The Trinity College Fire-Fighting Home Robot Contest: A Medium for Interdisciplinary Engineering Design

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Introduction

In this paper we introduce the Trinity College Fire-fighting Home Robot Contest, describe some of the engineering design problems it presents, and discuss examples of work done at Trinity. Held annually on the Trinity College campus in Hartford, CT since 1995, this is the largest robotics competition in the U.S. open to contestants of any age, affiliation, ability, or experience. The goal of the contest is to stimulate interest in robotics and to encourage invention by persons of all ages. A $1,000 first prize is awarded in both the junior division (high school and younger) and the senior division (all others). The contest was expanded in 1998 to include affiliated regional events that use the Trinity College rules; at this writing, events are scheduled in Fort Worth, Calgary, and Seattle. Winners from the regional contests will compete in the final event, held at Trinity on April 19, 1998. Participation engages engineering students and professionals in a motivating, open-ended interdisciplinary project. Design of a fire-fighting mobile robot is a challenge that is appropriate, for example, as a senior engineering design project.

The object is to develop a computer-controlled, autonomous machine that can navigate through a 8 ft. by 8 ft. maze, find a fire (a lit candle), and extinguish it in minimum time. The robot must operate without human intervention; radio control and joystick control are not permitted. The walls of the maze (painted white) are 13" high, the hallways are 18" wide, and the floor is flat black. Thus the robot simulates the real-world operation of a robot performing a fire-security operation in a single-story home. The maze geometry, which is known beforehand by the contestants, includes four rooms and connecting hallways. The robot does not know where the fire is located, and the fire can be in any of the rooms. Before extinguishing the flame, the robot must navigate to within 12" of it and show that it has recognized the flame. Each robot makes three runs, which begin at a designated starting spot. The score is the sum of the fastest two run times, multiplied by reduction factors for: 1) reliability (success on all three runs); 2) obstacle avoidance ability; 3) ability to return to the starting spot after extinguishing the candle; and 4) ability to trigger the robot's run using a 3.5 KHz tone that simulates a smoke alarm. The 1998 contest encourages the development of robots that do not rely on dead reckoning. Robots will receive a deduction for succeeding when ramps, which add uncertainty about path lengths, are placed in the maze.[1]

Engineering Design Problems

Development of a fire-fighting mobile robot is a constrained optimization problem that can be

[1] Full contest rules are found at the Web address: http://www.trincoll.edu/~robot.

addressed using engineering design principles. The problem can be stated as follows:

Design a mobile robot that fits inside a cube 12.25 inches on a side and that can navigate without human intervention from a fixed starting position through an 8' x 8' maze having four rooms and connecting hallways. The robot is to find a candle flame and extinguish it in minimum time. (If you have the fastest robot, you win $1000.)

To address this design problem, students must consider many of the sub-problems listed below.

1) Develop a mechanical system including general structure, placement of wheels and other supports, and location of batteries and electronic circuitry;
2) Develop a computer-controlled bi-directional motor drive system;
3) Develop devices that enable the robot to: a) sense the maze walls to the left and the right; b) sense a white stripe marking the entrance to each room; c) find a flame; and, as an option, d) respond to a 3.5 KHz tone that triggers the robot;
4) Choose a microprocessor that has enough digital and analog I/O lines to service the sensors and motors and is fast enough to handle necessary computations;
5) Choose software tools that ease the development and maintenance of the real-time system that controls the robot.

Designers can optimize their machines by focusing on the following:

1) Efficiency: Reduce the mass of the robot to improve performance and minimize power consumption. Develop power budget for electronic circuitry and stay within it;
2) Motor Controller Enhancement: Improve accuracy of the motor drive system to enable precise motion control;
3) Sensor Enhancement: Increase the sensitivity, signal-to-noise ratio, and repeatability of sensors and associated electronics. Sense the flame using both infrared and ultraviolet sensors, achieving redundancy in ambient environments rich in UV and IR background radiation;
4) Reliability: Design in a modular fashion to ease system integration and improve reliability and maintainability;
5) Cost: Achieve the above at minimal cost.

Design Approach

Participation in the contest by college and university teams has increased steadily, reaching a high of 21 teams among the 51 that competed in Hartford in 1997.[2] The designs entered by university and college teams in 1997 varied significantly; some used available components while others designed sub-systems from scratch. Some designers built robots from Lego components.

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2 Participating schools included the United States Air Force Academy, Tufts University, Massachusetts Institute of Technology, Pennsylvania State University, the University of Pennsylvania, and Trinity College.

This popular approach encourages creativity and shortens development time, allowing students to focus on sensors and software. At Trinity we have tackled robot development as an interdisciplinary exercise undertaken by teams of students with different interests (mainly electrical/computer engineering, mechanical engineering, and computer science) and levels of experience. We have developed sub-systems from scratch to encourage students to apply design methods, including use of CAD tools and concurrent engineering approaches, taught in our courses [2].

Since Trinity does not offer a formal course in robotics, most of the involved students register for independent study credit. They attend a weekly group meeting, submit regular written progress reports, and complete a semester project report. In the fall of 1997, eight students, including sophomores, juniors, and seniors, were enrolled in independent studies. In addition, five first-year students attended the weekly meetings and will formally join the team in Spring, 1998. These five participate in Trinity's Interdisciplinary Science Program (ISP), which recruits promising science and mathematics first-year students. The ISP includes a research or design project in the second semester, when students work closely with a faculty member.

These students will have the opportunity to work on a team with more advanced students who will serve as co-workers and role models. In the fall of 1997, the Trinity team was divided into four working groups, identified as the Blue Team (electrical team), Red Team (interfaces and sensors), Black Team (software), and Green Team (system maintenance). Each team's progress was recorded on a large dry-erase board located in an electrical engineering laboratory. The Green Team was helped by a retired mechanical engineer once responsible for manufacturing operations at an aerospace company and now eager to help with machining tasks. Thus students had the chance to work with a knowledgeable practitioner more than fifty years their elder.

Robot Designs

Trinity's first working robot (Phoenix) competed in the 1996 and 1997 contests. It won the $500 second-place senior division prize in 1997. A second robot, Ot-Bot, is nearly complete and will compete along with Phoenix in the 1998 contest. Phoenix uses a Motorola MC68HC11 microcontroller programmed using Interactive C. It employs stepper-motors to drive two wheels centrally positioned on each side of the robot, and it uses machined casters for additional support. A table-driven frequency synthesizer, designed with VHDL and realized in an Altera EPM7096 CPLD, provides timing pulses for the stepper motors [1]. This chip provides 64 discrete speeds for each wheel, yielding evenly spaced robot forward velocities in the range 0-18 inches per second along with precise tracking and positioning. Phoenix has two modulated infrared reflectance sensors on each side, facilitating alignment to walls, wall following, and edge detection. These capabilities allow us to avoid the use of dead-reckoning. The side sensors use infrared emitters and photo-transistors that are precisely aligned in fixtures to match their responses. Phoenix's erratic behavior in the 1996 contest, first blamed on software problems, proved to be the consequence of motor resonances. The motor drive system was rebuilt by a student in the summer of 1996 and Phoenix rose again, to compete in the 1997 contest.

Software development in 1996 was carried out primarily by two students: a second-year engineering major, and a junior computer science major. This team developed our first wall-following codes and it determined some key physical parameters related to the robot's dynamics. The 1997 software team consisted of five students, led by the computer science major, now a senior, and including engineering majors and computer science majors. This group was composed of capable, strong-willed individuals, and it took some time for them to develop as a team. Their work demonstrated the need to document their work, maintain software backups, and develop modular, serviceable code. Inclusion of computer science students provided an interdisciplinary team experience and raised the quality of our software.

Our second robot, Ot-Bot, was started in Spring, 1997 and was operational by December, 1997. Ot-Bot is a front-wheel drive machine that uses d.c. servo motors driven by a PLL-based d.c. motor controller designed at Trinity. Ot-Bot uses a second-generation IR side sensor board designed by students using Mentor Graphics PCB layout tools. The board contains four IR emitter/photo-transistor pairs and associated signal processing circuitry. To gain understanding of the Mentor tools, the electrical design team visited Pitney-Bowes, Inc. to consult with their PCB layout group.

Current Projects

Development of mobile robots has generated a multitude of open-ended projects, which have encouraged close faculty/student work outside the classroom. A number of these projects have focused on the development of technologies for future mobile robots. Some projects have been undertaken as senior design exercises. One senior project was completed last year: the design of an on-board computer network linking master and slave microcontrollers via a synchronous serial bus. Of the twelve senior design projects under way in the Trinity Engineering Department in 1997/98, five are directly related to fire-fighting robotics: 1) a scaled-up robot based on technology developed for Phoenix and Ot-Bot; 2) an improved PWM controller for a brushless d.c. motor with optical encoder; 3) a fiber-based network for linking master and slave microcontrollers; 4) a dual-processor board with DMA interface connecting a 16-bit microcontroller and a DSP chip; and 5) a capacitive reflector proximity sensor and associated mixed-signal ASIC (MOSIS chip).

Assessment and Conclusions

Experience at Trinity College indicates the benefits for engineering students associated with designing mobile robots. Fire-fighting robot design improves student skills with CAD tools, computer interfacing, design of programmable logic, and use of VHDL. It also introduces such topics as noise reduction, relationship between hardware and software, sensor development, modularity, software engineering approaches, and system efficiency. Moreover, students acquire and apply such basic practical skills as machining, PCB design, soldering, and wire-wrapping. They learn to appreciate the importance of system maintenance and the benefits of designing sub-systems that can be used again. In addition, they learn to work as a team, handle disagreements and pressure in competition, and seek advice from professional engineers. The project encourages students to learn from one another, and it promotes close contact with faculty outside the classroom.

Fire-fighting robot design has engaged the interest of some of the best engineering students at Trinity College. They are highly motivated and they are willing to work long hours completing their designs. Involvement in robot design encourages creativity, teamwork, and interdisciplinary problem solving. As progress is made, ideas are generated and new design problems are identified. The next generation of independent study and senior design students can address these problems.

References

[1] D. Ahlgren, M. Guillorn. *Table-Driven Frequency Synthesizer for Stepper Motor Control.* Presented at 1997 Symposium of Connecticut Microelectronics and Optoelectronics Consortium, Yale University, March, 1997.

[2] D. Ahlgren. *CPLD-Based Design in the Introductory Computer Engineering Course.* Presented at the 1997 ASEE Annual Conference, Milwaukee, June, 1997.

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