# New Directions in Fire-Fighting Robotics

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## Abstract

The Trinity College Fire-Fighting Home Robot Contest (TCFFHRC) encourages inventors of all ages and levels of skill to develop autonomous fire-fighting home robots that can find, and extinguish as quickly as possible, a randomly placed fire in a model house. Open to persons of all ages and levels of skill, the contest engages a wide community of roboticists, whether school children or professional engineers, in a challenging shared design task, promotes robotics as a learning medium, builds international connections, strengthens cooperation, teamwork, and learning outside the classroom, and promotes the development of robots that someday will fight fires in real homes.

This paper describes the contest's history and participation, and it presents changes to the rules that apply to the 2005 contest. As a case study the paper describes past and current projects carried out by the Trinity College Robot Study Team (RST) and demonstrates that the new 2005 contest rules have already had educational and technological impacts.

## Background: The Trinity College Fire-Fighting Home Robot Contest

In 1994 the first Trinity College Fire-Fighting Home Robot Contest, organized by engineer and entrepreneur Jake Mendelssohn, attracted 22 robots from around the United States. Since it moved to Trinity College in 1995, this annual event has grown into one of the world's best-known robot competitions. The mission of the Trinity College Fire-Fighting Home Robot Contest is to motivate inventors of all ages and skill levels to create autonomous robots that can efficiently find and extinguish a fire in a model home. The contest encourages application of science and technology principles in an atmosphere of creativity, teamwork, and friendly competition.

The contest awards cash prizes in five divisions: Junior, High School, Senior, Expert, and Walking and gives special awards for inventive design and cost effectiveness. Starting in 2003 the contest offered junior-high and high school teams the opportunity to take a theoretical test, the first robotics Olympiad associated with a major robotics contest. In 2004, 115 robots from the US and abroad competed at Trinity College in April. We plan for a modest expansion in 2005. Teams from more than eighty colleges and universities have competed over the years, and regional contests that use the TCFFHRC rules have been held in such locations as Beijing, Buenos Aires, Calgary, Dallas, Denver, Los Angeles, Philadelphia, Tel Aviv, Toronto, Seattle, and Shanghai. A regional fire-fighting robot contest begins operation in Singapore in 2005. For more information about the contest, the reader is referred to [1].

Since 1999 the author and his colleague Igor M. Verner have assessed the educational impact of the contest through an annual survey; assessment results have been reported in [2] – [6] for example. In [6] Professor Verner described a change in the goals of the survey and discussed survey validity:

> The survey goals have moved from a focus on general information and contestant feedback about their robot projects to analyzing and evaluating learning experiences and outcomes. The survey validity has been increased through the following actions: (1) increasing survey population by making it a part of the contest registration procedure, (2) Comparing students' self-assessment and teachers' evaluation data, (3) Using a subsequent survey to validate results of previous ones.

In [6] Professor Verner disclosed three important survey results: (1) that almost all university and high school students report significant progress in project-related skills through participation in the fire-fighting contest; progress in their project skills, due to participation in the fire-fighting robot project; (2) that progress in general (theoretical) skill was less than progress in technical and teamwork skills; and (3) that most students reported that the contest challenge increased their interest in science and engineering and motivated them to specialize in science and engineering. Another important outcome was that several key participants indicated the need for refreshment of the contest tasks; since 1994, there had been no major changes in contest rules, changes that were overdue.

**New Directions**

Administrative changes that took place prior to the 2004 TCFFHR encouraged broader participation in contest decision-making and eased the process of refreshing the contest rules. Change was accomplished by appointing a local advisory committee, including an event coordinator and a new chief judge, and a technical advisory committee (TAC), whose membership included leading members of the educational robotics community. Members of the TAC contributed new ideas regarding changes that might be implemented starting in 2005. The objective of these changes was to increase the design challenge while rendering the robots closer to fire-fighting automata that could find and extinguish a flame in an environment more representative of a real home.

Rules have changed for every contest division; some noteworthy changes are described in the following sections.

<u>Senior and High School Divisions</u>

In 2005 the High-School Division will include two categories, the standard-level (SL) and the entry-level (EL). The Senior Division, which includes university and professional teams, and the High School SL category will use the new 2005 standard arena. This SL arena has four rooms with connecting hallways, and the fire (a lit candle) will be placed at random in any of the rooms. Robots will placed at the home (H) position to start.

The 2005 SL arena has two new features-- a staircase, and floor areas with rugs (Figure 1). The starting point (home) position is at the base of the staircase, shortening the path length for robots able to climb stairs. The addition of rugs to the standard maze imposes new requirements for motor drive and mechanical design.

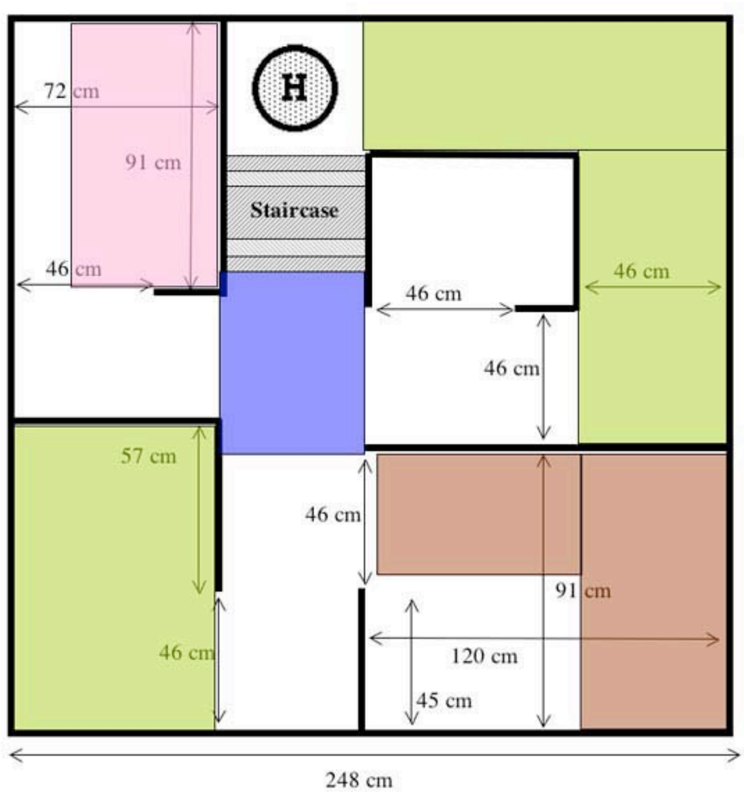


Figure 1. 2005 Standard Arena (shaded areas indicate presence of rugs)

The High School entry level category, the Junior Division, and the Walking Division will use the EL arena, which is identical to the SL layout but lacks the staircase and the rugs.

As in previous contests, teams may elect several operating modes each of which yields a time-reduction factor. Robots that combine reliable operation (extinguishing of the flame on all three allowed runs) with successful performance in the elective operating modes finish highest in the contest. The 2005 TCFFHRC will continue to offer these operating modes: Audio Start—robot begins operation after detecting smoke detector alarm; Furniture Mode—robot avoids cylindrical “furniture” placed in the arena’s rooms; Return to Start Mode—robot returns to home base after extinguishing the flame. A new elective for 2005 is Clutter Mode in which robots must operate in the presence of household clutter (simulated toys, furniture, etc.) strewn about in rooms and hallways.

Expert Division

The Expert Division was established in 2001 to challenge the most experienced firefighting robot designers and to identify the best robots in the contest. Each year the Expert Division has presented new and more challenging tasks. In 2001 and 2002 Expert Division robots were required to operate within the standard arena using all of the operating mode deductions (audio start, arbitrary start, furniture, etc.) In 2003 the contest added a new challenge, a two-story arena whose internal arrangement was changed from run to run. The simulated house consisted of a 3m x 3m first floor that is linked to a 2m x 2m second floor by a 15-degree ramp (Figure 2). In 2004 the contest added a search-and-rescue task so that robots would attempt to carry out the work of a fire department scout robot that searches for a baby in a two-story house, marks the baby's location and puts out fires. This simulated baby is a small doll that emits an IR beam, modulated at 36.7 kHz, that can be detected by A/V remote control receivers. On each run the robot tries to complete four tasks within six minutes: (1) put out candle 1; (2) put out candle 2; (3) find and mark the baby by placing an audible (1 kHz) sounder within 20 cm of the baby; and (4) go up and down the ramp at least once in a controlled fashion. The team's final score is the total number of tasks completed during the allowed three runs. Run time is used as the tiebreaker.

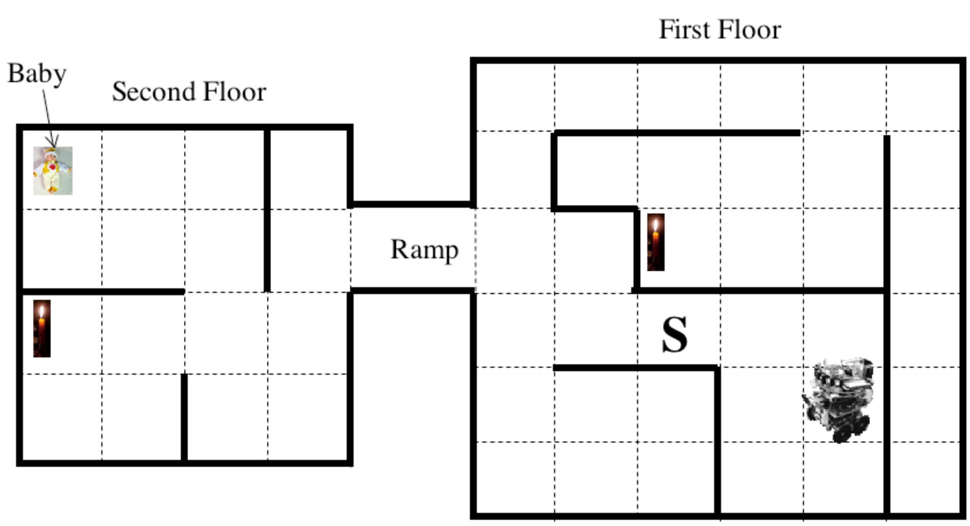


Figure 2. Two-Story Expert Division Arena--Top View

The Trinity College robot DJA-1.5 was designed to perform all four of the Expert Division tasks (Figure 3). DJA-1.5's four-wheel differential drive system uses two Intelligent Motion Systems NEMA 17 High Torque integrated stepper motors and drives (www.imshome.com). DJA-1.5 uses sensor-based mapping to navigate through the unknown maze. The drive system allows precise dead-reckoning operation when necessary. This robot uses a Hammamatsu Model R286 UV flame detector for detecting a candle flame from a distance as well as focused, crossed IR detectors for precisely locating a nearby flame. The sensing, motor control, and mapping tasks are complex processes that require considerable computational power, realized here by a Motorola MC68HC332 microcontroller board with 1 MB RAM. Students designed a custom printed circuit board for interconnecting sensors, computers, and control outputs. All hardware worked as expected, but the complexity of the software was underestimated and testing time was limited. Nevertheless, DJA-1.5 finished in a second-place tie in the 2004 Expert Division. In addition, a student used DJA-1.5 as the platform for a senior design project related to maze navigation based on a neural network.

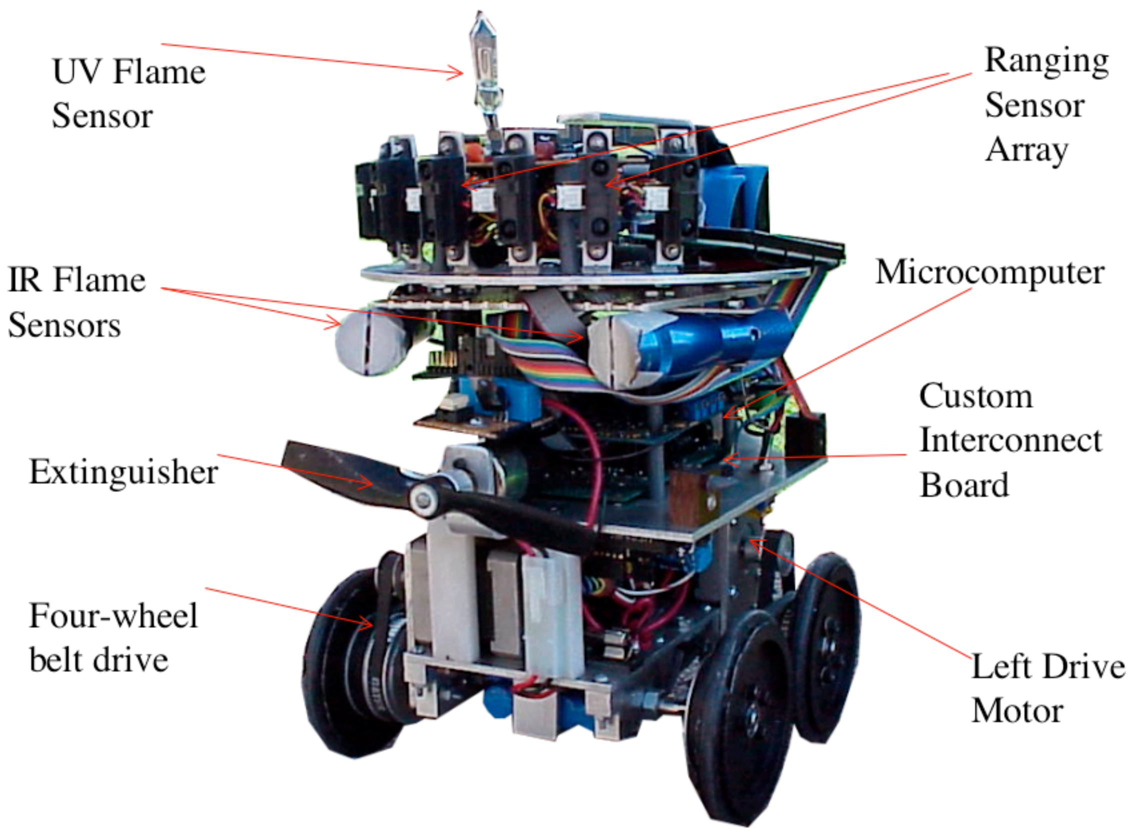


Figure 3. Trinity College Fire-Fighting Robot DJA-1.5 Showing Major Components

In part to address complexity issues like those experienced with DJA-1.5, the 2005 Expert Division allows use of robot swarms (interacting groups of robots). Use of swarms allows entering teams to develop any number of simple specialist robots and to achieve redundancy and reliability. Teams that develop swarms for the 2005 Expert

Division will address challenging design issues including problem decomposition and task assignment, navigation algorithms, obstacle avoidance, cost versus complexity tradeoffs, inter-robot communication, and ways to avoid collisions among members of the swarm.

Concept Arena

While the EL, SL, and expert arenas offer the official operating environments for the contest divisions, a new Concept Arena will allow us to evaluate directions for future rule changes and allow competitors from different contest divisions to compete in the same maze. Designed by Joe Jones, engineer at iRobot, Inc. and designer of the Roomba vacuum cleaner, the Concept Arena offers several paths through the maze, each requiring a higher degree of capability (Figure 4). For example, simple robots that use dead reckoning may find their way from the start position (S) to the candle through carefully measured motion control. A somewhat more capable robot would follow the left wall from the start position; an even more capable robot would combine wall following with object detection in order to traverse the field of obstacles in a shortened path to the candle. Robots that can open the door or climb the stairs may choose even shorter paths to the candle, but the shortest route goes through the 5 cm x 5 cm "mouse hole."

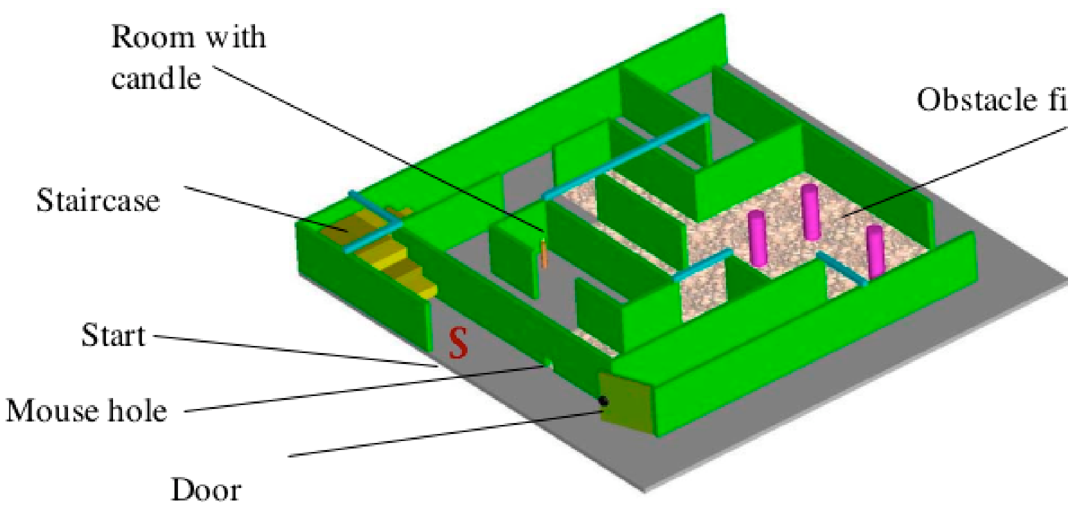


Figure 4. Concept Arena

**Undergraduate Robotics Activities at Trinity College**

Since 2000, the first-year engineering design course (ENGR 120) has used fire-fighting robot development as the medium for introducing students to the practice of engineering design. Readings (e.g. [7] - [8]), guest lectures, and class discussions introduce students to major fields of engineering, design philosophy and terminology, aesthetics, engineering ethics, and professional practice, while the text [9] supports robot design. Using the fire-fighting robot design theme, the course emphasizes teamwork and the development of basic skills including sensor applications, interfacing, motor control, and programming. The references [10] – [12] provide detailed descriptions and evaluations of the course. In 2005 the ENGR 120 teams will build robots to compete in the 2005 Standard Level arena.

Members of the Trinity Robotics Study Team (RST) engage in higher-level projects in robot design. The RST students have participated in the fire-fighting contest since 1995. Since 2000 they have also competed in the AUVSI Intelligent Ground Vehicle Competition (IGVC) [13] - [14]. RST membership includes undergraduates all four college years and comprises 10-15 students each semester enrolled for independent study credit.

The first successful RST robot, Phoenix, required a two-year design effort that resulted in a second-place finish in the Senior Division in 1997 and a first-place finish in 1998. Subsequent designs, including Bob, MiniBob, Ot-Bot, DJA-1.0, and DJA-1.5 have placed in the top-five of the Senior Division or the Expert Division. The contest motivated RST students to design a six-legged walking fire fighter and a fire-fighting hovercraft that will enter the 2005 contest. Two other current projects stem from the new TCFFHRC rules—a robot swarm that qualifies under the new Expert Division rules, and a tiny autonomous robot (7 cm x 7 cm) designed to go through the Concept Arena's mouse hole.

A new direction for the RST is to design a standard computer module that may be used in all three projects (swarm, hovercraft, and concept robot). Constraints imposed by the three projects include low cost (imposed by the need to build several robots comprising a swarm); small size (need to fit the concept robot through the mouse hole); and light weight (need to achieve hovering behavior as efficiently as possible). Figure 5 shows a printed circuit board layout for an embedded computer that will be used by all three projects. Designed by RST Chief Engineer Matthew Gillette '05 using Mentor Graphics PADS layout tools, the board includes a PIC microcontroller, H-bridge motor driver, and in-circuit programming port. The board provides six analog ports, eight general-purpose digital I/O lines, and a UART serial communication port. These ports are sufficient to service ranging sensors, motors, flame detectors, and extinguishers.

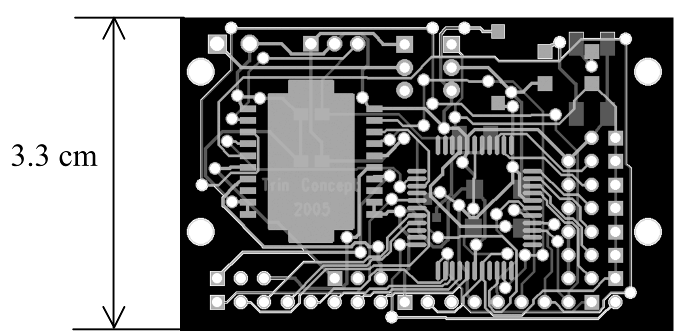


Figure 5. Concept Robot CPU/Motor Driver Board

## Conclusions

This paper has presented the history and background of the Trinity College Fire-Fighting Home Robot Contest, and it has described enhancements and rules changes related to the 2005 contest program. The paper has introduced past and current contest-related student work at Trinity College and it has shown that design projects currently underway stem from the upgraded contest rules. It is hoped that the new directions described in this paper will continue to encourage inventors of all ages and levels of skill to develop novel and realistic autonomous fire-fighting home robots, advancing fire-fighting technology while motivating students worldwide and providing a medium for engineering education at all levels.

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## Bibliography

[1] URL www.trincoll.edu/events/robot/. Last visited 1/2/05.
[2] I.M. Verner, D.J. Ahlgren and J. Mendelssohn, "Fire Fighting Robot Competitions and Learning Outcomes: A Quantitative Assessment," *Proc. 2000 ASEE Annual Conference*, St. Louis, 2000.
[3] I. Verner, D. Ahlgren. "Fire-Fighting Robot Contest: Interdisciplinary Design Curricula in College and High School." ASEE J. Engineering Education, July 2002.
[4] D. Ahlgren, I. Verner. "An International View of Robotics as an Educational Medium." Proc. 2002 International Conference on Engineering Education, Manchester, England, August 2001.
[5] I. Verner, D. Ahlgren. "Fire-Fighting Robot Contest: Interdisciplinary Design Curricula in College and High School. *J. Engineering Education,* July 2002, 355-359.
[6] D. J. Ahlgren, I. M. Verner, D. Pack, S. Richards. "Effective Practices in Robotics Education," Proc. of 2004 ASEE Annual Conference, Salt Lake City, June 2004.
[7] H. Petroski, *Invention by Design*. Harvard University Press, 1996.
[8] P. Dominick et al. *Tools and Tactics of Engineering Design.* J. Wiley, 2001.
[9] F. Martin, *Robotic Explorations, a Hands-On Introduction to Engineering*. Prentice Hall, 2001.
[10] I. M. Verner, D. J. Ahlgren. "Conceptualising Educational Approaches in Introductory Robotics." *Int. J. Electrical Engineering Education*, 41(3), 2004, 183-201.
[11] D.J. Ahlgren, "Fire-Fighting Robots and First-Year Engineering Design: Trinity College Experience." *Proc. 31st ASEE/IEEE Frontiers in Education Conference*, Reno, 2001.

[12] D. J. Ahlgren, "Meeting Educational Objective and Outcomes Through Robotics Education." *Robotics, Automation, Control, and Manufacturing: Trends, Principles, and Applications,* Vol. 14, TSI Press, 2002, pp. 395-404.
[13] URL http://www.igvc.org/deploy/. Last visited 1/2/05.
[14] M. Bovard, M. Gillette, T. de Lanerolle, B. Marinkovic, N. Trinh, P. Votto, D. Ahlgren, K. Nepal, A. Tamrakar. "Design Evolution of the Trinity College IGVC Robot ALVIN." *J. Robotic Systems*, 21(9), 2004, 461-469.

**Biography**

David J. Ahlgren is Karl W. Hallden Professor of Engineering at Trinity College and is Director and Host of the Trinity College Fire-Fighting Home Robot Contest. Professor Ahlgren has been a faculty member at Trinity College since 1973, and he served as department chairperson from 1990-1999. His scholarly interests lie in robotics, modeling and simulation, and broadband communications amplifiers. Dr. Ahlgren received the B.S. in Engineering from Trinity College, the M.S. in Electrical Engineering from Tulane University, and the Ph.D. in Electrical Engineering from The University of Michigan, Ann Arbor.