AN INTERNATIONAL VIEW OF ROBOTICS AS AN EDUCATIONAL MEDIUM

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Abstract *¾ This paper introduces the Trinity College Fire-Fighting Home Robot Contest and describes the curricular impact of the contest in colleges and high schools. We present and discuss student work motivated by the contest. Finally, we evaluate the educational impact of the contest based on data from Contest participant surveys and draw conclusions about the merits of the competition and the benefits to educational robotics internationally.*

Index Terms ¾ Educational robotics, robot contests, educational outcomes, survey data.

THE FIRE-FIGHTING CONTEST

Contestants in the Trinity College Fire-Fighting Home Robot Contest (TCFFHRC) design autonomous robots that navigate through a maze and extinguish a candle in a race against the clock. Focused on a practical application of robotics, the contest aims to increase awareness of robotic fire fighting while encouraging use of robotics as a theme for teaching engineering design. Articles in such publications as *Popular Mechanics, IEEE Robotics and Automation Society Magazine, Electronic Design, Scientific American, and the New York Times* have helped to make this event popular and well known. In 2002 the Institute of Electrical and Electronics Engineers (IEEE) voted to become a technical co-sponsor of the TCFFHRC.

The fire-fighting robot problem challenges persons of all ages and affiliations including university students and professors, high school and middle school students, professional engineers, and hobbyists. The goal is to develop a small computer-controlled, autonomous robot that navigates through a model house an 2.5 m. by 2.5 m. maze) and extinguishes a lit candle. The maze, whose geometry is known in advance, includes four rooms and connecting hallways. 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 putting it out. The score is the sum of the fastest two run times of the allowed three runs. Robots earn reductions in time for reliable operation, obstacle avoidance ability, arbitrary starting point, and non-dead reckoning operation. The reader will find further details about the contest in [1]-[4] and on the Web site http://www.trincoll.edu/events/robot/. In 2002, 185 robots, representing the inventiveness of more than 400 designers, took on the contest challenge at the main event on the Trinity College campus in Hartford, CT USA.

In the contest's nine years, teams from more than 70 universities and colleges have participated. In 2002 teams entered more than eighty robots from middle schools and high schools. Affiliated regional fire-fighting contests in China, Israel, Argentina, India, Canada, and the United States have encouraged participation from around the world (Figure 1), with especially high numbers of robots from the Peoples Republic of China and from Israel. Israeli high school students receive support from the Ministry of Education, which has authorized robotics as an elective matriculation subject.

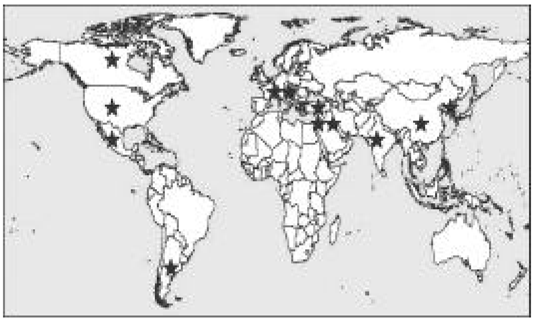

FIGURE. 1
WORLDWIDE PARTICIPATION IN THE TCFFHRC

TRINITY COLLEGE EXPERIENCE

Trinity is an independent undergraduate liberal arts college that has offered engineering instruction 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 first-year engineering design course, motivated senior design projects, and served as a focal point for a robotics study team that has competed in the TCFFHRC for the last seven years. Many students find that development of a successful autonomous fire-fighting mobile robot is the most engaging and challenging project encountered in their undergraduate years.

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First-Year Design Course

The TCFFHRC motivated the development of a freshman-level course, ENGR 120: Introduction to Engineering Design--Mobile Robotics, which has been offered annually since 2000. The primary goals of the course are to introduce students to the engineering field, to inform students about the discipline and philosophy of design [5]-[6] and to engage them in team-based design projects using robotics as the medium. While carrying out the robot design project, students gain hands-on experience in the laboratory, learn to use lab instruments, and develop programs in the C language. The course also focuses on improving communications skills through a series of assigned oral presentations and written reports. Through guest lecturers from academia and industry, students are exposed to such topics as design practices in industry, engineering ethics, global issues, and lifelong learning. The enrollment limit for ENGR 120 is 21, allowing formation of seven teams with three students on each team. Each team is assigned a mentor, an undergraduate who has taken the course, who acts as team advisor and facilitator. Each team attends a one-hour weekly workshop that focuses on robot design technique, development of lab skills, and programming. The semester's workshops culminate in the design and testing of a fire-fighting robot for the competition. To build robots the teams use the Lego Mindstorms kit and the Handy Board computer (www.handyboard.com), relying on the text by Martin [7] as the primary reference. To prepare for the fire-fighting design, students carried out several projects from the book including development of Braitenberg vehicles and wall following algorithms.

Robotics Study Team

The Robotics Study Team (RST) was organized in 1996 to develop machines to compete in the TCFFHRC. The RST's robot Phoenix placed first in the 1998 TCFFHRC, Ot-Bot placed second in the 2000 Middle East FFHRC in Tel Aviv, and TCFFHRC Expert Division robot MiniBob placed second in 2001 and fourth in 2002. RST members include undergraduates from all four years of study and from several major fields including Engineering, and Computer Science. Members of the RST enroll for independent study credit, and they meet as a seminar each week. Each student joins a subject-oriented group (electronics, mechanical, software, sensors) that gives a weekly seminar report. Together the RST seminar and the Robot Engineering Laboratory form a learning environment in which the experienced students serve as mentors and teachers. In this way the RST builds its knowledge base of robotics from year to year, continually encouraging students to tackle more complex projects. Current projects include development of improved sensor arrays for ranging and object detection, improvement of fuzzy-based navigation algorithms, design of a "smart" camera for robotics, and development of four- and six-legged robots for fire fighting. The RST also takes part in the AUVSI Intelligent Ground Vehicle Competition [8] and has developed ALVIN, an autonomous land vehicle that has competed in the IGVC since 2000.

Senior Design Projects

Motivated in part by the Accreditation Board for Engineering and Technology, a current focus in engineering education is on interdisciplinary team-based design. Teams from many universities have developed fire-fighting robots as senior design projects and have competed in the TCFFHRC. Fire-fighting robotics has also served as the theme for graduation projects for advanced high-school science students in several countries [9]

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

DESIGN AND TECHNOLOGY IN HIGH SCHOOLS

Fire-fighting autonomous robot design 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 and 73 students from seven schools in 2000.

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 [10]. 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. The discipline includes three subjects:

- Logic in Automated Control Systems at grade 11,
- Applications of Computerized Control at grade 12,
- Machine Control Workshop at grade 12.

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. In the project the student implements some creative assignment in design and technology of Machine Control and documents the project results in the form of an R&D report. A more detailed description of the discipline may be found in [9].

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. Examples of project assignments include: an autonomous robot for climbing up on walls and solving spatial puzzles by means of a robot-manipulator.

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. The Machine Control discipline in this rural school has been taught since 1990 with a series of graduation projects related to the automatic control of a greenhouse based on programmable logic controllers.

In 1998 one of the teachers, Eyal Hershko, started his graduate studies at the Technion and majored in educational robotics. He has developed a fire-fighting project in his school since 1999 with Dr. Verner serving as project consultant. The Meviot Eron robot team participated in the 2000 local fire-fighting contest (3rd place) and in the TCF2HRC 2000 (shared places 12 to 16).

The study of Talrick™ and Rug Warrior™ robot kits, the user manuals and the text [11] was an important initial step of 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 of 2000-2001 currently in progress. The team is divided into 2 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 TCFFHRC rule changes in 2001.

CONTEST ASSESSMENT

Educational surveys have been administered to contest participants each year since 1999 in order to assess learning outcomes of contest-oriented curricula and attitudes of the participants about the program. There were 112 respondents in 1999, 123 in 2000, 243 in 2001, and 342 in 2002, a generally increasing proportion of the participants. Below, we present selected results from these surveys.

Motivation Factors (2002)

The 2002 survey data regarding personal motivation for participating in the contest are summarized in Table I below. The motivation factors are listed in the first column of that table. The second, third, fourth and fifth columns present data about specific groups of respondents. The number in each cell shows the percentage of respondents who consider specific motivation factors important or very important to their participation in the contest.

TABLE I
MOTIVATION FOR PARTICIPATION IN THE 2002 CONTEST (%)
JUNIOR, HIGH SCHOOL, UNIVERSITY, ENGINEERS

Motivation factors	Jr.	Hi.	Stud	Eng
1. A positive attitude towards the subject, the method and the framework suggested by the contest	81	94	95	100
2. Awareness of the practical need of knowledge and experience acquired through participation in the contest	71	86	93	100
3. Prizes, travel grants and other stimulation of your participation in the contest	69	41	36	38
4. Taking pleasure in robot gaming	75	86	80	50
5. Ambition to cope with the contest challenges and win a reward	69	76	69	70
6. Opportunity to apply your ideas, and reinforce practical and learning skills	100	93	91	90
7. Interest in high course grade	44	48	48	13
8. Demonstration of professional skills	63	58	73	63

The following features are revealed by the data presented in Table I:

- A high level of learning motivation is indicated by all respondents.

- Motivation is influenced by a combination of factors, each important to a certain sub-group of respondents.
- The absolute majority of respondents from all groups reported a positive attitude towards the contest subject, method, and framework contributed to contest participation.
- The university students assigned the highest marks to the opportunity to apply their ideas and reinforce practical and learning skills. They also valued highly the practical knowledge gained through the contest, and most took pleasure in competing.
- The ratings for six (out of eight) motivation factors assigned by the engineers are close to the university students' ratings
- Demonstration of professional skills was a significant motivation factor, but it was less important than most of the learning motivation factors.

Progress in Subjects (2000)

In 2000, four groups of participants were examined: 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 school students.

The 2000 questionnaire asked each respondent to estimate his/her progress in 17 fields gained as a result of working on the contest project. The answers are summarized in Table II.

The list of 17 fields is presented in the first column of Table II.

TABLE II
PROGRESS IN FIELDS (2000)

Fields	Progress in theory				Progress in practice			
	Jr.	Hi.	Stud	Eng	Jr.	Hi.	Stud	Eng
Electronics	75	59	79	60	63	68	87	87
Computer comm.	63	56	68	40	63	59	73	53
Microprocessors	50	24	73	67	50	19	73	73
Assembly lang.	25	26	57	60	25	31	60	60
High-level lang.	38	48	49	60	50	50	46	60
Motors and gears	50	56	62	53	63	56	65	73
Mechanical design	75	54	46	53	75	54	49	67
Robot kinematics	50	43	50	60	50	41	64	67
Sensors & measure.	50	59	71	73	50	63	82	87
Data analysis	38	24	62	40	50	22	68	40
Physical fields	25	37	41	27	38	34	46	27
Math models	50	23	54	53	38	18	60	53
Control systems	50	48	67	67	50	58	65	73
CAD tools	38	13	47	40	38	20	54	40
Systems design	50	46	67	67	50	51	68	73
Robot programming	63	56	61	67	63	56	70	80
Teamwork practice					50	95	95	60

The second and the third columns characterize progress achieved in the fields in both theoretical knowledge and practical knowledge. The second and the third columns are divided into four sub-columns, which display data on the four groups--junior school (Jr.) and high school (Hi.) students, university students (Stud.) and engineers (Eng.). Each cell presents the percentage of respondents from the group specified in the sub-column that made considerable or extensive progress, in the 2000 contest, in the subject associated with the cell row.

The following features are revealed by the answers:

- Most of respondents found that their contest-oriented curricula related to all 17 fields.
- In most fields the majority of respondents considered their progress to be either considerable or extensive.
- Such progress takes place both in theoretical and practical studies.
- The progress in teamwork of the high school and university students is significantly higher than of the junior school students and engineers.
- The university students achieved higher progress in electronics, computer communication, microprocessors, and sensors and measurement. They had lower level progress in high-level language programming, mechanical design, and physical field concepts.

Another section of the questionnaire asked respondents to describe their own activities in main project-related subjects (drive mechanism, mechanical structure, control circuits, micro-controller, sensor system, steering planning, extinguishing device, system software and other subjects (to be specified). For each subject respondents were asked to specify their involvement in various types of activities (adapting, constructing, designing, improving and integrating).

Our findings include the following:

- Contestants from all four groups were involved in extensive practical work with robot systems.
- 40-80 % of the university students were involved in each of the five types of activities, with more attention (on the average) occupied to integration and design of the robot components.
- University students spent most of their effort working on the extinguishing device, the sensor system, the mechanical structure, the drive mechanism, and the system software.
- University students were involved in the practical activities less than engineers but more than high school students. The lowest involvement with practical activities was in the group of junior school students.

Views of Teachers and Students (2002)

In the 2002 survey, teachers and team guides were asked for their views of student progress in theory and practice associated with fourteen subject areas. This survey enabled the comparison of the student's assessments with the teachers' assessments. Table III presents the results. Students and teachers agreed on the areas of greatest educational benefit (electronics, teamwork practice, sensors, motors and gears, and computer communication) and on the areas of least benefit (assembly language, simulation). It is evident that teachers and students views correlate strongly across the subjects.

TABLE III
COMPARISON OF LEARNING OUTCOMES BY TEACHERS AND STUDENTS, THEORY AND PRACTICE (2002)

Subject Area	Theory		Practice	
	STUDS	TEACH	STUDS	TEACH
Electronics	62	69	71	86
Teamwork	79	67	83	66
Sensors	69	69	72	62
Motors & Gears	61	57	67	62
Comp Commun.	64	52	65	61
Physics Applic.	55	60	55	52
Microprocessors	60	53	59	55
Math Applic.	63	53	61	55
Control Theory	50	53	51	50
High-Level Language	60	47	59	52
Kinematics	43	43	40	45
Structure	44	40	46	45
Assembly Language	43	40	43	41
Simulation	39	31	39	32
Correlations	0.83		0.85	

CONCLUSION

This paper has introduced the Trinity College Fire-Fighting Home Robot Contest, and it has described curricular enhancements and student projects at Trinity and in Israel. We have presented survey data from the 2002 and 2000 contest surveys and have drawn conclusions about learning outcomes and motivating factors. 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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