A Fire-Fighting Robot and Its Impact on Educational Outcomes

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ABSTRACT

In this paper we discuss the educational experiences gained through the design, construction, and competition of a fire-fighting robot. We focus on two significant educational outcomes: 1) teamwork skills and 2) the ability to frame, define, and resolve difficult, real-world problems. We also discuss the practical experience gained through building a robot with high performance, reliability, speed, and accuracy specifications. The four sub-modules of the robot design – namely motion control, sensors, independent power supply development, and a fire-extinguishing mechanism – each stress the two significant educational outcomes. The desire to win the competition is a constant source of motivation and tests the limits of a student's patience, education, and teamwork skills. This desire to win also encourages the students to reach for the highest standards of performance, reliability, speed and accuracy. Each design and construction phase taught the students how to frame, define, and then resolve problems encountered. We show how each stage of the fire-fighting robot design, construction, and competition contributes toward improving the desired educational outcomes.

INTRODUCTION

Recently, the criteria to evaluate a university engineering program have changed such that the primary emphasis will be on how well the critical educational outcomes for the individual institution are met[1, 2]. To this end, the United States Air Force Academy has designated seven desired educational outcomes: producing officers with 1. breadth of integrated, fundamental knowledge; 2. ability to frame and resolve ill-defined problems; 3. effective communication skills; 4. skills as an independent learner; 5. teamwork skills; 6. intellectual curiosity; and 7. military professionalism[3]. In this paper, we illustrate the role of a fire-fighting robot project in an engineering curriculum and its contribution to these educational outcomes. Our primary focus in this paper is on outcomes number two and five with some discussion of how the experience also contributes to the other educational outcomes.

The goal of the fire-fighting robot project is to create a wheeled robot with capabilities to navigate through a specially designed maze, detect a candle flame (simulating a fire), extinguish the flame, and return to a designated location within the maze. To obtain this goal, four different "low level" modules must be successfully developed: a motion control module, a sensor module, a fire-extinguishing module, and a power supply module. Once the four separate modules are created, they must then be integrated into an overall control module for the fire-fighting robot.

In this paper, we discuss two different fire-fighting robot projects and their impact on the corresponding teams concerning the desired educational outcomes. The emphasis of the paper is based on the project completed during the 1997 spring semester with discussion on the second fire-fighting robot project currently under construction. For the remainder of the paper, we will refer to the group who completed the project in the spring of 1997 as the past team, and the group now creating another fire-fighting robot as the current team.

During the design phase of the project, students immediately discovered the tight interrelationship between the four modules. For example, the selection of robot driving motors dictates the necessary power source, while the size of the power source determines the dimensions of the robot frame needed to house both motors and the power supply. The total weight of the robot, on the other hand, governs the selection of appropriate motors with sufficient torque delivering capabilities. The design phase encourages students to frame and resolve various problems for which there are no single "correct" answers, and the decisions are made through a cooperative effort between team members. For both fire-fighting robot projects, the Academy teams consisted of two cadets majoring in Electrical Engineering. Actual construction of the robot, i.e., "building" the four different modules, also provided the past team with opportunities to practice engineering and teamwork skills. For example, the cadets had to use teamwork skills to divide the tasks of the project evenly among the team members and each member of the team had to accomplish the assigned tasks for the overall success of the project. The educational value of the robot building experience to some degree serves all seven educational outcomes.

EDUCATIONAL OUTCOMES AND A FIRE-FIGHTING ROBOT PROJECT

The fire-fighting robot project can be ideally used in a senior design course or an independent study course. The past project team worked on the project in a senior design course while the current team is working on the project in an EE independent study course. Students thrive in such courses since they allow students the freedom to create, test, and develop their own ideas.

Design Process

In the beginning of the project design phase, cadets met with the mentor regularly to create an "optimal" fire-fighting robot. The initial design was modified many times before final decisions were made. The robot frame was first designed to house motors, sensors, batteries, and an electronic circuit board. To develop the robot frame, the two cadets independently designed separate frames which were later combined into one after studying advantages and disadvantages of each design(educational outcome number five). The cadets researched various robot frames before designing their own, which indicated intellectual curiosity (educational outcome number six). During the design stage, the cadets also had opportunities to practice their skills of framing and resolving a problem which has numerous possible solutions (educational outcome number two); each initial design solution was then evaluated and studied among the group. The cadets exercised their oral communication skills (educational outcome number three) while presenting their solutions to the team. Finding a suitable motor for the motion control of the robot forced the cadets to again solve an ill-defined problem. The cadets learned advantages and disadvantages of various types of motors: dc vs. stepper, permanent magnet vs. charged, brush vs. brushless, etc. This type of learning helped them with skills to become independent learners(educational outcome number four). The motor control was performed by the Motorola 68HC11 microcontroller along with a motor control chip and simple TTL logic chips. From a previous microcomputer programming course, the cadets had already gained the fundamental knowledge (educational outcome number one) required to program the microcontroller for generating the necessary motion control signals for the robot motion.

The proper design of the sensor module is essential to the navigation and control of the fire-fighting robot since sensors provide the robot with the means to interact with the surrounding environment. Such interaction includes obstacle, wall, and fire detection. The wall detection must be performed as the robot moves through the maze. The sensor should inform the motion control module of an approaching wall in time to prevent a collision. During this phase of the project, the cadets studied available sensors and made a selection based upon the discussion among the team members: the cadets exercised skills related to educational outcome numbers two and five. Obstacle detection is another important consideration in the design of the sensor subsystem. The annual Trinity College competition [4] grants contestants an option to place obstacles within a maze, which may well simulate furniture obstructions in a real building. The robot, therefore, must be able to navigate through the room, searching for a fire, while also avoiding obstacles which may lie in its path. This means the cadets must either design the wall detecting sensors to also detect obstacles (if so, the sensors must be located to meet the requirement) or design a set of separate sensors for obstacle detection purposes. Teamwork skills played a vital role in developing an agreement on how to solve the associated ill-defined problems during this stage.

The design of the power supply provides the cadets with another opportunity to exercise related skills for educational outcomes two and five. For example, the cadets had to select battery sources for both motors and an electronic circuit board from many available choices. The fire-extinguishing module yields an arena for creativity and imagination. Multiple solutions surfaced during this stage which include the use of a fan-like device, a CO_2-gas gun, a hammer, a water gun, etc. The cadets from the past team discussed many options and came to the conclusion to use a fan-like device. The current project team still considers both a fan-like device and a CO_2-gas gun. This design phase renders itself naturally to skills of the framing and resolving an ill-defined problem as well as team work skills.

Construction

The cadets of the past team divided their tasks evenly between the two members: one member worked on the motion control and power supply modules while the other worked on the sensor module and the fire-extinguishing modules. For the motor control module a DC motor from a model air plane was used by the past team. The current project team, however, selected a ball bearing DC gear-head motor with a built-in Hewlett Packard encoder. The rationale behind the selection of the current project team is that the motor provides more power and the encoder feedback provides more accurate control of the robot motion. The past experience provided the current project team with additional information to frame and resolve the ill-defined problem of the motor selection. A motor driver chip made by S.G. Thompson along with simple logic gates were used to interface the motors with the 68HC11 microcontroller by both teams. The cadets learned how to program the microcontroller using an assembly language. For the past team the entire program was written using assembly language. However, the current project team found that using assembly language for a project such as the fire-fighting robot can be very tedious: as a result the team is now using the C programming language along with a C cross compiler for the 68HC11 microcontroller.

The choices made for the motors and the particular microcontroller also allowed opportunities for cadets to practice their engineering skills which include the second and the fifth educational outcomes. The cadets had to make decisions on the number of power sources and whether or not they should use other electronic components, such as a voltage divider to generate necessary voltages to the robot components. For further construction and implementation details on the motion control module, see [5].

During the construction phase of the wall and obstacle sensors, both teams decided to use an infrared LED/phototransistor pair. See Figure 1. The cadets from the past team initially considered putting a ring of IR emitter/detector pairs around the robot but, after a heated discussion, the past team came to a conclusion that only three pairs were necessary. The discussion proved to be valuable experience for it emphasized to both cadets the importance of effective communication skills.

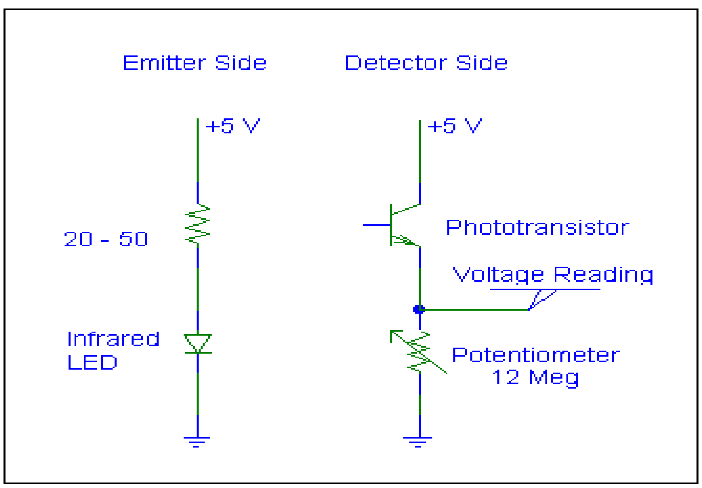

Figure 1. Schematic for IR emitter/detector pair

One sensor was placed facing the front of the robot, and an additional sensor was placed approximately sixty degrees on either side of the front sensor. This provided ample side coverage as well as front-biased sensor detection. Figure 2, below, graphically displays the placement of the sensors as well as the circular robot frame. In order to further reduce the effect of noise, an average of four sensed values was taken for each sensor.

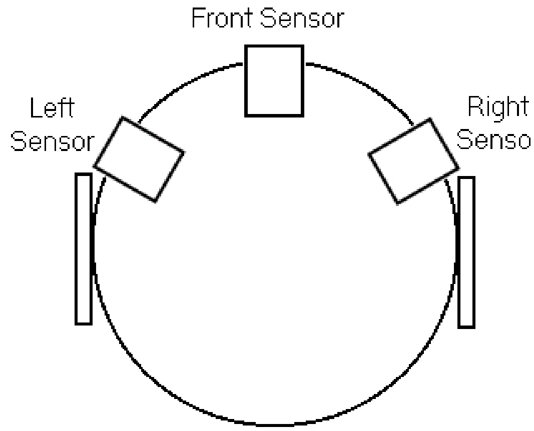

Figure 2. Sensor layout on the robot

The flame detector comprises an array of four phototransistors similar to the one shown in Figure 1. The difference between the wall (and obstacle) detection sensor and the fire-detector lies in the wavelength of infrared radiation needed to activate the detector. Again after some discussion, the past team cadets decided to use two sets of detectors: one on the side of the robot and the second set in the front of the robot.

For the fire-extinguishing module, the past team decided to use a fan-like device. Although not very realistic, the device worked well for extinguishing the flame. As mentioned before, the cadets had to consider all available options including, a water gun, a CO_2 gun, a balloon filled with water, etc. The numerous options gave a fun filled discussion between the cadets and the mentor. During the construction phase of the four modules, the teamwork skills as well as skills to frame and resolve ill-defined problems were used time after time. The cadets received suggestions from the mentor concerning all aspects of the project, but they were free to incorporate or reject the suggestions.

Competition

The actual competition was held in April, 1997. The fire-fighting robot created by the past team participated in the contest and performed valiantly. Despite their first appearance in the contest, the Academy team demonstrated their ingenuity by performing the fire-extinguishing task with the most difficult option: one with the furniture obstacles placed within the competition maze. Although they did not win the contest the experience presented cadets with a valuable chance to demonstrate their finished work and broaden their knowledge of fire-fighting robots by observing other participating robots. To the end of the competition, the cadets displayed their teamwork skills and resolving an ill-defined skills by calibrating and modifying multiple motion control and sensor parameters.

DISCUSSION

In this section, we briefly describe how the overall experience has and will contribute to the seven educational outcomes of the Air Force Academy. First, the cadets must combine and incorporate their knowledge learned from previous courses in electrical engineering, mechanical engineering, and computer science into the project. The experience allowed cadets to practice and use their fundamental knowledge. As discussed in the last section, the project contains multiple problems with multiple answers, and therefore gives ample opportunities to practice the skills related to framing and resolving ill-defined problems. The team of two cadets must constantly communicate among themselves and frequently with the mentor. This helps the cadets to develop effective communication skills as well as teamwork skills. The division of work necessary for a successful project also presents chances to work on teamwork skills. Dividing the project tasks has worked well so far. Since there are concepts the cadets do not initially know but are required for the project, the project encourages the cadets to become independent learners. For example, cadets from the current team have independently learned the C programming language as well as how to use the C cross-compiler on their own. As for the intellectual curiosity educational outcome, again, the project proved to meet the goal. As alluded to earlier, the cadets from both the past and the current teams have studied books and articles related to mobile robots which indicates their intellectual curiosity of the subject. Finally, the pursuit of excellence for each facet of the project is desired educational outcome number seven: a military officer who performs excellence in all s/he does.

CONCLUSION

This paper described the educational value of the fire-fighting robot project. In particular the paper showed how the project provides opportunities to practice and develop two of the seven educational outcomes at the United States Air Force Academy: skills to frame and resolve ill-defined problems and effective teamwork skills. It also develops to a lesser degree the remaining five educational outcomes. The design and construction stages of the project encourage students to develop ideas and allow the students to experiment with their ideas to meet the project goals. Throughout the project, the students must demonstrate the teamwork skills to arrive at mutual agreements on numerous design decisions as well as the amount of work responsibility for each member of the team. So far, the project has fostered the desired skills, and we will report the complete results at the upcoming conference.

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