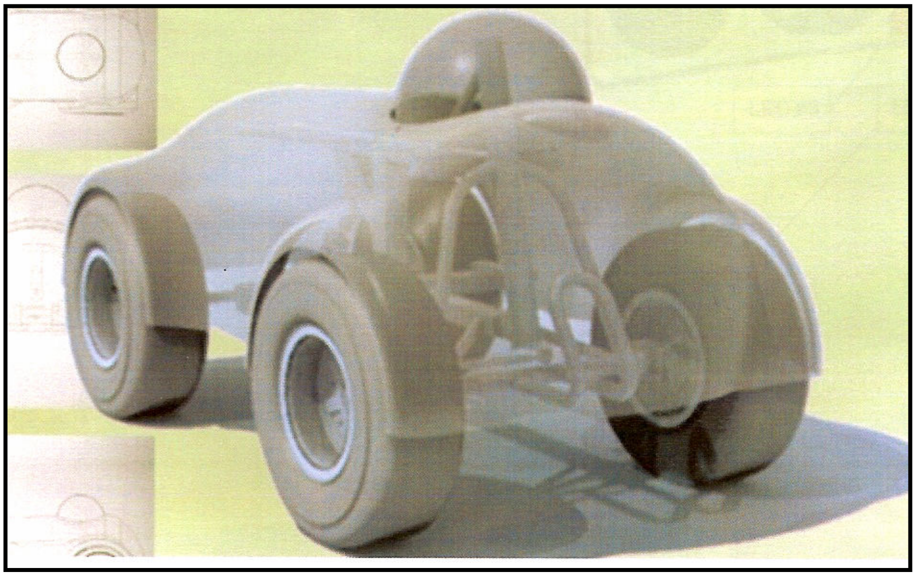
An additional issue is low classroom performance as a result of inadequate preparation. Many institutions have developed tutoring programs to assist students. [1-3] Purdue University has tools in place to identify struggling freshmen and offer assistance. In this case, midterm grades and attendance logs are submitted by the instructor at midterm, and students are notified that assistance is available to help improve their performance. Students, of course, must take the initiative to request this assistance.

Hands-on, Minds-On Activities

At the Purdue University College of Technology in Columbus, Indiana, robotics activities have been added to a first-year MET course that not only comply with core learning objectives, but also provide some excitement and fun to the class. Students are first introduced to robotics using robots made from LEGO™ bricks, wheels, motors, and a programmable logic controller. Special software is used to program the robots to accomplish some simple tasks that prepared the students for the major project/competition of the class. A similar activity at Prairie View A&M University was developed in January, 2007 as part of a design competition intended to increase retention. The theme of the competition was Nanotechnology and Science, and used LEGO robots to demonstrate design principles. The culmination of this project was a competition held during Engineers' Week at the school.[4]

The Purdue Columbus MET department partnered with a local company, MotoTron, to offer the class an opportunity to develop and program an embedded control system for the small car shown in Figure 1. The competition is called the Mechatronics Career Discovery Challenge. Mechatronics requires skills and knowledge including mechanical engineering, electrical engineering, physics, software engineering, systems engineering and mathematics. MotoTron, which develops embedded systems for industrial applications, believes in the need to train technologists to meet future challenges and developed this challenge to address this need. Students were required to attend two days of training (7 hours each day). By the afternoon of the first training day, student teams were programming the motor of the car to run in very specific ways. On the competition day, the teams were given a course to navigate with their car, using their programmed systems and a GPS sensor located on the car. The student teams were also

Figure 1. The robotic vehicle used in the competition



required to participate in a design review and to acquire data like velocity and heading during the competition. This progressive effort in robotics provided the students with a fun and interesting activity that will hopefully encourage them to remain in the MET program.

LEGO™ Robotics

To familiarize the students with programmable logic controllers and sensors, the LEGO™ Mindstorm Robotics Invention System was introduced. Working from instructions, each student constructed a "tankbot" containing two motors that independently powered the two tracks. Additionally, two accessories were built utilizing the touch sensor and the light sensor.

The programming software that comes with the system, ROBOLAB, has several training missions built into it. The students are led through the training missions and taught how to structure their programs and how to use the motors and sensors to control the robot. One class period was used to construct the robot and accessories and teach the basics of ROBOLAB.

For the second class using the LEGO robotics, the students are presented with two challenges. The first was to program their robots to follow a trapezoidal shape that was displayed on the floor using duct tape. The second challenge was designed to use the light sensor. Several layers of tape were used in such a way that a small line of a white surface was visible between strips of colored tape. The challenge was to have the robot stop on the white line. This was clearly more of a challenge. A couple students basically gave up on the light sensor and programmed their robot using timers to stop on the line. However, several others experimented with the light sensor and successfully programmed the robot to recognize the white line among the darker colored lines and stop the tankbot right on the line.

While fairly simple, this work with the LEGO robotics was enjoyable for the students and helped to develop their thinking about the general process of programming robots and using input information from sensors to control the robot. At the University of Nevada-Reno, faculty have created an entire course using LEGO robotics technology with the overall goal "for the student to learn the fundamentals of structured computer programming, the design process, and creative thinking."[5] Programming the MotoTron vehicles would certainly be more complicated than programming LEGO robots, but this exercise proved to be a good introductory activity to the design process and structured programming.

Mechatronics Challenge

The mechatronics challenge utilized robots (Figure 1) built on a toy chassis but employed the same sensors, actuators and embedded computers to drive the robot around the course as are used on the control systems that MotoTron develops for expensive yachts. Much of the theory taught during the 14 hours of class is the same theory used in vessel autopilots to navigate boats automatically through all sorts of sea conditions. This challenge teaches state of the art skills using state of the art tools. MotoTron employees worked evenings and weekends to create the vehicles and the curriculum. They believe that this challenge will inspire the same passion in future technologists that already exists in their current employees.

The challenge was also extended to the local high schools and community college leading to two teams of high school age students but no one from the community college. Also competing were three groups from the MET program and one group from the Computer and Information Technology program from the University. Facilities for the training were provided by the University while representatives from MotoTron conducted the training. All equipment and software was provided by MotoTron with the exception of Matlab, which the University already had available. A third organization, the Community Education Coalition, provided lunch for the participants during the training sessions and the competition and also provided the prizes for the teams. The Community Education Coalition is a partnership of education, business, and community stakeholders whose mission is focused on aligning and integrating the community learning system, economic development, and quality of life. (www.educationcoalition.com)

Training Sessions

The training sessions were conducted at the University on two Saturdays in October. Since more than 20 students were involved, teams were formed to accommodate the limited number of computers available. Plus, cooperative learning was encouraged.

Matlab and Simulink

While Matlab is an advanced mathematical tool, it has been used in freshmen-level courses. The Polytechnic campus of Arizona State University has designed and implemented an optional one-hour course "to teach Matlab and programming concepts within a broader context of developing problem solving skills for real world engineering applications."[6] Additionally, an Introduction to Mechanical Engineering course at Michigan State University teaches students to use Matlab, Excel and Basic. In fact, the lab portion of the course ended with "students using a version of Basic to program mechatronics microcontrollers."[7] This course at Purdue Columbus uses Matlab to program a mechatronics embedded controller.

Matlab and its environment were the first topics of the training, with teams learning how to navigate in Matlab, how to use its powerful function library, and how to display the current workspace. The structure of Matlab and the various add-ons available were discussed. One of those add-ons, Simulink, is an environment for multi-domain simulation and model-based design for dynamic and embedded systems. It provides an interactive graphical environment and a customizable set of block libraries that allow design, simulation, implementation, and testing of time-varying systems.

Students are instructed to create a new model in Simulink by dragging a sine wave into the blank window to provide the source. A gain is also applied, and a scope is added to allow the signal to be observed. The sine wave, gain, and scope are then grouped into a subsystem. A trigger is added to tell the model how often to perform the calculation. Students observe in the scope that the signal indeed looks like a sine wave, but the sampling time of the trigger is too large, leading to an odd looking stepped signal. The sample time is adjusted on the trigger, and the observed signal eventually appears like a smooth sine wave. This is a rather simple example but illustrates some important parameters like sampling time and gain along with demonstrating the mechanics of Simulink.

MotoHawk

MotoHawk is an add-on to Simulink to provide special interfaces to the embedded controllers. These interfaces are:

- Inputs/Outputs – Blocks that allow the user to read and set voltages and currents to devices connected to the controller
- Operating System Triggers – Blocks that allow the user to connect to the timer interrupts of the controller.
- Datalink Services – Blocks that communicate with other devices on the network
- Probes, Calibrations, and Tables – Blocks that allow the user to monitor signals, provide adjustable parameters, and lookup tables
- MotoHawk will also automatically generate and build the software to run on the modules.

After MotoHawk is started within Simulink, the user must choose the embedded controller used on the vehicle. This leads to an important distinction about the purpose of MotoHawk. Simulations can still be performed in Simulink but MotoHawk generates and builds the software to run on the controllers themselves. So, Simulink can be used to check the desired signal and MotoHawk is used to create the code to run the controller module on the robot. Simulink is the simulation tool and MotoHawk provides the connection to the hardware.

MotoTune

The final piece of the software tool chain is called MotoTune. This tool can communicate with the embedded controller from a personal computer in order to reprogram the controller and interact with it while the controller is running. MotoTune communicates to the controller via a USB-CAN interface. The CAN (Controller Area Network) network is the high speed communication path to the controller. CAN is used in most cars and trucks to allow the engine, transmission, automatic braking system, stability control system, and passenger restraint system to communicate. MotoTune forms a connection to the controller via the CAN link. The USB-CAN device is connected to the personal computer and MotoTune is configured to communicate with the controller. A spreadsheet display is created from within MotoTune and the original sine wave tool is then loaded into this display and shows the current value of the signal. MotoTune also updates the display periodically. The value can be right-clicked and the speed of the update can be increased. This tool chain from Matlab to Simulink to MotoHawk to MotoTune provides the path for building an application program for the embedded controller. The final step of the process is to connect it to a mechatronic control system.

Anatomy of Mechatronic Systems

Mechatronic systems consist of four basic components: sensors, actuators, wiring and a controller. Sensors are devices designed to measure quantities like temperature, pressure, speed and position. Typically, the sensor measurement is converted to a voltage or current for delivery to and decoding by the controller. An Analog-to-Digital Converter (ADC) is used by the microprocessor of the controller to convert the analog voltage or current to an integer number. This requires an extra conversion to determine the number of volts in each digital count.

Actuators include motors, solenoids, hydraulic valves, and injectors. These devices cause other devices to move. Some actuators have integrated sensors. In many cases, actuators are the output instruments of the robot, responding to the input from the sensors based on the control program. The parallels with the LEGO robots are apparent since the LEGO robots have light and touch sensors to provide input information and motors to provide output control. The details of how to create the control program, how to download it to the robot, and how to control the robot interactively may be different, but the process is the same.

Wiring is needed between the controller, sensors and actuators. Wiring diagrams are included with the training materials. The final component of the system is the controller, the central brain of the system. The software in the controller is responsible for reading sensors, communicating with network devices, and driving actuators.

Implementation on the vehicle

In order to illustrate the process just presented, the teams are taken through an example of building a control system for the steering actuator. The process starts with defining a set of requirements for the steering system and then building the interfaces to collect the inputs and send messages to the outputs. The steering system positions or maintains the steering actuator based upon a steering position sensor command, which is a signal with a range of -100% to 100%, corresponding to 100% left steering and 100% right steering.

The steering position sensor outputs an analog voltage that varies based on how far the linear actuator motor has moved. The position sensor voltage is converted using an analog-to-digital converter to a signal in units of percent. A simple look-up table is defined in MotoHawk, containing values of digital counts versus percent. For example, the sensor outputs 0 to 5 Volts and the ADC uses a 10 bit converter. The number 2 raised to the 10^{th} power yields 1024 counts, so the output of the ADC is in counts (0 -1023). Zero counts corresponds to zero volts and 1023 counts corresponds to 5 volts. The conversion to percent produces a table with 0 counts corresponding to -100% (100% left steering) and 1023 counts representing +100% (100% right steering). A fault is added to the controller to tell the robot to stop should the sensor wires become disconnected. After formulating the appropriate conversions, the teams compile the controller software and download it to the hardware on the robot. With the robot powered and MotoTune operating on the computer, the teams can calibrate the sensor by moving the steering to 100% left or 100% right, changing the count value to correspond to the table values. This activity, while tedious, demonstrated to the teams the importance of mathematics, especially concerning binary numbers and their use in real world applications.

Other control applications are produced for the speed controller, brake controller and speed sensor. At this point, on the second day of training, the teams are provided an opportunity to connect a remote control receiver to the robot and to run the robot using a remote operator station containing joysticks, paddles, knobs, switches, lamps and displays. This is wireless remote control and the teams enjoyed this opportunity to run the cars.

Automatic Guidance

To make the vehicle automatically navigate a course defined by a series a waypoints, a control system that can detect the robot's position and guide it through the course is required. Waypoints are geographic locations on earth defined by latitude and longitude. Traversing a course using waypoints is as simple as determining the bearing or heading to the next waypoint and then traveling in that direction. Calculating the direction is where some really interesting math and trigonometry are required. The first equation below computes the distance in meters between the

$$d = 2\mathrm{R}_e\, a\sin\left(\sqrt{\left(\left(\frac{\sin(lat2-lat1)}{2}\right)^2 + \cos(lat1)\cos(lat2)\left(\frac{\sin(lon2-lon1)}{2}\right)^2\right)}\right)$$

where

d = distance in meters

R_e = radius of earth

$lon2,\ lat2$ is the destination waypoint in radians

$lon1,\ lat1$ is the origin waypoint in radians

two waypoints. The second needed equation is the heading between two waypoints and the equation below is used to compute it.

The final step in the process is to add a GPS sensor to collect the latitude and longitude data and to build a control system using the equations to guide the vehicle through the course. This is completed during the second day of training. Each team is supplied with a navigation computer that is to be placed in the model and will read the GPS and heading sensors, and use the supplied route data to compute the course to steer.

$$C = \tan^{-1}\left(\frac{\sin(lon2 - lon1)\times\cos(lat2)}{\cos(lat1)\sin(lat2) - \sin(lat1)\cos(lat2)\cos(lon2 - lon1)}\right)$$

where

C = the heading between the waypoints in radians

lon2, lat2 = the destination waypoint in radians

lon1, lat1 = the origin waypoint in radians

Competition Day

On the day of the competition, the teams were given a table of six waypoints to navigate. The table entries included latitude, longitude, corridor width and speed limit. The day chosen was in November and this presented a problem. The batteries used in the vehicles were sensitive to cold temperatures and quickly lost their power. Representatives of MotoTron went to purchase new batteries but they, too, did not perform particularly well. The problems delayed the competition and forced a modification as the teams struggled to get their vehicles to run. Eventually, each team was able to successfully navigate the course autonomously. Only in one instance did a programming error lead to a runaway robot car. In the end, there was no competition but the students enjoyed the project. The prizes supplied by the Community Education Coalition were equally divided among the participants with each participant receiving a $100 gift card to a local electronics store.

The teams were also required to participate in a design review with a judge from a local company. His evaluation was that he was impressed with the performance and insight from each team and considered it a major achievement that the teams were able to get their vehicles running given the range of skills of the participants. Table 1 provides a record of the written observations of the evaluator. Highlights of his comments included the leadership shown by the only girl – a high school girl – involved in the competition; the outstanding performance of the team from the Computer & Information Technology department of the Purdue University College of Technology in Columbus; the challenge of programming this robot compared to the LEGO Mindstorms robot; and, that the teams recognized that the accuracy of the GPS was the most critical item in guiding the vehicle.

Conclusions

While the competition did not occur exactly as planned, everyone considered the effort worthwhile. More than 20 students from a university, community college and high school came together to learn how to build a control system for a robotic vehicle. The partnering company, MotoTron, had the opportunity to evaluate these students and employed one of the participants as an intern starting in January, 2008. Additionally, they identified three other participants who would fit well in their organization and planned to recruit them when openings are available.

Representatives of MotoTron were quite pleased with effort and energy of the participants. The training class used for the participants is very similar – especially the first day – to the training course they offer customers, who are usually degreed engineers and technologists. To their surprise, the teams performed quite well and were able to complete the first day of training at the same pace as the professionals. The second day of training was modified to remove some

Table 1 Comments recorded by Tom Dollmeyer, an engine systems engineer for Cummins, Inc., who served as the design reviewer for the teams involved in the project.

All of the teams understood why the robot did not run the path precisely. They correctly identified that the accuracy of the GPS plays the most important role in guiding the vehicle along a course.
Most teams, when asked what they would do differently, identified that deeper understanding of the navigation computer would help them better understand how the robot figured out which course to follow.
Most teams understood the roles of the different tools being used: Matlab/Simulink for application design and MotoTune for programming, calibration, and adjustment.
Two of the teams were experienced users of Mindstorms and found the difference in approach in the programming environment to be interesting and a bit challenging.
Simulink proved to be understandable even by the high school teams.
The most successful high school team had a very good leader. She kept the team focused.
One team, from the C&IT department, clearly understood and embraced the tool the best. Their model was clear, well laid out, and functioned with additional features.

Geodetic theory regarding navigation of the robots. In the end, the teams essentially installed a pre-built navigation computer to use as the sensor signals for a simple steering controller.

As for the first-semester MET class, the students were exposed to a real-world application in robotics, first using LEGO robots and then advancing to a more sophisticated robot. Where in previous semesters this class was only a review of math and an introduction to spreadsheet analysis, those activities have been retained while adding real-world projects to keep the students interested in Mechanical Engineering Technology.

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