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Socially Responsible Engineering Education Through Assistive Robotics Projects: The RoboWaiter Competition

David J. Ahlgren · Igor M. Verner

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Abstract This paper proposes an approach to promote students' social awareness as part of challenging projects in robot design. A new robot contest was developed to motivate and focus these projects: RoboWaiter, the first international robot competition in the rapidly growing area of assistive robotics. RoboWaiter has been held since 2009 in Hartford, Connecticut in conjunction with the annual international Trinity College Fire-Fighting Home Robot Contest. We describe how dialogue among the authors and members of the Connecticut Council on Developmental Disabilities (CTCDD) directed development of RoboWaiter and led the CTCDD actively to participate in the organization and execution of the contest. We discuss the assignment and rules of the competition as well as the engineering challenges associated with designing robots for RoboWaiter. We also present responses of contest participants, both engineering students and people with disabilities. These reflections indicate that the challenge of creating a fetch-and-carry robot raised curiosity among engineering students and increased their interest in participating in the project. Moreover, the RoboWaiter project helped students to recognize the social challenge of assistive robotics and to understand that engineering work has importance beyond pure technical achievement. Participation of people with disabilities in the robot contest was motivated by the wish to draw public attention to the need for new assistive technologies and to inspire socially responsible education in universities and schools.

D.J. Ahlgren (✉)
Department of Engineering, Trinity College, Hartford, CT 06106, USA
e-mail: David.Ahlgren@trincoll.edu

I.M. Verner
Technion – Israel Institute of Technology, Haifa 32000, Israel
e-mail: ttrigor@technion.ac.il

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1 Introduction

Studies of engineering education programs point to the need for more effective integration of engineering knowledge with contextual knowledge, competencies of practice, and values of professionalism and ethics that define the work of engineers for the good of those they serve [1]. In addition, studies of engineering outreach programs indicate that one of the factors impeding interest in the engineering profession is a stereotype that views engineers as technocrats who deal with machines but who are indifferent to human needs [2]. Consequently the authors believe that engineering education must change directions if it is to address these factors and that it is important to develop projects and other assignments that require students to apply engineering principles to solve problems that benefit society at large. Such projects inherently encourage socially responsible engineering education. One approach to socially responsible engineering education is through learning practice in assistive technology [3]. In this paper we describe an approach that addresses a perceived deficiency in engineering education while addressing a significant societal need.

According to the Bureau of Industry and Security, U.S. Department of Commerce, more than 17% of Americans have a disability, and half of that cohort has a severe disability. The number of persons with severe disabilities is increasing and will continue to grow as the population ages [4]. Many persons with disabilities benefit from an assistive technology (AT) device, an "item, piece of equipment, product or system, whether acquired commercially off the shelf, modified, or customized, that is used to increase, maintain, or improve the functional capabilities of persons with disabilities" [5]. In a 2005 survey by the U.S. Department of Education, National Institute on Disability and Rehabilitation Research, 64% of respondents used some form of assistive technology. The most common were mobility assistants (canes, crutches, walkers, scooters and wheelchairs), hearing aids, and oxygen tanks. Most respondents who used AT said it made them more productive and more aware of their rights [6]. A U.S. Bureau of Commerce report pointed out that there is an active and rapidly growing AT industry that manufactures more than 17,000 products and employs more than 20,000 workers [4]. Still, according to the Assistive Technology Industry Association, the number of people currently using AT is only a fraction of those who could benefit from it [5]. Thus, it is appropriate to raise awareness among engineering students about the needs of those people and to encourage them to solve associated design problems.

There is a growing body of research focused on the creation of robots to assist people with physical impairments in their daily life activities. One of the problems faced by these people is the need to move things around the house. A number of recently developed fetch-and-carry robot prototypes address this need. Taipalus and Kosuge [7] present a fetch robot with sophisticated architecture and complex functionality. The mobile robot is equipped with two computers (one for real time control and the other for image processing), four cameras, and an arm with touch and optical sensors attached to the gripper. The functionality includes navigation in the controlled environment, recognizing and gripping a predefined object and delivering it on a tray to the human. Another example is a fetch-and-carry robot developed at Georgia Tech [8]. The robot can fetch objects and open drawers on command, performing functions sometimes carried out by service dogs. To interact with the Georgia Tech service robot, a person with disabilities points a laser at an object and gives a verbal command to the robot; an example is a command to open a drawer or to close a door [9]. In both examples the robots were tested as laboratory prototypes for further research and development. Tapus, Mataric, and Scassellati suggest that establishing robot competitions directed to challenging problems of assistive robotics can have a stimulating effect on research and accelerate its practical implementation in the field [10]. Sharing this view, we established the assistive robotics competition RoboWaiter in order to inspire students and young researchers in the subject and involve them in socially responsible education.

2 Genesis of an Assistive Robotics Competition

The inspiration for an assistive robotics competition came from the Connecticut Council on Developmental Disabilities (CTCDD), a leading support and advocacy organization that promotes the "full inclusion of people with disabilities in community life" [11]. In 2006 the CTCDD proposed that an assistive robot competition be linked to the Trinity College Firefighting Home Robot Contest (TCFFHRC), an international event held in Hartford, CT since 1994 [12, 13]. Planning and consultation among CTCDD and Trinity staff resulted in a new competition "Find the Child" that took place as part of the 2007 and 2008 firefighting contests. In "Find the Child", autonomous robots searched for a warm doll representing an autistic child hiding from a perceived threat. The search for a more challenging, realistic, and unique task led to the establishment of RoboWaiter in 2009. The RoboWaiter competition that emerged from the planning process was consistent with our continuing effort to upgrade and enhance the TCFFHRC and use it as a laboratory of experiential engineering education [14, 15].

Many robotics competitions, including the firefighting contest, originated from posing innovative robotics assignments. RoboWaiter poses an innovative assignment, which we describe later in the paper, but it also engages persons with disabilities, the contest clients, in choosing the theme, developing the rules, and participating in the event. In retrospect, we discerned several significant steps, described below, that took place during the development of this unique assistive robotics competition.

2.1 Opening the Communication Channel

As mentioned above, the impetus to establish a contest with an assistive robotics theme stemmed from communication with CTCDD members. From this communication, it was clear that people with disabilities are strongly interested in robots and that they recognized the real need for robotic devices that aid those with disabilities. We note that a member of the CTCDD who had attended the firefighting robot contest initiated communication.

2.2 Clarifying Mutual Expectations

Useful feedback from "Find the Child" participants, CTCDD members, and supporters was collected by means of questionnaires and interviews conducted by the second author. The data suggested the need to revise the event to focus on a more relevant and challenging assistive robotics theme. Also, persons with disabilities expressed the desire that the new assistive robotics assignment should more closely address an important need. The feedback also indicated that all surveyed persons expressed interest in extending their knowledge of assistive robotics.

2.3 Establishing a Vision

After the 2008 contest, a planning group, consisting of three members of the CTCDD and the lead author, met to create a new vision for the assistive event and to explore themes having greater significance and challenge than "Find the Child". After extended discussions, the group chose a theme that represented an area of personal concern to CTCDD members—the need for a person with disabilities to retrieve food from a refrigerator during an emergency, when a personal assistant is not present. The authors felt that this theme would present a strong robotics challenge requiring the design and integration of mechanical, electrical, and sensing sub-systems. The vision that emerged from the planning process consisted of two main elements:

- *Bringing people with disabilities in as clients of RoboWaiter design.* We share the proposition [16] that these people can and should be involved, as critical consumers, in design, evaluation, and research of assistive technologies. Following recommendations of [16], we created a focus group in which people from the CTCDD could identify and describe the nature of the mobility-related problems that they encounter. The focus group put forward ideas for possible robotic solutions of the problems and their experimental design in the framework of the contest.
- *Integrating the RoboWaiter project in a robotics course.* Since 2009, the study of user-centered design [17] with orientation to special needs of people with disabilities has been integrated in ENGR 120 (Introduction to Engineering Design—Mobile Robots), a first-year course at Trinity College. In the spring of 2009 and 2010, a total of six ENGR 120 student teams, each with three students, developed robots for the RoboWaiter contest. In the spring of 2011, all eight teams in the course designed fetch-and-carry robots and participated in RoboWaiter. The inclusion of RoboWaiter as a design theme in ENGR 120 provided opportunities to discuss the role of engineers in improving lives of persons with disabilities and to discuss associated questions in Biomedical Engineering, Engineering Ethics, and Engineering Science.

2.4 Developing a Framework

The TCFFHRC and the RoboWaiter contests emerged from the planning process as compatible, mutually supportive, and strongly coupled events. They share many goals—to stimulate creativity and to encourage students of all ages to engage in projects that have societal benefits, for example—and both encourage development of new technologies. Both take place in scale-model arenas outfitted to the contest theme, and both require participants to solve engineering design problems spanning several disciplines. The scoring equations for both events emphasize reliability over speed. Persons who enter either competition have the opportunity to participate in other events on the contest weekend including a theoretical test, a robotics symposium, and a poster session. Finally, the RoboWaiter and fire-fighting contests present engineering challenges related to integrating such diverse design elements as algorithm development, programming, gripper design, sensing and obstacle avoidance, and motor control. It was clear that the TCFFHRC would provide an adequate framework within which the new RoboWaiter competition could be integrated.

2.5 Pilot Implementations

Three pilot RoboWaiter contests were conducted (2009, 2010, and 2011). Nine teams entered the 2009 contest. A team of first-year engineering students from Grand Valley State University, Michigan, developed the winning robot, which completed the RoboWaiter task on all of its three runs. A professional engineer from Florida built the 2009 second place robot, and a high school student from Ort Givat Ram High School in Jerusalem developed the third place robot. These promising successes, and the diversity and enthusiasm of the participants, encouraged further development of the contest. In 2010, the second pilot year, the contest was conducted in two divisions. The Standard Division from 2009 was retained and an Advanced Division event was added. Other changes included simplifying the standard division challenge to encourage participation.

The Advanced Division assignment required robots to interact with a refrigerator and to retrieve plates of food from a lower shelf or an upper shelf. This upgrade added elementary "smart home" features to the contest, lending greater realism and challenge. In 2010 eleven robots competed in the Standard Division and three competed in the Advanced Division. Robots represented teams from the U.S., Canada, Israel, and China. Four robots in the Standard Division received honorable mention prizes but none fully completed the RoboWaiter task. In 2011, the third year, the number of teams rose to 25 including 16 in the Standard Division and nine in the Advanced Division with representation from the U.S., Canada, Israel, China, and Indonesia. Robots in both divisions completed the RoboWaiter tasks.

3 The RoboWaiter Challenge

Recent research in service robotics considers the increased use of robots to carry out routine home tasks, such as cleaning, organizing, and delivery, as a grand challenge for robot manipulation in human environments [18]. Challenging characteristics of robot operation in human environments include the following: presence of autonomous actors (people, pets, and robots), variability, combining manipulation and mobility, and use of specialized tools. These characteristics appear in varying degrees in the RoboWaiter contest task, as described below.

Fig. 1 RoboWaiter arena

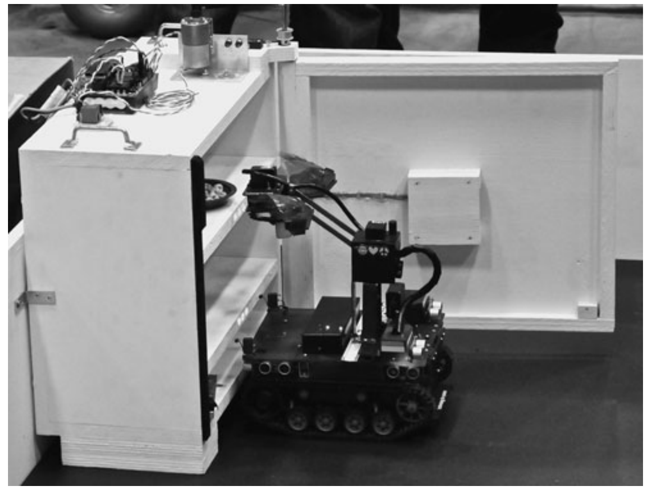

Fig. 2 Advanced Division RoboWaiter robot finding the plate

The task simulates a domestic situation where Grandpa, a person with a disability, instructs an autonomous assistive robot to pick up and transport a plate of food from a refrigerator to a kitchen table where he is sitting in a wheelchair. A second person with mobility impairment, Grandma, is present during robot operation. The scaled kitchen measures $2.5 \times 2.5\ \text{m}^2$, and it includes the refrigerator, a table, a sink, and a chair.

When directed by a signal from the judge, the RoboWaiter robot should move from its home position to the refrigerator, pick up the plate, move to the table where Grandpa sits, place the plate on the tabletop, and return to the initial position [12]. This action must be fully autonomous. The judge examines the robot operation and measures the time from the start signal until the plate is placed on the tabletop. Figure 1 captures the moment when the judge starts the robot from the initial position (upper left corner of arena). People in the photo are robot team members, people with disabilities, caregivers, and spectators.

Below we present further details of the RoboWaiter Standard Division and Advanced Division tasks.

3.1 RoboWaiter Standard Division

In the Standard Division all the objects are placed in the arena in known positions except for the chair, whose position is constrained in one direction only. A 30 cm white circle marks the robot's home position. Robots must avoid collisions with the sink, the chair, and the doll that represents Grandma. In this division a single shelf 21–23 cm above the floor represents the refrigerator, and the plate is a plastic pet food can top approximately 10 cm in diameter. A shelf beacon, consisting of three bright red LEDs spaced 2 cm apart on the edge of the shelf, guides the robot to the plate. The center of the plate is aligned with the center LED. In addition, there is a bright red LED centered on each of the exposed table edges. These LEDs serve as beacons that guide robots to their destination.

Scoring bonuses are given for implementation of the optional operating modes: Return Trip Mode, Food Mode, and Arbitrary Start Position Mode. A robot succeeds in the Return Trip Mode if it delivers the plate to the table and returns to the starting position. For this success the robot's measured run time is reduced using a multiplier of 0.8. In the Food Mode, the robot must carry breakfast cereal in the plate; for this mode the run time is also adjusted by 0.8. A multiplier of 0.85 is associated with Arbitrary Start Mode. In that mode, the arena judge chooses a starting position other than the standard start position. Each robot has three trials, and the time limit for each trial is four minutes. Robots that succeed on all three trials are placed in the highest finishing category, and the winner is the robot with the lowest run time within that group. If no robot completes three trials, robots with two successful trials are considered, and so forth. The Standard Division rules require the robot to fit into a cube measuring 30 cm on a side, and the robot must complete its task within four minutes. Touching the Grandma doll or moving Grandpa's wheelchair on any trial will disqualify the robot for that trial.

3.2 RoboWaiter Advanced Division

The Advanced Division arena is identical in size and general layout to the Standard Division arena except that the positions of the doll and the chair may be changed from run to run. Also, the Advanced Division uses a scale model "intelligent" refrigerator. The refrigerator has a lower shelf and an upper shelf, each fitted with a three-LED shelf beacon as described above (Fig. 2).

The refrigerator has a computer-controlled door opener that is actuated when a proximity sensor, embedded in the floor 65 cm from the center of the door, detects the presence of the robot. An infrared beacon centered on the refrigerator door guides the robot to the sensor. This beacon emits approximately 300 mW at 880 nm and is modulated at 8 kHz. When equipped with a well-designed receiver, a robot will be able to detect this beacon as far away as 2 m. In addition to the proximity sensor, the floor sensor includes three bright white LEDs, which the robot can use to verify its position.

Advanced Division robots begin their task when the judge issues an audio start signal. A 3.5 kHz signal indicates that the plate is on the bottom shelf, and a 7.5 kHz signal indicates that the plate is on the top shelf. After interpreting this start signal, the robot must navigate to the floor sensor, guided by the beacon and embedded floor LEDs. When the floor sensor detects the presence of the robot, the door opens automatically within five seconds, exposing the two shelves. The robot must pick up the correct plate and navigate back over the sensor to close the door. To finish the autonomous service task, the robot goes to the table, places the plate on it, and returns to the home position.

3.3 Arena Design Considerations

One of the main challenges of organizing the RoboWaiter is design of the contest arena for presentation of robot performances. The factors affecting design of the arena are discussed below.

- *Consistency with arenas used in the fire-fighting robot contest*. This factor emerges because RoboWaiter and Fire-Fighting Robot contests are held in parallel in the Trinity College Gymnasium. In this situation, selecting the RoboWaiter arena of the same size as the Fire-Fighting arena simplifies distribution of arenas in the Gymnasium, eases their assembly and disassembly, and makes it possible for the contests to share parts of arenas.
- *Convenience of access and observation*. From experience with the Fire-Fighting contest, the $2.5 \times 2.5\ m^2$ size was chosen. The arena's size and shape facilitate easy access for team members and judges and convenient observation for spectators. Persons with disabilities, when sitting at the edge of the arena close to the performance space, can experience a sense of intimacy and involvement.
- *Realistic presentation of the assistive robot operation*. The RoboWaiter arena is a complex environment, which realistically represents a typical home kitchen in the presence of two persons. The arena contains a minimal but representative set of kitchen fixtures (a refrigerator, a kitchen table, and a sink) and a furniture piece (chair), scaled with respect to their typical sizes in real kitchens. This realistic environment supports situated learning [19]. It forms the social context, which can enrich learning through the practice of design, building, and operating robots. Another positive effect of creating the realistic environment is that it helps to attract public to watch the RoboWaiter contest by transforming robot performances into a theatrical show.
- *Moderated uncertainty of the environment.* The use of a completely structured environment with constant predefined locations of objects enables simplified operation of a robot and thus may reduce the challenge and realism of the robot task. To avoid this effect, in the contest arena design space has been provided for variability: some dimensions are given approximately, and positions of the Grandma doll and some of the items are not predefined and can change from run to run.
- *Consideration of the ethical aspects of human-robot interaction.* The environment should take human factors into account. As follows from research on the subject [20], approaching a patient by an assistive robot should be properly organized. In particular, the majority of male patients participating in that research preferred the right robot approach direction. Based on this observation, the RoboWaiter environment is organized so that the robot, while delivering food, will approach the doll representing Grandpa in the wheelchair from the right direction. One more relevant issue is human safety, which is especially important in assistive robotics. Importance of this issue is emphasized in the RoboWaiter contest rules so that the run is immediately disqualified if the robot touches any doll or item.

4 Design Challenges Posed by RoboWaiter

The development of a RoboWaiter robot is a challenging interdisciplinary task involving sensing, interfacing, mechanics, and programming. Since the robot must succeed on all three runs, reliability is a primary design goal. Table 1 below presents the main RoboWaiter sub-systems and associated design requirements and possible solutions. Each of the sub-systems presents a significant design challenge that requires research, detailed development, and careful testing. A brief discussion of each sub-system follows.

4.1 Robot Base

The design requirements in Table 1 emphasize the main goal, that the robot base must provide reliable, controllable motion of the robot throughout the RoboWaiter arena. In the 2009–2011 RoboWaiter events, teams used a variety of commercial and non-commercial robot bases (the rules allow both kit and unique designs).

Table 1 Design goals, requirements, and solutions implemented in the projects

Sub-systems	Solutions/Devices
Robot Base. *Goal*: Provide reliable locomotion. *Requirements*: Programmable, controllable, fast, capable of limited dead reckoning & well controlled turns	Commercial base (iRobot), NXT, or custom-designed base. Sensor-based control of d.c. or stepper motors.
Sensor System. *Goal*: Enable navigation, object & plate detection. *Requirements*: Detect arena features (walls, obstacles), visible beacons on shelf & table, start signal. Advanced Division: Also identify audio start frequency (3.5 kHz or 7.5 kHz), detect door & floor beacons.	Ranging sensors for navigation and obstacle detection (IR, LIDAR), IR and visible light detectors (photo-transistor, camera), microphone, tone decoders.
Robot Arm and Gripper. *Goal*: Grab, hold, and carry plate. *Requirements*: Deployable, retractable, robust; accommodate dimensional tolerances (e.g., 21–23 cm shelf height), grip plate (handle more than one plate geometry), good tactile properties. *Advanced Division*: 3D motion—handle plates on lower and upper shelves.	Study and model 3-D motions (CAD modeling, animation); integrate sensing devices in gripper; design end-effector; choose materials that provide good tactile properties.
Software. *Goal*: Provide means to verify, integrate, and tune all sub-systems. *Requirements*: Test and debug motor drives, sensors, arm/gripper. Enable test of robot behaviors-navigation, plate detection, obstacle avoidance, plate conveyance, return to home.	Choose programming environment (LabView, HandyBoard, Interactive C, Lego NXT, or Linux-based microprocessor). Develop test protocols.

The commercial bases included the iRobot Create and the Lego NXT. Several teams used Lego components to construct a programmable base while other teams created their own bases using d.c. motors and metal or plastic assemblies. A reliable base is the starting point for a successful RoboWaiter robot, and great care must be taken to understand and fully test the base.

4.2 Sensors

The RoboWaiter rules impose many requirements on the robot's sensing system. The robot must be able to measure its position relative to arena walls and other obstacles. Low-cost IR ranging sensors (e.g. the Sharp Electronics type GP2Y0A21YK [21]) have worked well in this application. The robot must also be able to detect and decode audio start signals—3.5 kHz in the Standard Division and 3.5 kHz and 7.5 kHz in the Advanced Division. Robots must also detect red light emitted by LEDs on the refrigerator shelves and the table. The proper operation of the robot relies on these sensors, and seeking improved sensors requires continual effort.

4.3 Arm and Gripper

Development of a controllable mechanism able to grip, hold and convey the plate is perhaps the most challenging task for the RoboWaiter designers. An arm design used by a successful team in 2009 employed a slot that mated with the edge of the RoboWaiter plate. This arm worked well for this specific plate. Another second successful design in 2009 used a clamping device that, when opened, could be lowered onto the table from above, enclosing the plate. The gripper then closed onto the plate and securely held it. Several teams in the 2010 RoboWaiter contest used Lego-based grippers; an example is shown in Fig. 3.

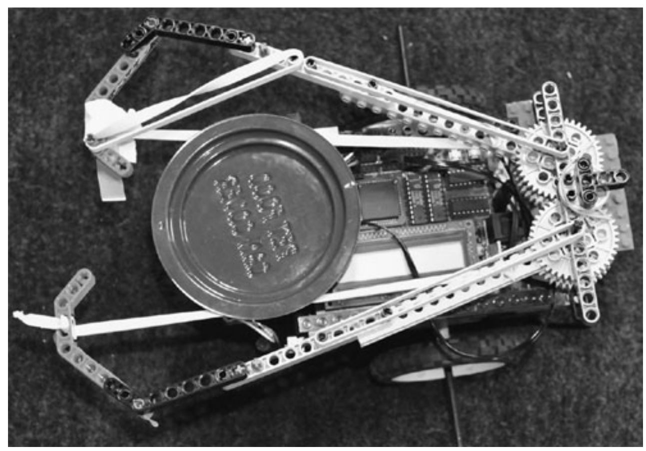

Fig. 3 Lego-based gripper shown holding the plate

This gripper arm was actuated by a servo that drove two gears to achieve opening and closing action. A second servo allowed the whole arm assembly to be rotated by 180 degrees, allowing the arm assembly to be folded back over the robot during navigation maneuvers. The plate rested on thick rubber bands strong enough to hold the plate. This device successfully grabbed the plate in the 2010 Standard Division event.

Optimal design of a gripper for the RoboWaiter Standard Division is an open problem that gives students opportunities to analyze forces and moments, choose appropriate materials, and apply modern design tools including 3D CAD modeling and animation packages. Gripper design for the Advanced Division is more complex, but successful designs were demonstrated in the 2011 contest. For example, the Advanced Division robot "DU99 RWE", developed by a team from UNIKOM, the Indonesian Computer University, made two successful runs and secured the plate from both upper and lower shelves using its arm, gripper, and lift mechanisms.

5 Involvement of People with Disabilities in the RoboWaiter Competition

Traditional participants of robot contests are contestants—students, hobbyists, and engineers—who design, demonstrate, and compete with their robots. In case of the RoboWaiter an additional category of participants is included—people connected to the Connecticut Council of Developmental Disabilities (CTCDD). For these participants the RoboWaiter contest opens an opportunity of active social interaction in a public event where they can learn about modern assistive technology and personally engage in discussions with engineers on developing new assistive robots to answer their needs.

Persons with sensory and motor impairments represent a serious challenge for education and care programs. Their limited range of movements and minimal interaction with the environment can prevent the acquisition of adaptive skills and put these persons at increased risk of a poor quality of life. Recently, considerable emphasis has been placed on finding ways of counteracting the aforementioned risks. Researchers have begun to develop intervention programs that involve the presentation of favorite stimuli across various periods of the day in an attempt to increase indices of happiness among persons in this group [22].

The evolution and organization of RoboWaiter were in large part directed by persons with disabilities, who, as a result, have a high investment and sense of ownership and pride in the contest. The lead author, who is also the contest director, meets, on average, four times each year with three members of the sponsoring organization, the Connecticut Council on Developmental Disabilities. This group serves as the executive planning committee for RoboWaiter. Committee meetings serve to evaluate past RoboWaiter competitions and to plan the next contest. The evaluation activity including discussion of contest surveys, facilities, and accessibility issues, provides the basis for planning for the next event. Meetings also consider funding issues, and they serve as forums in which Council members discuss and make choices about such important contest-related questions as theme development, rules formulation, funding, public relations, participation, judging, and awards. The executive planning committee also chooses a keynote speaker, a leading expert in the field of assistive or rehabilitative robotics, who delivers a public lecture on the day of the competition. In addition to these planning responsibilities, members of the executive committee encourage attendance by persons with disabilities, recruit judges for the event, and oversee the scoring process on the day of the event.

6 Contest Surveys and Interviews

Looking back on what went well and what needs improving in the robot contest is critical for its further development [13, 23]. In this section we present results of surveys and interviews carried out at the 2009–2011 RoboWaiter contests. Reflections were collected by means of questionnaires and interviews during and after the contests from two categories of people involved in RoboWaiter: contestants, and individuals with disabilities. Because of communication difficulties experienced by people of the second category, the questionnaires and interviews were conducted with assistance of their caregivers. We note that the number of survey respondents is small because of the limited size of the pilot contests, but we believe that meaningful trends are indicated and worth presenting to the reader.

6.1 Reflections of Contestants, 2009–2010

We posed the same set of questions to contestants in the 2009 and 2010 RoboWaiter surveys. The central question focused on personal reasons for participation. A list of possible reasons was given and respondents were asked to quantitatively evaluate the importance of each on the scale from 1—not important to 5—very important. The reasons and mean grades of the evaluations given by 18 respondents were: engineering challenge (4.54), curiosity (3.99), humane challenge (3.93), interest in assistive robotics (3.57), interest to major in the subject (3.53), job/scholarship opportunities (3.40), and social challenge (3.31). These results suggest that the main reasons for participation in RoboWaiter were engineering challenge, curiosity in the assistive robotics contest, and humane challenge. The other reasons were somewhat less important but still relevant. The relatively low evaluation of social challenge suggests a need to enhance interactions among planners, supporters, and participants.

In 2010 we administered a survey to students who participated in the Trinity College Fire-Fighting and RoboWaiter contests. In its central question the students were asked to estimate their progress in a list of subjects, abilities and motivation factors due to robotics studies and participation in the robot contest project. They estimated their progress by selecting one of the four grades: considerable, significant, little, or none. Eighty-four students answered the survey; among them 74 participated in the fire-fighting contest and 10 in the RoboWaiter contest. We calculated the percentage that rated their progress as either considerable or significant on the Fire-Fighting contest survey and on the RoboWaiter survey and compare the results in Table 2.

From Table 2 we see that evaluations of learning progress for the two contests in many subjects and abilities were high and comparable. Indicated trends were: (1) evaluations of

Table 2 Progress in subjects, abilities, and motivation (%)

Subjects	Student progress		Abilities and motivation	Student Progress	
	Fire-fighting	RoboWaiter		Fire-fighting	RoboWaiter
Electronics	75.7	70.0	Identify, solve problems	87.7	70.0
Mechanics	56.8	90.0	Design & conduct experiments	74.0	60.0
Microprocessors	71.2	40.0	Work with others	86.3	80.0
Sensors, measurement	82.2	80.0	Take initiative	83.6	60.0
Control	75.3	80.0	Make decisions	78.1	50.0
Systems design	81.7	60.0	Set priorities	79.5	50.0
Robot programming	68.5	80.0	Understand user needs	58.3	50.0
Robot navigation	78.1	80.0	Understand social responsibility of engineers	63.0	60.0
Robot manipulation	65.8	70.0	Participate in future robot projects	87.8	80.0
Robot interaction with environment	63.0	70.0			

RoboWaiter were higher in mechanics, likely because of the need to design the claw and gripper mechanisms, and (2) responses for the firefighting contest were stronger in the "take initiative", "make decisions", and "set priorities" areas. Lower evaluations in these latter three areas and in microprocessors and system design may indicate the need better to address these areas in RoboWaiter projects. Still, the comparable, and even higher, evaluations of the RoboWaiter contest, compared to the well-established Fire-Fighting contest, point to its good potential for facilitating learning.

Along with members of the CTCDD the authors presented an invited workshop, "RoboWaiter: The Assistive Mobile Robot Competition" at the 2009 Annual Conference of the National Association of Councils on Developmental Disabilities (NACDD), Albuquerque, NM [23]. The workshop gave us incentive to more deeply analyze perceptions and attitudes of RoboWaiter contest attendees. For this purpose, prior to the workshop and four months after the competition, we conducted a series of written interviews with a number of contestants and supporters. We find the responses very instructive, and we present and analyze a sample of comments below.

From the response by a professional engineer:

> I had not given assistive robotics much thought before the competition. As an engineer, I tend to get focused on a task and forget about people. The project gave me lots of new ideas. I think it was a very effective way to get people thinking about what robotic technology can do for people with disabilities.
> Socially responsible education is very important. Students have to get out in the real world. For an assistive robotics project, I think it would be very valuable for students to interact with people who have disabilities and get their feedback.

The respondent recognized the importance of socially responsible education and noted that RoboWaiter has succeeded in raising awareness, promoting creative thinking in a new realm.

From the response by a university student from Connecticut:

> In RoboWaiter learning robotics and programming, as well as social, moral, and humane issues take place. These experiences help students realize what their education is leading up to, and how they can end up changing the lives of so many people.
> It was great to have participation of people with disabilities. There is no downside to them being there and seeing how robots could potentially help. Their participation can also help in coming up with new ideas, as they converse with the builders.

The respondent noted that in RoboWaiter she learned robotics fundamentals together with societal issues. The student appreciated participation of people with disabilities in the contest.

From the response by a high school student from Israel:

> RoboWaiter made me more conscious of the main purpose of building a robot—to help people. I saw people with disabilities enjoying the contest and was happy that we made them to have a smile on their face when they saw the robot work. This was more important than the result score.
> More people should come to compete and more people with disabilities should come to view the competition because it make them happy when they see the robots and people who try to help them with technical equipment and give them hope.

The respondent recognized humanistic orientation of RoboWaiter and the potential of assistive robotics.

The RoboWaiter survey was conducted also in 2011. Nine students filled the survey form. All of them noted that participation in the contest motivated or even strongly motivated their interest in assistive technology, robotics, and in developing robots that can provide real assistance. The contest inspired them to think about a person with disability as a customer of assistive robotics who can help designers to make more realistic robots. The survey included open questions, presented below together with a sample of responses:

Question 1: How do you envision the needs of the disabled community with respect to assistive technology?

– We have to develop our technology so it will be able to help and improve the quality of their life.
(High school student)

– Personal independence plus control of their world plus more time to do satisfying things.
(Professor)

– To feed people who can't do it themselves and encourage that, with the robot, they can!
(University student)

Question 2: What did you learn through your experience with the RoboWaiter competition?

– What it is to program very hard programs in minimal time.
(University student)

– Yes, better still at designing robots.
(University student)

– Reliability matters! Simple controls are needed. Override ability is necessary. "STOP" is important.
(Professor)

Question 3: What did you like about the RoboWaiter competition? What did you not like?

– Good level of competition. Slight concern about how much professional help foreign students get.
(Professor)

– It was fun. Not enough practice on arenas.
(University student)

– I liked the atmosphere and the team spirit. It was an amazing experience to come here.
(High school student)

The answers above indicate that the respondents considered their participation in the contest as a motivating, instructive, and joyful experience. Also they provided constructive feedback about possible improvements to the contest event.

6.2 Reflections of People with Disabilities and Caregivers

Written interviews prior to the conference workshop were conducted also with CTCDD members who attended the RoboWaiter in wheelchairs. We present below comments of one of these persons, as we believe that they are worth the reader's attention:

– I would like to learn more about how robots can assist people with disabilities in various places such as in homes, cars, employment, etc.

– I feel RoboWaiter is more of education and an awakening to the participants that robots could be essential to people with disabilities of any age... more teams should have the opportunity to come to the competitions because RoboWaiter is a wonderful experience.

– I have watched the robotic contests at Trinity College. I've enjoyed them. They are exciting! I think the RoboWaiter gives a realistic demonstration of a service that a robot could provide to someone with a disability.

– The RoboWaiter competition teaches students that, through technology, they can help people with disabilities in their own homes. Engineering students come to understand that with increasingly sophisticated devices being developed and produced, persons with disabilities will enjoy happier, more productive lives.

These comments and responses from other people indicate eagerness of persons with disabilities to learn more about assistive robots, to support RoboWaiter, and to promote understanding among engineering students about needs for assistive technology. It is clear that RoboWaiter is an exciting event for these persons. The reasons for supporting the RoboWaiter, pointed out by the CTCDD people were: wish to attract attention to needs of users of assistive technology, increase awareness among potential users, introduce students to the subject, inspire dialogue between users and developers of AT and foster its development.

6.3 NACDD Conference Workshop

At this 2009 workshop we presented and promoted the RoboWaiter assistive robotics competition before members of National Councils of Developmental Disabilities. Creating effective dialogue with the audience during the session was difficult but crucial for achieving the goal. We solved this challenging communication problem by using Personal Response Systems (PRS) or clickers. For attendees of our talk this was absolutely new technology, but they found it simple and convenient. For us, the use of PRS gave an opportunity to operatively collect data on perceptions and attitudes of the target group. Some of the data are presented below.

Among eighteen session attendees there were council officers, people with disabilities, and researchers. At the end of the session we asked the attendees to what extent they agreed with a number of statements, using a scale from strongly disagree to strongly agree. The statements and percentage of people who agree or strongly agree with them are as follows:

1. In the near future robots will be in wide use in helping people with disabilities (88.3%).
2. People need basic knowledge in robotics in order to use home robots properly (41.1%).
3. Engineering education should foster students' awareness of the needs of people with disabilities (82.3%).
4. Educational programs in universities and schools should include practice directed to help people (100%).
5. People with disabilities can benefit from active participation in assistive robotics programs (100%).
6. Collaboration between Councils of Developmental Disabilities and universities, offering assistive robotics education, is recommended (100%).

Because the topic of assistive robotics was new for many attendees, it was difficult for us to hypothesize their reactions. We were surprised to find that in many respects the attendees shared our opinions. All the attendees believed that educational programs in universities and schools should include practice directed to help people, people with disabilities can benefit from active participation in assistive robotics events, and collaboration between Councils of Developmental Disabilities and universities in the area of assistive robotics education can be recommended. Also, the majority of the attendees agreed that in the near future assistive robots will be in wide use and that engineering education should foster students' awareness of the needs of people with disabilities. Responses to the statement that "people need basic knowledge in robotics in order to use home robots properly" were varied. While some of the attendees agreed with the statement, others felt that assistive technology should be developed so that unskilled users can manage it.

6.4 Reflections of Contestants, 2011

As part of the RoboWaiter 2011 survey we asked several attendees of the competition to fill a supporter's survey form. Eight people participated, among them three persons with disabilities, three caregivers, and two assistive technology specialists. The questions of the supporter's survey were similar to that of the above-discussed contestant's survey, but were posed from the observer's perspective. All respondents of the supporter's survey pointed that the RoboWaiter motivated or strongly motivated their interest in assistive technology and robotics, interest in sharing their needs with designers and in helping them to develop more realistic robots. Below we quote some of the responses to the open questions from the survey.

To the first question, on the need for assistive technology, persons with disabilities answered:

– It is greatly needed.
– Robots may in the future be part of making life better for persons with disabilities to be more independent.
– As the population continues to age, the disabled community will continue to increase as will requirements for assistive technology.

An AT specialist pointed the needs which, for her opinion, are most relevant:

– Flexibility issues with their legs, back, body. Assistance with stairs. Assistance with entering a vehicle and putting away a wheelchair.

To the second question about the most vivid impression from the contest, respondents noted that

– The enthusiasm demonstrated by the competitors expresses hope for continued development (person with disabilities).
– For most teams it was difficult to accomplish the contest assignment (AT specialist).
– There is still much room for improvement in this field, but students have showed a desire to help people with disabilities and our students are our future (caregiver).

To the third question, all respondents expressed interest to be involved in the next contest:

– I will continue to support the events to promote inclusion in community life for persons with disabilities (person with disabilities).
– I would like to get updates in any new developments (AT specialist).

The last question asked supporters what they liked or did not like about the contest. Here are some of the answers:

– Spirit of camaraderie among students (caregiver).
– Very creative and innovating. Great youth participation (AT specialist).
– That so many students from different countries have learned of the importance of improving lives of those with disabilities (caregiver).

In summary, the surveys and interviews conducted at the 2009–2011 contests point to appreciation of the RoboWaiter by contestants and persons with disabilities, and they suggest that RoboWaiter has raised awareness of robotics among those persons and awareness of assistive robotics among engineers.

7 Conclusion

This paper presented a new robot competition, RoboWaiter, which encourages development of service robots to aid persons with mobility impairment. The competition is unique because it engages real people with disabilities in its planning and execution. As a retrospective exercise we found that five main steps were needed to manage the relationship between two organizations while creating an accessible and realistic contest: opening the communication channel, clarifying mutual expectations, establishing a vision, developing a framework, and implementing pilot contests. This model may be useful to other organizations seeking to develop similar client-driven events.

We characterize RoboWaiter as a system that has three interdependent and inseparable components: educational, social, and engineering. The educational component focuses on raising awareness of assistive robotics, exposing students to assistive robotics and associated design problems, and promoting creative thinking practices. The social component includes participation by persons with disabilities as planners, volunteers and judges, and engagement of these persons with contestants and supporters at the contest event. The engineering component is driven by the robot design problems defined by interpreting the RoboWaiter rules. The resulting engineering challenges are inherently multidisciplinary, requiring design of mechanical, sensing, electronic, and control elements. All aspects of the design present problems related to sensing and control which, solved, may allow the robot to complete the RoboWaiter assignment autonomously and reliably in the shortest time.

We recognize the importance of future surveys that provide continuing feedback about contest outcomes. As the contest grows we will have the opportunity to survey larger samples and to test our pilot survey results, which were gleaned from surveys of participants and supporters at the 2009, 2010, and 2011 contests. From those surveys our findings were that the contest presented challenging problems in robot design and encouraged engineers and students to think creatively in an applied area of assistive robotics that was new to them. RoboWaiter helped some of the participants to recognize the social challenge of assistive robotics and to learn that engineering work can have importance beyond pure technical achievement. Reflections of the participants showed that RoboWaiter presented a significant engineering challenge and that designers were eager to take on the new work and to test their robots in the competition. Curiosity was also an important motivator, but equally so was the humane challenge. Such factors as social challenge, interest in assistive robotics, interest in majoring in the subject, and opportunities for jobs, scholarships, or advanced studies were also seen as strong motivators in the pilot studies. Among the sample of supporters surveyed, primary motivation factors were attracting attention to the needs of persons with disabilities, creating awareness, introducing students to the assistive technology subject, and creating dialogue among users and developers of assistive technology. Supporters were very interested in robotics, consistent with their active engagement as contest officials and their continuing involvement in it. RoboWaiter offered social benefits to persons with disabilities including the opportunity to interact with contestants and spectators, engagement through serving as contest designers and judges, and empowerment through a yearlong planning process. Such close involvement in RoboWaiter opened to persons with disabilities many opportunities for joyful experiences, from participating in contest planning to cheering for the teams.

While immersing the participants in a challenging activity, the contest has involved real persons with disabilities in developing an international robotics competition and in participating in it. Feedback from these individuals indicated that robot competitions could play an important social role in drawing public attention to the need for new technologies, inspiring technological development, and fostering engineering education.

We believe that RoboWaiter has made good progress, and we look forward to a bright future for the contest. Our plan is to enhance social impact of the contest by encouraging wider participation of university students and school pupils, focusing project assignments on creating more socially compatible RoboWaiter robots, and directing the contest assignment so that it addresses emerging problems of assistive robotics.

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References

1. Sheppard SD, Macatangay K, Colby A, Sullivan WM (2008) Educating engineers: designing for the future of the field. Jossey-Bass, San Francisco
2. Tan KK, Genalo LJ, Verner IM (2010) Guest editorial: spec issue on outreach to prospective electrical, electronics, and computer engineering students. IEEE Trans Ed 53:1–2. doi:10.1109/TE.2009.2032275
3. Piket-May M, Avery J (2001) Service learning first year design retention results. In: Proc front in educ conf, pp 19–22
4. Assessment of US assistive technology industry (2007) US Department of Commerce Technology. https://www.disability.gov/viewResource?id=13934274. Accessed 18 November 2011
5. Assistive technology outcomes and benefits (2004) Assistive Tech Industry Association and Special Education Assistive Tech Center. http://www.atia.org/i4a/pages/index.cfm?pageID=3681. Accessed 18 November 2011
6. Carlson D, Ehrlich N (2005) Assistive technology and information technology use and need by persons with disabilities in the United States. US Dept Educ Natl Inst Disabil and Rehabil Res. http://www.ed.gov/rschstat/research/pubs/at-use/at-use-2001.pdf. Accessed 18 November 2011
7. Taipalus T, Kazuhiro K (2005) Development of service robot for fetching objects in home environment. In: Proc IEEE int symp comp intel in robot and autom (CIRA), pp 451–456

8. Nguyen H, Kemp CC (2008) Bio-inspired assistive robotics: Service dogs as a model for human-robot interaction and mobile manipulation. In: Proc IEEE RAS/EMBS int conf on biomedical robotics and biomechatronics (BioRob 2008), pp 542–549
9. Jain A, Kemp CC (2010) EL-E: an assistive mobile manipulator that autonomously fetches objects from flat surfaces. Auton Robots 28:45–64. doi:10.1007/s10514-009-9148-5
10. Tapus A, Matarić MJ, Scassellati B (2007) The grand challenges in socially assistive robotics. IEEE Robot Autom Mag 14:35–42. doi:10.1109/MRA.2007.339605
11. Connecticut Council on Developmental Disabilities (2011) http://www.ct.gov/ctcdd/. Accessed 18 November 2011
12. Trinity College Fire-Fighting Home Robot Contest (2011) http://www.trincoll.edu/events/robot. Accessed 18 November 2011
13. Verner I, Ahlgren D (2002) Fire-fighting robot contest: interdisciplinary design curricula in college and high school. ASEE J Eng Educ 91:355–359
14. Verner IM, Ahlgren DJ (2004) Robot contest as a laboratory for experiential engineering education. J Educ Res in Comp 4(2):1–15, Special issue on robotics in undergraduate education
15. Verner IM, Ahlgren DJ (2007) Robot projects and competitions as education design experiments. Intel Autom Soft Comp J 13(1):57–68, Spec Issue on Educ Robot
16. Seale J, McCreadie C, Turner-Smith A, Tinker A (2002) Older people as partners in assistive technology research: the use of focus groups in the design process. Technol Disabil 14(1):21–29
17. Abras C, Maloney-Krichmar D, Preece J (2005) User-centered design. In: Berkshire encyclopedia of human-computer interaction, vol 2, Berkshire Publishing, Great Barrington, pp 763–768
18. Kemp CC, Edsinger A, Torres-Jara E (2007) Challenges for robot manipulation in human environments. IEEE Robot Autom Mag 14(1):20–29
19. Cobb P, Bowers J (1999) Cognitive and situated learning perspectives in theory and practice. Educ Res 28(4):4–15
20. Dautenhahn K, Walters M, Woods S, Koay KL, Nehaniv CL, Sisbot EA, Alami R, Siméon T (2006) How may I serve you? A robot companion approaching a seated person in a helping context. In: Proc of the 1st ann conf on human-robot interaction, Salt Lake City, Utah, USA
21. Sharp Distance Sensor (GP2Y0A21YK0F) (2011) http://sharp-world.com/products/device/lineup/selection/pdf/opto201107_e.pdf. Accessed 18 November 2011
22. Lancioni GE, O'Reilly MF, Campodonico F, Mantini M (2002) Increasing indices of happiness and positive engagement in persons with profound multiple disabilities. J Dev Phys Disabil 14:231–237. doi:10.1023/A:1016020320752
23. Ahlgren D, Verner I, Langton M, Baker J, Legault A, Preneta E (2009) RoboWaiter: the assistive mobile robot competition. In: Proc nat assoc of councils on dev disabil ann conf workshop, Albuquerque

David J. Ahlgren is Karl W. Hallden Professor of Engineering at Trinity College and Director and Host of the Trinity College Fire-Fighting Home Robot Contest and the RoboWaiter Contest. He earned 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. Professor Ahlgren has been a faculty member at Trinity College since 1973, and he served as department chairperson from 1990–1999. His interests include robotics, simulation and modeling, electronics, and engineering education.

Igor M. Verner is Associate Professor at the Department of Education in Technology and Science, Technion–Israel Institute of Technology. He received the M.S. degree in Mathematics from the Urals State University and the Ph.D. in computer aided design systems in manufacturing from the Urals State Technical University, Yekaterinburg, Russia. He received the teaching certificate in technology from the Technion. His research interests are in engineering, mathematics and science education with emphasis on technological learning environments, experiential learning, robotic modeling, human-robot interaction, and socially responsible education. Dr. Verner serves on board of the International Journal of Engineering Education and International Journal of Robotics, Education and Art.