FIRE-FIGHTING ROBOT INTERNATIONAL COMPETITIONS: EDUCATION THROUGH INTERDISCIPLINARY DESIGN

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Abstract -- *This paper introduces the Trinity College Fire-Fighting Home Robot Contest (TCFFHRC), evaluates the curricular impact of the contest at university and high-school levels, and provides examples of student projects inspired by the contest. We evaluate the contest by analyzing participant survey data from the 2000, and 2001 contests, and we present our conclusions about the educational benefits of developing a robot for this competition.*

Index Terms—Robotics competitions, fire-fighting robots, interdisciplinary teamwork, assessment.

THE FIRE-FIGHTING CONTEST

The Trinity College Fire-Fighting Home Robot Contest (TCFFHRC) requires contestants to design autonomous robots that can navigate through a maze and extinguish a candle in minimum time. Established in 1994, the contest has grown from a single event in Hartford, Connecticut into a set of regional competitions in the United States, Europe, the Middle East, South America, and Asia. The contest focuses contestants' efforts toward a practical application of robotics, the development of an autonomous fire-fighting robot for use in a home. The TCFFHRC aims to increase awareness of robotic fire-fighting, encourage team-based education, and promote robotics as a theme for teaching engineering design. Articles in such publications *as IEEE Robotics and Automation Society Magazine*, *Electronic Design*, *Scientific American*, the *London Times*, and the *New York Times* have helped to make this event popular and well known.

The TCFFHRC is open to persons of all ages, affiliations, and levels of skill. Thus the contest provides a challenging design problem to a wide range of designers including professors, university students, fifth graders, professional engineers, and hobbyists. The participant's goal is to develop a small computer-controlled, autonomous robot that can navigate through a model house (a 2.5-m. by 2.5-m. maze), find a candle, and extinguish it. The maze includes four rooms and connecting hallways, and its dimensions are known in advance by the contestants. The candle is placed at random in one of the four rooms, and the robot must navigate autonomously to within 30 cm. of the flame before extinguishing it. The score is the sum of the fastest two run times of the allowed three runs. This raw score is reduced by factors for reliability (success on all three runs), ability to avoid obstacles (furniture mode), starting in response to a simulated smoke alarm, and non dead-reckoning operation [1] – [3]. A full description of the contest is published at the TCFFHRC Web site www.trincoll.edu/events/robot/.

The 133 robots entered in the 2001 contest at Trinity College represented the work of more than 400 designers, including individuals from eight countries and five continents. These countries included The People's Republic of China, South Korea, Israel, France, Romania, and Argentina. Since the first contest in 1994, teams from more than fifty universities have participated. In 2001, the contest offered four levels of competition: junior (for students below 9th grade), high school (grades 9 – 12), senior (university students, graduate engineers, and scientists), and the new expert division. Expert division robots are expected to operate in furniture mode, non dead-reckoning mode, and smoke alarm mode, and they must be able to operate from a randomly chosen starting location in the maze. In 2001, the number of entries that qualified for the final competition were as follows Junior High Division, 12; High-School Division, 36; Senior Division, 36; and Expert Division, 5.

FIRE-FIGHTING ROBOTICS AND UNDERGRADUATE ENGINEERING AT TRINITY

Trinity is a four-year undergraduate institution that has offered engineering instruction in a liberal arts setting for over one hundred years. Trinity's Engineering Department offers an ABET-accredited B.S. in Engineering. At Trinity, the TCFFHRC has encouraged the development of a new first-year engineering design course, provided problems addressed by fourth-year students in formal design projects, and has motivated a robotics study team that has competed in the TCFFHRC for the last six years. Students feel that development of a successful autonomous fire-fighting mobile robot is one of the most engaging and challenging projects encountered in their undergraduate years.

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First-Year Design Course

Motivated by the TCFFHRC, one of the authors developed a new first-year course ENGR 120: Introduction to Engineering Design--Mobile Robotics that was offered first in the spring of 2000 and again in the spring of 2001. This course (1) introduces students to the field of engineering; (2) offers hands-on laboratory assignments; (3) presents engineering design from philosophical and professional perspectives, through assigned readings [4], [5]; (4) offer students the opportunity to evaluate engineering as a major field; (5) exposes students to engineering topics including robotics, software development, basic instrumentation (oscilloscope, signal generator, voltmeter), use of CAD packages for mechanical and electrical design, mechanical and electronic construction techniques, real-time data collection and analysis, motor control methods (PWM, PD/PID, fuzzy logic), micro-controller interfacing, use of sensors for ranging and flame detection; and (6) presents students with a challenging, open-ended design project.

In ENGR 120, students work in teams of three. During the course of the semester, each team develops a fire-fighting autonomous robot using Legos and the Handy Board, a small Motorola MC68HC11-based computer used for educational robotics, instrumentation, and research (visit www.handyboard.com). A series of laboratory experiments introduces students to major topics associated with the design of sensor-based mobile robots. Topics covered in these experiments include programming in C, interfacing and calibration of sensors (ranging sensors and infrared sensors for candle detection), motor control procedures, wall following, edge detection, and software testing. As a first exercise in robotics, students develop their own version of the HandyBug, a small robot that senses walls and turns to avoid them; and they investigate Braitenberg vehicles, which sense light sources and can be programmed to be attracted by the light or repelled by it. The primary reference is the new text by Fred Martin, "Robotic Explorations—A Hands-On Introduction to Engineering" [6].

Robotics Study Team

A second locus for robotics at Trinity is the Robotics Study Team (RST), organized in 1996 to develop robots to compete in the TCFFHRC. The RST's robot Phoenix won first place in the 1998 TCFFHRC, Ot-Bot took second place in the 2000 Middle East Fire-Fighting Home Robot Contest in Tel Aviv, and Mini-Bob gained second place in the Expert Division of the 2001 TCFFHRC. The team also participates in the annual International Ground Vehicle Competition (IGVC). Information about the IGVC can be found at (www.secs.oakland.edu/SECS_prof_orgs/PROF_AUVSI/).

The RST engages students from all four college years. Its members, about ten each semester, receive independent study credit. Although the RST attracts primarily engineering students and computer science students, its membership includes those majoring in the humanities, arts, or social sciences. Each student joins a disciplinary group (electronics, mechanical, software, and sensors) that carries out research and experimentation related to team objectives. Each group gives a weekly oral presentation in the seminar. Team members work in the Robot Engineering Laboratory, which is open at all hours to the students.

Projects underway include the following:

- Refinement of sensor arrays for ranging and object detection.
- Refinement of navigation algorithms that employ fuzzy logic rules.
- Improvement of PC-based programs that simulate the operation of a mobile robot in a maze.
- Development of versatile, micro-controller-based motor control systems.
- Development of a "smart" miniature camera for robotics.
- Development of ALVIN II, an autonomous land vehicle to compete in the 2001 International Ground Vehicle Competition
- Development of a vision system for ALVIN utilizing optical flow analysis.
- Development of Hexabob, a six legged walking robot prototype.

Senior Design Projects

Motivated in part by the basic learning outcomes set by the Accreditation Board for Engineering and Technology, a current focus in engineering education is on interdisciplinary team-based design. Teams from several universities have developed fire-fighting robots as senior design projects. Fire-fighting robotics has also served as the theme for graduation projects for advanced high-school science students in several countries [7].

Engineering students at Trinity College have completed more than 15 projects in robotics as graduation projects. These include 1) capacitive proximity sensor for robotics; 2) micro-controller-to-DSP interface; 3) DC motor controllers; 4) vision system for mobile robotics; 5) ultrasonic ranging system for obstacle avoidance; 6) design of ALVIN I; and 7) FIRE, the fuzzy infrared robotic explorer.

DESIGN AND TECHNOLOGY IN HIGH SCHOOLS

Design of fire-fighting autonomous robots has served as the theme for graduation projects for advanced high-school science students in several countries. Since the 1998-99 school year high-school students in Israel have participated in TCFFHRC and in the local fire-fighting robot contest organized by the Israeli Ministry of Education. The Israel delegation at the TCFFHRC included 24 students from five schools in 1999, 73 students from seven schools in 2000 and 81 students (10 robots) from seven schools in 2001.

This experience serves as an impressive example of how to integrate robotics into the high-school curriculum with the support of the national school system [8]. In Israel, robotics is taught in high schools in the framework of the Machine Control discipline.

Machine Control is an optional matriculation subject studied in the eleventh and twelfth grades. This discipline has been authorized and accredited as one of six main disciplines preferred by the Israeli universities among the matriculation subjects. Higher achievers have a privilege to prepare an advanced graduation project as a substitute of the national exams in the three subjects of Machine Control. A more detailed description of the discipline may be found in [7].

Many graduation projects in Machine Control prepared in the last three years relate to designing, constructing and operating robot systems. Such projects are based on creative work determined by a general goal of building a robot system that implements specific predefined intelligent functions. Topics in electronics, computers, mechanics, control, as well as in physics and mathematics are added to the conventional syllabus of Machine Control as necessary to enable robot design and operation.

A growing number of high schools are now developing curricula and carrying out projects related to the fire-fighting contest. As an example, we consider a fire-fighting robot project, which is been carried out at the Meviot Eron high school. In 1998 one of the teachers started his graduate studies at the Technion and majored in educational robotics. He has developed a fire-fighting project in his school since 1999. The Meviot Eron robot team participated in the TCFFHRC 2000 (shared places 12 to 16) and 2001 (place 7).

The study of Talrick™ and Rug Warrior™ robot kits, the user manuals, and the text by Jones, Seiger, and Flynn [9] were important initial resources for the project activities. This experience helped the teacher and the students to acquire knowledge on mobile robots, recognize problems to be solved, and develop their own fire-fighting robot.

The robot team in 1999-2000 consisted of 13 students. The team was divided into five groups: structure, sensors, fire extinction, software and management. The structure group designed and built the robot structure, considering carefully the location of the center of gravity and the need to reduce robot weight. The sensors group dealt with calibration of sensors and real motors and with the kinematics of robot straight and circular motion. The fire extinction group examined several possible solutions for extinguishing candles, chose a suitable propeller device, and mounted and tested it on the robot. The software group dealt with maze navigation logic and programming robot movements. The management group coordinated the project schedule, logistics, reports, and presentations.

The robotics project at Meviot Eron was studied with a view to the value of contest-oriented curricula and methods of interdisciplinary design education. As a result of the study several improvements were made in the curriculum for 2000-2001. The 2000-2001 team was divided into two groups of equivalent amount of project work and responsibilities: structure and fire extinction (S&FE), and sensors and software (S&S). The S&FE group examines a number of alternative variants of the robot structure and fire extinction by means of physical and mathematical modeling, and CAD. The S&S group deals with robot XY kinematics, application of shaft encoders for the position control, and algorithms and software for maze navigation as required by the 2001 TCFFHRC rules.

CONTEST ASSESSMENT

In this section, we describe the tools and methods we have employed since 1999 to carry out formal assessment of the contest. Our educational surveys have assessed learning outcomes of contest-oriented curricula and attitudes of the participants. Answers were obtained from 112 respondents in 1999, 123 respondents in 2000, and 242 respondents in 2001. Results of the recent 2001 survey have been analyzed and are presented below.

Four groups of participants were examined in the survey: junior school students (grades K-10), high school students (grades 11-12), university students, and engineers. Of those who responded to the 2000 survey, 34.1% were university students, 37.4% were high-school students, 16.3% were engineers, and 12.2% were junior high-school students.

The 2000 survey questionnaire asked each respondent to estimate his/her progress in a number of fields gained as a result of working on the contest project. The list specified 17 main fields of study students would encounter in a contest-oriented curriculum (electronics, computer communication, microprocessors, assembly language, high-level language, motors and gears, mechanical design, robot kinematics, sensors and measurement, data analysis, physical field concepts, mathematical modeling, control systems, CAD tools, systems design, robot programming, and teamwork). For each field the respondents evaluated their progress in theoretical and practical knowledge.

The following features were revealed by the answers:

- Most of respondents found that their contest-oriented curricula related to all 17 fields.
- The average percentage of students reporting progress in each field is 89.3%.
- In most fields the majority of respondents considered their progress to be either considerable or extensive.
- For example, 83.8% of students stated on their considerable or extensive progress in electronics, 79.5% in sensors and measurement, and 57.9% in mechanical design.
- Such progress takes place both in theoretical and practical studies. As for microprocessors, an equal number of students 73.0% mentioned considerable or extensive progress in theory and in practice.
- The progress in teamwork was especially high.

- Considerable or extensive progress was reported by about 95% of university and senior high school students.

The 2001 questionnaire asked respondents to describe their personal significant contribution to main subsystems of the fire-fighting robot (drive mechanism, mechanical structure, micro-controller, control circuits, sensor system, steering planning, system software, and extinguishing device). For each component respondents were asked to specify their involvement in various types of activities (designing, constructing, testing, improving, and installing). The participants were asked also to indicate the contribution of their team to each subsystem (was the system received from the teacher, guide, or others; ordered through a market search; significantly modified; or newly developed).

The answers given by students are summarized in Table I. The list of eight main robot components is presented in the first column. The second, third, fourth, fifth and sixth columns present data about specific types of activities. The number in each cell of these columns shows the percentage of respondents involved in a specific activity with a certain robot component. The number in each cell of the seventh column indicates the percentage of respondents indicated that the robot subsystem mentioned in the corresponding row was newly developed or significantly modified by their team.

We observe from Table I that contestants were involved in extensive practical work with several robot subsystems. Although the majority of teams used drive mechanisms and micro-controllers ordered in the market, more than 60% of the university students indicated that each of the other six sub-systems of the fire-fighting robot was newly developed or significantly modified by the team. University students spent most of their effort working on the extinguishing device, the sensor system, the mechanical system, and the control circuits. The authors add that for all teams, system integration, software development, and overall system testing were significant, and time-consuming tasks.

CONCLUSIONS

We have introduced the Trinity College Fire-Fighting Home Robot Contest, and we have described curricular enhancements and student projects at Trinity College and in Israel. We have presented survey data from the 2000 and 2001 contest questionnaires, and we have drawn conclusions about the educational value of contest participation and about participants' attitudes. Data show that the contest has led to considerable progress in theoretical and practical areas, both at the K-12 and university levels. Moreover, the TCFFHRC has offered a challenging design problem that has motivated participants of many ages and affiliations, from around the world. It is clear that the TCFFHRC occupies an important niche in the universe of robot contests.

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TABLE I

PARTICIPATION IN PRACTICAL ACTIVITIES IN TWO OR MORE SUBJECTS (%)

Components	Designing	Constructing	Testing	Improving	Installing	Developed
Drive mechanism	51.3	48.7	71.8	57.7	51.3	39.7
Mechanical structure	55.1	56.4	67.9	59.0	50.0	79.2
Micro-controller	26.9	24.4	64.1	34.6	48.7	20.3
Control circuits	46.2	53.8	69.2	44.9	44.9	64.3
Sensor system	42.3	55.1	79.5	56.4	60.3	59.3
Steering planning	55.1	46.2	67.9	57.7	51.3	61.8
System software	50.0	46.2	60.3	46.2	46.2	60.3
Extinguishing device	57.7	56.4	69.2	53.8	55.1	71.4