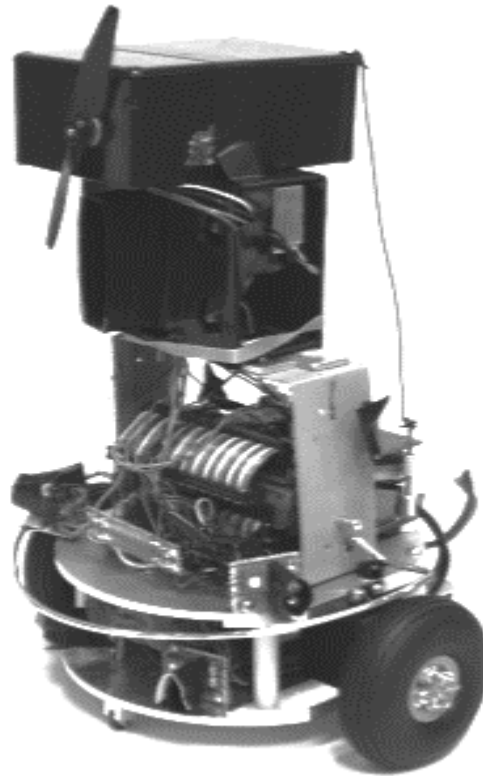


Fire-Fighting Robot: The United States Air Force Academy Experience

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ABSTRACT

In this paper we present an overview of the ongoing study on fire-fighting robot projects at the United States Air Force Academy. The main objectives of this paper are: 1) to demonstrate the usefulness of a fire-fighting robot project as a tool for students to integrate their undergraduate knowledge and 2) to present the lessons learned as a part of the Academy educational experience. The project has been offered to seniors and juniors majoring in Electrical Engineering in a senior design course and an independent study course. A team of two students has participated in the project during the past academic year and one new team is taking the challenge this year. The essential goal of the project is to design and create a wheeled robot which navigates through a maze searching for a fire, simulated by a burning candle, detects the candle light, extinguishes

the flame, and returns to a designated location in the maze. To accomplish this goal, students must integrate knowledge gained from classes on engineering design, circuits, controls, signals and systems, feedback control, computer programming, mathematics, and engineering mechanics, to name a few. We show educational values associated with the design, construction, and implementation phases of the project. Completion of the project does not require an expertise in robotics as we illustrate the steps necessary to construct such a robot. Student learning is motivated by participation in an international fire-fighting robot competition.

INTRODUCTION

Endowing engineering students with capabilities to combine and incorporate concepts is one of the many important goals of engineering educators. The importance of such capability is highlighted by the Accreditation Board for Engineering and Technology requirement for all undergraduate electrical engineering programs to include a capstone senior design course. At the United States Air Force Academy, the objective of our capstone course [Electrical Engineering 464, Senior Design] is to provide opportunities for cadets to exercise their design skills in a project. The course is designed to bring an individual student or student team and a faculty mentor into a close working relationship. A project is chosen such that the faculty mentor can provide expert guidance on the subject.

One of many possible such projects is building a wheeled robot. To design one, students must combine skills learned from mechanical engineering courses, circuit theory learned in electrical engineering courses, and programming skills learned in computer engineering related courses. Of course, students must also use fundamental knowledge gained from their math and physics courses. Our first effort to this end was creating a wall following robot[1]. Two cadets participated and created a semi-working robot. The robot had minimal capabilities to move in a straight line and turn but did not contain any “high level” reasoning module to successfully guide itself through a maze. The experience we gained from the effort, however, was valuable.

We learned about the fire-fighting robot competition, organized annually by Trinity College, through our department head. He was aware of our effort with the mobile robots and noticed a good match between our effort and the educational opportunities for cadets to participate and compete in an international robotics tournament. Two senior cadets accepted the challenge and created the first Academy fire-fighting robot, christened FRED (Robotic Fire Extinguishing Droid), which participated successfully in the competition in the spring of 1997. See the photo.

Creating a fire-fighting robot was a valuable experience for the cadets who participated. First of all, the project encouraged cadets to be creative, one of the desired characteristics for engineers. Rules governing the competition, such as the size of the maze, were given to the cadets who designed both the robot hardware and strategies to have their robot navigate through the maze. Second, the project provided opportunities for cadets to

practice technical skills learned in their engineering courses. For example, designing the motion control circuitry and interfacing it with a microcontroller or a microprocessor allowed cadets to use concepts learned in circuit related courses with knowledge gained in microcomputer design and/or instrumentation courses. Third, the project was a motivational tool for cadets to learn new concepts. To complete the goal, cadets learned new concepts independently or with the help of a faculty mentor. For example, the two cadets who participated in the contest had to learn how to construct a sound activation system for FRED. Finally, participation in the competition gave the cadets an opportunity to demonstrate their hard work on FRED as well as a chance to broaden their perspectives on the project by studying other competing robots and interacting with students from other institutions who had worked on similar projects.

A varying range of project complexity options await those who would like to participate in creating a fire-fighting robot. On one end of the spectrum, a custom-made robot can be built which requires help of professional machinists, a high power microprocessor (microcontroller), and precise motors with related circuitry. On the other end of the spectrum would be a home-made robot with supporting hardware designed from common electronic components such as resistors, switches, amplifiers, and inexpensive DC motors. As discussed in the next section, we have taken a path between these two ends of the spectrum to construct the robots at the Academy.

DESIGN, CONSTRUCTION, IMPLEMENTATION

In this section, we describe design considerations, construction, and implementation of a fire-fighting robot, necessary for educators and students who wish to create their own robots. In addition, we share our experience with FRED as well as two other fire-fighting robots under construction.

Design

Obtaining the rules of the competition, available via the Internet [2], is the first step to take before any design begins. For example, the size of the robot must be smaller than an 18 x 18 x 18 inch square box. The size is constrained by the official maze dimensions in which a robot must traverse. Fig. 1 shows the official robot maze used in the Trinity College competition.

The actual shape of a robot must then be decided. As can be seen from the photo, we chose a circular robot frame. The body is equipped with a wheel on each side driven by a DC motor, and a swivel wheel in the front and the back. The rationale for the body shape selection is to minimize opportunities for a robot to collide with its surrounding obstacles. With any other robot body design, one must consider how each motion will affect varying chances of undesirable collisions with surrounding walls. The platform design must also leave room to incorporate motors and electronic components: having two circular plates separated by two supporting beams on opposite sides of FRED (see the photo) proved to satisfy this requirement. Materials to construct the robot body must be considered next.

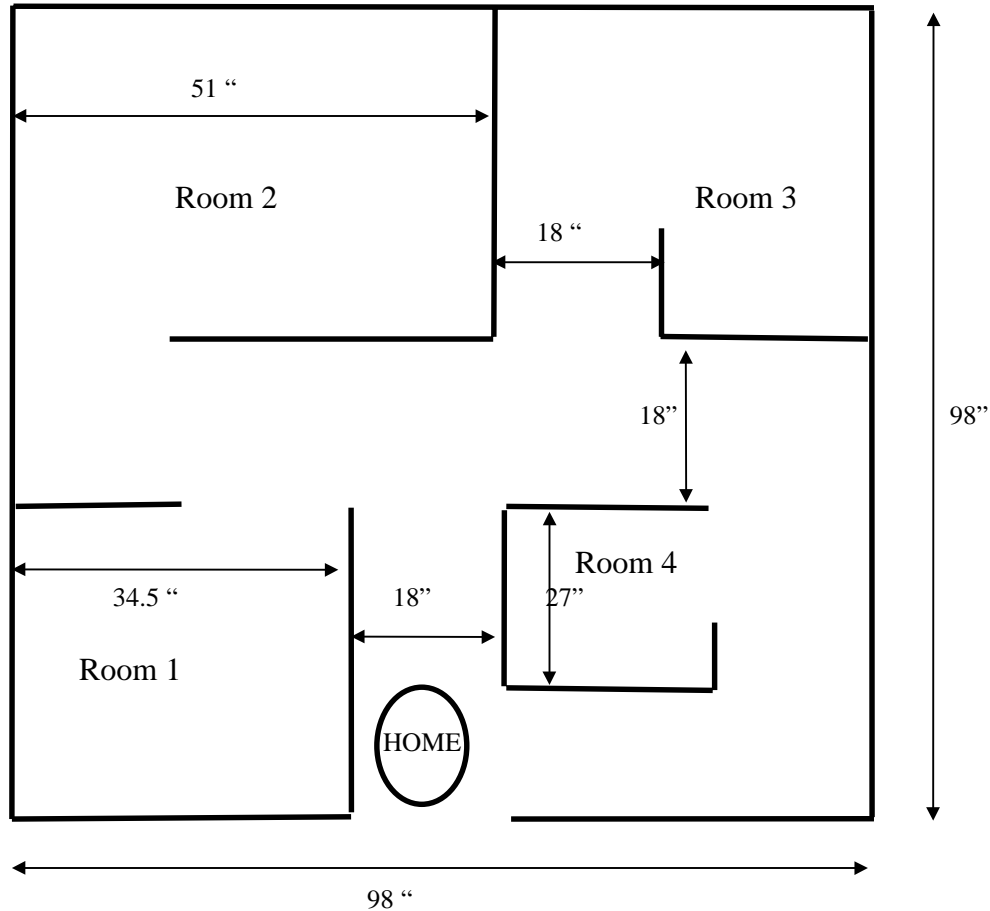


Figure 1. Official Trinity Maze [2]

Although the robot can be made with any material (wood, steel, aluminum, Lego blocks, etc.), we selected aluminum for all three robots since the material is sturdy and light. Wheels can be purchased from a hobby shop or taken from toy cars.

Once the robot frame is designed and material selected, one must consider the type of motors to be used for the robot motion. Common choices are stepper motors and DC motors. The motor section must guarantee sufficient torque to move the entire robot, so one must carefully compute the total weight of the system which includes the frame, power source, and electronic systems. Ideally the robot should be completely autonomous. That is, the robot must carry its power source (batteries) for both the microprocessor (microcontroller) based board, sensors, as well as the motors. The size of the motors and the power consumption must also be considered carefully. Finding the right motor with desired size, torque, and power consumption can be a tedious task. FRED used DC motors from model airplanes while the second and the third robots currently being constructed are using DC motors with varying torque delivery capabilities. Stepper motors are easier to control compared to the DC motors, but have a limited torque capability. Another important issue is whether shaft encoders should be used along with the motors. Many motors now come with built-in encoders; however, the

cost of such motors can be high. As an example, motors used in one of the robots being constructed which do not contain encoders cost approximately \$5.00 each, while motors used for another robot with built-in encoders cost \$27.00 each. Each motor used for FRED has a built-in tachometer and costs about \$25.00 each. Although countless methods exist to extinguish a flame, a fan-like device is the most common choice. For all three robots, a \$0.50 DC motor drives the fan.

The next item to be considered is the type of electronic circuitry a robot will have. One can (and one such entry actually appeared in the 1997 competition) mount an entire personal computer on a robot and use it as the “brain” of the robot. In most cases, however, designers have used microcontrollers. Microcontrollers are small computers built into a VLSI chip. The chip contains a microprocessor, memory, and I/O ports. The popularity of microcontrollers can be easily found in the auto industry where they are used in anti-lock braking systems, fuel-injection control systems, suspension systems, as well as in dash-board panel controls. All three of our robots used the Motorola 68HC11 microcontroller. Microcontrollers manufactured by Intel, Siemens, Texas Instruments and other companies exist on the market. The advantage of using a microcontroller as the control module for the robot is that a microcontroller has many built-in features which make timing and input/output control easy. The necessary code is typically developed on a PC and then downloaded to the microcontroller. One could hardwire the robot to perform a task[3], but it is not very desirable since the robot could only perform one function; furthermore that would not meet the requirement of being a robot¹ as defined by the Robot Institute of America[4].

The next item to be considered is the type of sensors to be used by the robot. At least two sensor applications are necessary: one to help navigate the robot through the maze without colliding with the walls, and the second to detect the candle light. The easiest way to detect walls is using an infrared light emitter/detector pair. The amount of infrared light reflected off a detected wall will determine the distance between the robot and an approaching wall. One could investigate more elaborate methods of detecting obstacles using sonar sensors, laser sensors, or cameras, but for an undergraduate project the authors believe the IR sensors should be the choice. This is especially true on a limited budget. An IR sensor pair can be purchased from Radio Shack for less than \$2.50. For detecting candle light, again an IR detector can be used since candle light contains infrared radiation. Other important issues which need to be addressed are how many sensors for each applications should be used, and where on the robot should they be located.

Construction

One of the first things to consider in building a fire-fighting robot is the cost. As alluded to earlier, one can seek help from professional machinists employed by an institution to

¹ The Robot Institute of America defines robots as programmable devices which can carry out multiple functions.

build the robot frame according to a developed design. Other possibilities could range from using Lego blocks or constructing a wooden frame for the robot. For appearance sake, the money spent for a professional machinist could be worthwhile, and the cost

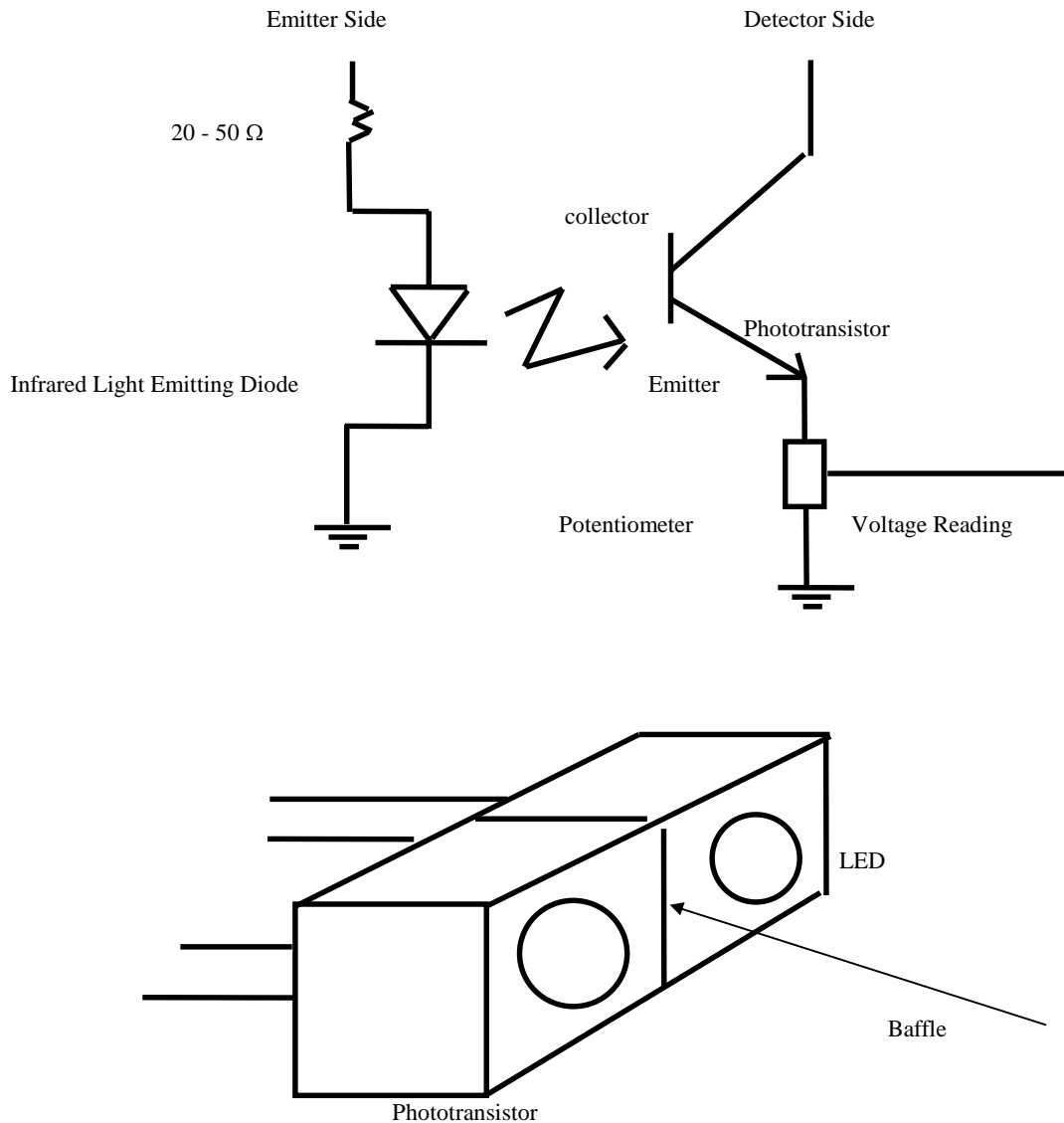


Figure 2. Infrared emitter/detector pair

can be minimized with a simple design. For example, since we used the circular design, only a few simple pieces needed to be constructed for our robots. The robot frame must be designed such that the selected motors will be positioned appropriately on the robot with enough ground clearance. Our experience shows it is crucial to work with a prototype before the final body construction.

The next step in the construction phase is building necessary circuitry for both sensors and control electronics. All three robots created at the Academy use IR sensors to detect

walls for navigation purposes. The basic circuit diagram is shown in Fig. 2. The light emitting diode transmits IR light. The phototransistor on the detector side then receives any reflected IR light and converts it into current which is in turn transformed into a voltage value. The analog voltage value is then converted to digital form using an analog-to-digital converter. FRED used four IR sensor pairs for wall detection and three IR detectors for candle light detection. Note how the sensors are located on the robot in the photo. Four wall detecting sensor pairs are located on the lower plate while the candle light sensors are located on the upper part of the robot. The motor control is performed with the help of the 68HC11 microcontroller which also interfaces with the sensors. For the actual motor control scheme, we refer the reader to [1]. Note that the voltage needed for the sensors is the same as that required by the 68HC11 microcontroller. This means we only needed two separate power sources for our robots: one for the motor and the other for all the electronic circuitry.

Programming

Once all hardware is completed, programs must be written to control the robots. Any programming languages can be used at this step. However, we found it extremely useful to use an assembly programming language when dealing with time critical tasks, such as reacting to an approaching wall within a desired time interval. We are also experimenting with a C programming language cross compiler to program our robots. The more important issue than the selection of a programming language is the strategy used to move the robot through the maze, find the candle, extinguish the flame, and return to an initial location, designated as HOME in Fig. 1. Unlike some other maze navigating competitions, all contestants know the maze (model house) dimensions before hand and should take advantage of the *a priori* information. As an example, a simple strategy would be to visit room 1, room 2, room 3, and room 4 of the maze shown in Fig. 1 in sequence, while checking for candle light. Even this simple task is not trivial to program since the robot must constantly avoid walls, look for openings into rooms, and keep track of where the robot is within the maze. Only after a robot can do this can the next task of finding the candle and extinguishing the flame be accomplished. During this stage of the project, ingenuity of the students participating in the project can surface since there are an infinite number of different ways to accomplish the desired task, and there is not a proven “best” method.

DISCUSSION

In this section we discuss lessons we have learned from our experience with fire-fighting robots. As mentioned before, the robot projects accomplished in our senior design project course, and in an independent study course initially started with a wall-following robot. From that experience, we gained the knowledge necessary to carry out the more challenging task of the fire-fighting robot project. For example, the wall-following robot project carried out by two cadets in 1996 provided necessary information to select an appropriate motor control scheme (pulse-width- modulated signals using DC motors) for most of the subsequent wheeled robot projects including the fire-fighting robot projects.

The wall-following robot project also confirmed our belief that creating a controlled situation, where students are responsible to develop and execute a project plan with an appropriate amount of guidance, is an important educational experience.

The first fire-fighting robot project yielded other valuable lessons. The study showed that a two member team is ideal for such a project. The work was evenly divided between the two cadets in creating FRED: one of the two students was responsible for the motion control hardware and software, while the other was responsible for sensor related hardware and software. Toward the end of the project, the cadets put the two sub-systems together and worked on the navigation strategies jointly. Their successful project can be attributed to various factors, but the most notable one was the careful planning by both the cadets and the mentor. Frequent interaction (at least once a week) between the cadets and the mentor was another important factor contributing to the success of the project. Another important lesson we learned is the importance of incremental accomplishments. The two cadets who created FRED first demonstrated incremental success on their sub-systems, which raised their confidence levels. The fire-fighting robot project can be easily extended and divided into multiple sub-modules to provide such rewards to all students who participate (motion control module, wall detecting sensor module, candle light detection module, flame extinguishing module, sound activation module, etc).

We believe the two new fire-fighting robots under construction will provide more valuable lessons. The changes we have made from our experience with FRED have resulted in some modifications on the selection of motors and the corresponding motor control scheme. The tedious work required to debug assembly language programs resulted in the decision to use C as the primary language: we use a 68HC11 cross compiler to convert and merge the high level program with time critical assembly language code. The project has attracted willing cadets, and the lessons and experiences gained from participating in such a project has proven to be very rewarding for all involved.

CONCLUSIONS

The fire-fighting robot project has been shown to be an effective educational tool to encourage and motivate engineering students to be innovative in combining knowledge and concepts learned into a meaningful project. Students who plan carefully have successfully completed the project. The project is an ideal educational tool in a senior design project course or in an independent study course. Limited experience with sensors and microcontrollers could lead to a slow project start, but most undergraduate engineering curriculums offer courses such as microcomputer programming and instrumentation to cover these concepts. Our experience with the fire-fighting robot has validated the educational value of the project: an educational tool to allow students to combine knowledge from various subjects; a project tool which allows students to practice engineering skills (design, construction, implementation, and test); and a motivational tool to encourage independent learning.

ACKNOWLEDGEMENT

The authors would like to acknowledge David Pittner and Byron Formwalt now both 2nd Lts, United States Air Force, who created the first United States Air Force Academy Fire-Fighting Robot, FRED. We also acknowledge valuable feedback provided by Colonel Klayton and Major Wright after reading the first draft of the paper.

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