A long-term approach to improving human-robot interaction: RoboCupJunior Rescue

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***Abstract*— This paper describes the motivation behind and development of a USAR environment for the entry-level division of RoboCup, namely RoboCupJunior Rescue. We describe the challenge as it has evolved since 2000. Further, we explain how we see a place for this initiative as part of a long-term plan to address issues in human-robot interaction, advancing technical literacy by introducing young students to robotics within a socially significant context. The need to be able to interact with technology is growing increasingly important. Preparing the next generation by exposing today's students to hands-on technology early on will provide a more sophisticated population that is ready and willing to interact with complex technology whenever and if ever they need to — no matter whether these students become engineers, roboticists, schoolteachers, fire-fighters, ambulance drivers, doctors or lawyers.**

I. Introduction.

Following the tragic terrorist attack on September 11, 2001, mobile robots assisted in the Urban Search and Rescue (USAR) operation that was conducted at the World Trade Center site in New York City. This was the first time that rescue robots had been used in a real disaster of this magnitude [1]. Members of the Perceptual Robotics Laboratory at the University of South Florida assisted as part of the first response team for nine days following the attack. Based on data collected during this time, a study was conducted which investigated human-robot interaction aspects of the operation [2]. The study examined interactions in five categories within the ecological and social niches:

- *Environment and Conditions (ecological niche)* — What are the physical environmental conditions like?
- *Task (ecological niche)* — What is the task that needs to be accomplished?
- *Agents and Skills (ecological niche)* — Who are the human and automated agents and what are their physical and cognitive skills?
- *Social Informatics (social niche)* — How do the agents organize and collaborate?
- *Communication (social niche)* — How do the agents communicate information between each other and the environment?

Many recommendations came out of this study, some of which are particular to the extreme mental (stress and depression) and physical (fatigue and air quality) conditions faced by the rescue workers. Other, more general issues of human-robot interaction were highlighted due to the fact that while the rescue robots were operated by a trained team of research scientists, they were working side-by-side with fire department and other rescue personnel who were not experienced at interacting with robots.

Once thought of as strictly research technology, robots have today walked out of the laboratory into offices, homes and schools. Although these machines are designed with human users in mind, many humans find them difficult to interact with; indeed, many people who are not "techies" do not even feel comfortable touching them. The typical tack taken when facing a user interface problem is to change the interface and make it easier for humans to use. An alternative approach is to change the humans and make them understand the interface better. Sometimes this route is taken by offering training for human users. However, this typically involves instruction on the use of one specific piece of technology rather than a more generalized approach to understanding automated devices.

We take the view that problems in human-computer, human-robot interaction are two-sided; there are issues on both the computer/robot side and the human side. To move forward, adaptation must take place on both sides. As robotics technology advances, humans must also be adapting so that they will be prepared to face new interfaces as they are developed. Similarly, as everyday humans become more educated and sophisticated in their knowledge about technology, robotic interfaces will be able to adapt to interact with a more sophisticated, more knowledgeable, more comfortable, more *technically literate* human user.

Advances in technology happen so quickly that new computer hardware and software becomes obsolete every 30 months [3]. Comfort with one system only lasts so long before it is upgraded, and users must be retrained. So the key here is literally *literacy*. Memorizing a poem is no substitute for knowing how to read; literacy allows exploration of any new and unfamiliar text. Similarly, *technical literacy*, i.e., comfort with and understanding of technology, allows exploration of new and unfamiliar systems. "Technical literacy is quickly becoming as important as the ability to read." [4]

How can technical literacy be achieved? Education researchers and psychologists have repeatedly demonstrated the importance of hands-on experiences to promote learning [5], [6]. *Constructionist* theory states that we learn best when actively involved in building or constructing something physical, external to ourselves and something that is personally meaningful [7]. Here, we focus on the notion of helping young students become more adept at interacting with technology through the use of robotics, integrated into a socially significant task. We provide a USAR environment and have students build robots to navigate through the environment in search of victims. The project is incorporated as one challenge within the *RoboCupJunior* initiative — RoboCupJunior Rescue.

This paper is organized as follows. We begin by providing some background on RoboCupJunior, outlining the program and offering a brief history. Then we describe the development of RoboCup Rescue as a senior[1], academic and research league within the well-established RoboCup initiative. Next we detail the evolution of the Rescue challenge at the junior level and its current state. Finally we connect back to our long-term research goals of improving Human-Robot Interaction through advancing technical literacy.

II. Background.

RoboCup (`www.robocup.org`), founded in 1997, is an international research and education effort [8]. Its purpose is to foster *artificial intelligence (AI)* and *robotics* research by providing a standard problem where a wide range of technologies can be integrated and examined. The ultimate goal of RoboCup is that by the middle of the 21st century, a team of fully autonomous humanoid robot soccer players shall play a soccer game with human world champions. In 2001, RoboCup Rescue was unveiled with the intention of sharing lessons learned from robotic soccer and applying them to a socially significant, yet characteristically similar domain. Today, RoboCup engages thousands of researchers worldwide, working in both soccer and rescue domains, and hosts an annual international tournament and academic conference, as well as an increasing number of national "open" events including America, Australia, Germany and Japan.

RoboCupJunior (RCJ) (`www.robocupjunior.org`) is the entry-level division of RoboCup, designed to introduce RoboCup to primary and secondary school students. The focus in the Junior league is on *education*. RoboCupJunior offers three challenges, each emphasizing both cooperative and competitive aspects. RCJ provides an exciting introduction to the field of robotics, a new way to develop technical abilities through hands-on experience with computing machinery and programming, and a highly motivating opportunity to learn about teamwork while sharing technology with friends. In contrast to the one-child-one-computer scenario typically seen today, RCJ provides a unique opportunity for participants with a variety of interests and strengths to work together as a team to achieve a common goal.

A. RCJ History.

RoboCupJunior began as a research project, exploring the idea of robotic soccer using the LEGO Mindstorms Robotics Invention Kit [9]. The original focus was on using robotics to teach young students about the field of Artificial Life. RCJ was first demonstrated at RoboCup 1998 in Paris.

The first international RCJ competition was held in 2000 in Melbourne, Australia at RoboCup-2000 [10]. Over 100 students took part, ranging in age from 8 to 19 and coming from 25 schools around Australia, as well as from Germany and the USA. At that time, the blueprint for RCJ tournaments was developed, involving a curriculum-based, student-driven approach. Three challenges were created, each requiring differing levels of technical sophistication to solve. Students typically use robot kits — the LEGO Mindstorms Robotics Invention Kit has been the most widely used, although the Fischertechnik Mobile Robot and Elekit SoccerRobo are also popular. Students build and program their robots under the guidance of mentors — school teachers, older students, parents and community leaders. All robots act autonomously. No remote control is allowed.

The second international tournament took place at RoboCup-2001 in Seattle, USA [11]. Twenty-five teams participated, nearly 100 students, ages 7 to 23, from the area surrounding Seattle, as well as other American states, England, Germany and Australia. In 2002, the third international RCJ tournament was held in Fukuoka, Japan. By this time, the initiative had gained popularity and for the first time, the event attracted teams from a wide geographical region — over 240 students and mentors incorporating 65 teams from 12 countries in North America, Europe and Asia. The fourth international RCJ event took place at RoboCup-2003 in Padova, Italy involving almost 300 participants from 67 teams in 16 countries.

B. RCJ Challenges.

Three challenges have been developed for RoboCupJunior. In the **Soccer** challenge, two teams of two robots each play soccer on a 4 foot by 6 foot field. A smaller, one-on-one game is also available and is particularly applicable to newcomers that have few resources for purchasing robots. The floor of the soccer field is lined with a greyscale mat and the ball is an electronic device that emits infra-red (IR) light which makes it detectable by a simple light sensor [12]. The rules of play are based on FIFA soccer rules and were adapted to robotic soccer following from the RoboCup Small-Size League rules.

For the **Dance** challenge, students build robots that move to music for up to two minutes. Creativity is emphasized — robots (and sometimes even students) are dressed in costume. This is designed to be an entry-level event, since it is possible to participate using simple robots that only employ motors and no sensors. In recent years, teams have been taking a multi robot approach to the dance, which opens the door to exploring new avenues of technical sophistication such as coordination and communication.

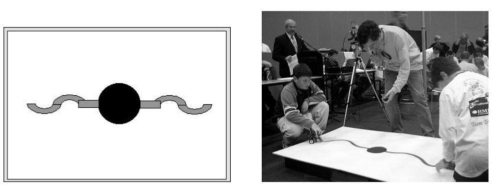
The dance event itself is exciting and innovative. Tremendous strides were made in 2002. Twelve teams participated, each demonstrating unique and creative ways of combining technology with art, music and culture. Some teams' routines told stories. Many teams shared their country's culture through

[1] We use the term *senior* to distinguish from the *junior* leagues within RoboCup.

traditional dances, music and costumes — worn by both robots and students. Several teams built robots out of wood, like puppets, dressed and decorated for the occasion. Another leap forward was taken in 2003. Eighteen teams participated — 68 students, 31% of whom were female. Again, there was terrific variety in application. There was, overall, a marked improvement technically in terms of hardware and software development. Most teams used multiple robots. Several used unique constructions, integrating their own components rather using a robot kit.

The focus of this paper is the third, *line-following* challenge, which has undergone the most change and has now evolved into RoboCupJunior **Rescue**. To begin with, at RCJ-2000, a *Sumo* event was held, designed as a middle-level challenge (see figure 1). Two robots followed wiggly black lines and competed for possession of a central circular region on the playing field. Only one robot was needed for each team and the environment was essentially static. The only dynamic elements were the two robots; but they had limited interaction and did not need to respond to each other, only to changes in their own location on the playing field.

After observing this event in 2000, it was decided to make a major change for two significant reasons. First, the idea of “sumo wrestling” is not really in line with the RoboCupJunior mission of friendly competition and fostering sharing through technology. Second, the anticipated introduction of RoboCup Rescue at the senior level [13] invited conception of a rescue-based activity at the junior level.



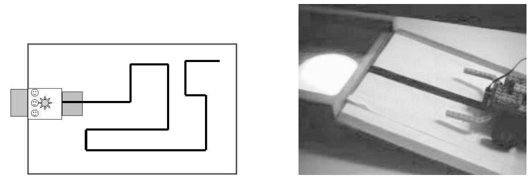
(a) Field layout. (b) The competition .

Fig. 1. RCJ line-following sumo, from RCJ-2000, Melbourne, Australia.

III. DEVELOPMENT.

For RCJ-2001[2], we introduced the notion of **RobCupJunior Rescue** and designed a scenario in which a robot follows a line through a simulated disaster scenario and attempts to rescue “victims” of the disaster. The scenario constructed for 2001 was that of a burning building, where the robot was supposed to “rescue” three victims stranded on the roof. This setup is illustrated in figure 2. The floor is white, and a black line turns in a maze-like pattern, then goes up a ramp to the roof, where the robot was supposed to nudge three toy people off the roof to a “safety net” below.

The challenge was timed, and robot took turns attempting to run through the course. Most students had trouble getting their robots to follow the line for the whole course, so the teams received points for passing designated positions on the course. More points were awarded for going up the ramp, and also for “rescuing” the victims by helping them reach the safety net.

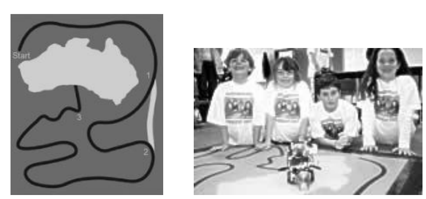


(a) Field layout. (b) Rescue robot climbing ramp.

Fig. 2. RCJ fire rescue, from RCJ-2001, Seattle, USA.

At RCJ-2001, only 4 out of 25 participating teams entered the rescue challenge. Only one of the teams was able to complete the course. While there are no dynamic elements in the environment, accurate control of the robot based on light sensor readings is essential and is surprisingly difficult. As well, the uneven terrain with a change in pitch where the robot reaches the ramp and a bump in the path between the flat field and the ramp makes the course even more challenging. It turns out to be quite hard to build a robot that has enough finesse to follow the line accurately and at the same time has enough traction and power behind it to ascend the ramp.

The original plan when we introduced the notion of RoboCupJunior Rescue was that each region around the world would develop a rescue scenario that was pertinent to their local setting, which gave countries an opportunity to be creative and display some home culture. In Australia, RoboCupJunior has the largest rate of participation. Nationwide in 2003, 723 teams competed in regional, state and national events — totaling 1991 students from 236 schools. The Australian RCJ committee designed their own rescue arena, pictured in figure 3. The objective is the same, but the course is different. A “Yowie” (an animal-shaped chocolate candy made by Cadbury) is placed in the map of mainland Australia, and each team’s robot has 90 seconds to follow the black line from the starting point to the mainland and reach the Yowie.



(a) Field layout. (b) The competition.

Fig. 3. RoboCupJunior Australia Rescue.

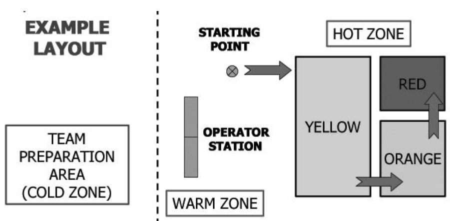
At RCJ-2002, a rescue event was not held. Although this was a decision of the local organizers (in Fukuoka, Japan), it reflected the sense that the idea of a junior rescue event had not yet caught on everywhere. This motivated a rethinking of the project. So for RCJ-2003, the RoboCupJunior Rescue challenge was redesigned to follow more closely the RoboCup Rescue league, which was now well-established amongst the senior teams.

[2]Held in August 2001, prior to the World Trade Center attack

A. RoboCup Rescue League.

Three years earlier, RoboCup Rescue was formed, taking direction from experiences at the long-standing AAAI Mobile Robot Competition and recent advancements in USAR research and development. The National Institute of Standards and Technology (NIST) designed a standard test bed for USAR which consists of three sections of increasing difficulty (see figure 4) [14]. The “yellow” section is the easiest. It has hallways, doorways and blinds on “windows”. The “orange” section comes next and is more difficult because doors are added as well as a second floor, which is reached via stairs or a ramp. Finally comes the “red” section, which is the most challenging. This section contains piles of rubble and various unexpected obstacles.

Human mannequins (adults, children and babies) are placed throughout the arena. Some are equipped with heating pads, voices and moving limbs. The primary goal is for robots to move about the arena and identify as many victims as possible, while creating a map of the space so that human rescue workers could theoretically go in, locate and rescue the victims. Timing and accuracy are important. Teams are scored based on victim identification. They lose points for missing victims and for mis-classifying something as a victim when it is not. Every delay, every mistake could cost human life in a real disaster scenario.



(a) Overview of field layout.

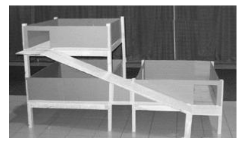
(b) The arena.

Fig. 4. NIST standard test bed for USAR.

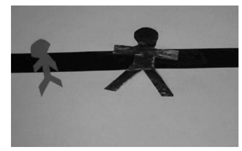
IV. Current Challenge.

In time for RCJ events worldwide in 2003, we designed and constructed a miniature version of the NIST standard USAR test bed especially for RoboCupJunior (illustrated in figure 5). The design is modular and features a varying number of “rooms”. These are connected by hallways and ramps. Two doorways are located at standard points in each room so that multiple rooms (modules) can be linked together easily. Modules can be stacked, to provide additional challenge; lighting conditions in lower rooms with a “roof” are different than in rooms with an open top. The number of modules in an arena is not fixed. We used three at the 2003 RoboCup American Open (as in figure 5a). We used four modules at RCJ-2003 in Padova.

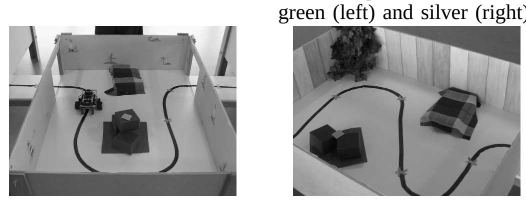
The floor of each room is a light color (typically white). The surface could be smooth, like wood, or textured, such as a low-pile carpet. The rooms can be furnished or bare; the walls can be decorated or left empty. This allows teams to enhance their modules with decorations of their own design. One idea is to let teams bring “wallpaper” to events as a means for sharing team spirit and local culture.



(a) Outside view.



(b) Close-up view of “victims;” green (left) and silver (right).



(c) Furnished rooms.

Fig. 5. RCJ urban search and rescue.

A black line, made with standard black electrical tape, runs along the floor through each room, entering in one doorway and exiting through the other. Along the black line, “victims” are placed randomly throughout the arena. The victims are like paper doll cut-outs, made of either green electrical tape or reflective silver material (see figure 5b).

One of the objectives with the design of the arena was to keep it simple enough that it could be solved by a single LEGO Mindstorms Robotics Invention kit, without requiring purchase of additional components (see figure 6). The kit comes with one light sensor, two touch sensors and two motors. The light sensor detects levels of brightness, returning a value between 0 and 100 where 0 indicates no light detected and 100 indicates maximum brightness. The setup described here is based on four distinct ranges (from darkest to brightest): black line to green victims to white background to silver victims.

As in the senior rescue game, teams receive points for detecting victims. They are penalized for missing existing victims and for mis-classifying victims (i.e., finding victims that are not really there). When the robot locates a victim, it is supposed to pause on its path and also make an audible beeping sound. We discovered that in a competition venue, the beep was practically impossible to hear given the noise level of a crowded hall. Here we suggest that an alternative, visual cue replace the audio signal. This could be done in one of two ways. Teams could purchase a lamp that interfaces with the LEGO kit; this is a standard 9V lamp brick add-on which costs approximately US$5. Teams could also display a message on the display of the Mindstorms’ RCX brick.

The new arena was tested in competition for the first

(a) The RCX the microcontroller; (b) A light sensor.

Fig. 6. Components of the LEGO Mindstorms Robotics Kit. The RCX has 3 output ports and 3 input ports. The light sensor plugs into an input port.

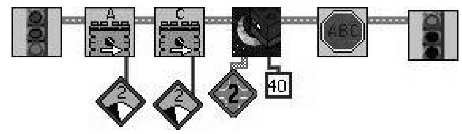


Fig. 7. A RoboLab program that tells the robot to go forward until the light sensor reads a value less than 40; then stop. "Modifiers" hang down from the main control loop, which moves horizontally across the diagram, and indicate speeds, thresholds and port connections.

time at a RoboCupJunior event in the UK in early Spring 2003. It was next used at the German Open in early April 2003 in Paderborn, Germany. Then the arena was used at the American Open, held in late April 2003 in Pittsburgh, USA. At RCJ-2003, in Padova, Italy, ten teams participated in RoboCupJunior Rescue, involving 41 students or 16% of participants. Note that 17% of the rescue participants were female, as compared to 8% females in soccer and 31% females in dance (clearly the best at attracting female students).

V. Arena for Advancing Technical Literacy.

In order to solve the RoboCupJunior Rescue task well, the basic concepts that comprise *technical literacy* must be well understood. The notion of technical literacy involves more than knowing about specific computer tools or equipment; it is about understanding a wide range of concepts which underpin modern Computer Science and Engineering, for example feedback loops, finite state machines, Markov models, search heuristics, knowledge representation, reasoning under uncertainty and planning [15].

We have been using *educational robotics* to teach various subjects for the past several years — from undergraduate courses in artificial intelligence and graduate courses in multi agent systems [16] to middle and high school lessons in basic physics [17]. As part of these curricula, we have set challenges based on the RoboCupJunior Rescue task described here, with great success not only in terms of the types of creative solutions devised by students but also in terms of the increased motivation and excitement exhibited by the students for otherwise potentially tedious subject-matter.

We have typically used the LEGO Mindstorms robot. This can be programmed using a number of different languages. For young students, a graphical language is easiest to learn. RoboLab [18] combines the National Instruments' LabView approach with RCX code (developed by LEGO) to create a flexible and understandable way to program the Mindstorms kits. A sample is shown in figure 7. For university students, a more traditional programming language may be more appropriate. Alternatives, based on C, C++ and Java, respectively, include: Not-Quite C [19], BrickOS[3] and Lejos[4].

No matter what programming language is used, students must have a good grasp of a number of Computer Science and Engineering concepts in order to solve the Rescue task effectively. For example:

- Students learn about the importance of *feedback* and how to program their robot to respond intelligently to the sensor values it reads. They are shown the example of a thermostat-controlled heating system, where responding immediately to every change in temperature can cause a furnace to get stuck in a mode of turning itself on and off repeatedly [19].
- A *finite state machine* provides a simple and general language for describing a process in which discrete transitions take place as a result of actions performed. Students learn to use robot sensors to determine the current state and to enumerate possible subsequent states and responses to each state. They learn how to model a process as a sequence of states, linked by actions.
- A *Markov model* is used to describe situations where more than one transition could occur in a given state and probabilities are attached to each possible change. Students analyze the Rescue task, describing possible solutions as sequences of steps and attaching likelihoods to each step or sequence.
- Methodologies from AI provide solid algorithms for conducting any kind of *search*. In the Rescue arena, robots are supposed to follow the black line, but if they lose the line, they are typically given a short amount of time to recover. This gives students an opportunity to implement a direct application of search by programming their robot to find the lost line using various heuristics.
- The RCX is a robust microprocessor, but it has a limited amount of memory (32K in RCX version 2.0) and it only allows 16-bit integer arithmetic. Techniques from the area of *knowledge representation* become necessary in order to program a sophisticated robot given these types of hardware constraints.
- *Reasoning under uncertainty* involves designing networks of probabilities, attempting to model the known elements in an environment and identify the unknown elements, drawing conclusions which may be modified as more information becomes available. Programming a robot to locate victims in rooms with varying lighting conditions is one application of these concepts.
- Looking ahead and deciding what to do next, reasoning in an uncertain and dynamic world, modeling the environment, making decisions — all of these factor into *planning*. The notions of establishing contingencies, determining heuristics to choose between plans and evaluating a plan after it executes can be applied widely.

[3]http://brickos.sourceforge.net
[4]http://lejos.sourceforge.net

We have illustrated through examples that the concepts of technical literacy are extremely powerful for helping to accomplish the RoboCupJunior Rescue task. It should also be seen that knowledge and understanding of these concepts indicate a level of technical sophistication that will help humans to interact effectively with any kind of technology.

This statement is not an empty claim. Since 2000, we have been attempting to examine and evaluate the educational value of kids' interactions with robotics and with the RoboCupJunior initiative in particular [10][11]. We have conducted video interviews and paper surveys at many RCJ events. In each case, we asked students questions about how they felt their skills and interests in various areas changed through their involvement in RCJ. Every year, the sample size has increased and the trends remain the same.

For example, statistics for 2002 are shown in figure 8. Students were asked to rate, on a 5-point scale, their change in interest and ability as they relate to different skill areas. For example, given the statement "My interest in mathematics increased as a result of working on the RoboCupJunior team", they selected one of the following responses: "Yes very much", "Somewhat", "Not much", "No", "I don't know". We asked 3-5 such questions on each topic area; the questions can be divided into two groups: inquiries about ability and inquiries about interest. Results shown are averages for ability-based questions within each area. Over 60% of respondents indicated that their abilities in programming, mechanical engineering and electronics increased by participating in RCJ. Most of the students felt that their skills directly related to technical literacy improved as a result of their participation in RCJ.

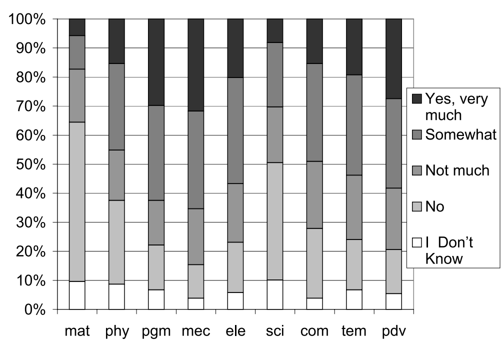


Fig. 8. Statistics from RCJ-2002, Fukuoka, Japan. Data was collected from 104 students (57% of participants). Key: math (mat), physics (phy), computer programming (pgm), mechanical engineering (mec), electronics (ele), general science (sci), communication (com), teamwork (tem) and personal development (pdv).

VI. Summary.

We have detailed the background, history, development and current state of the RoboCupJunior Rescue challenge. We have positioned this event as a means to promote technical literacy, an area which has a direct impact on issues in human-computer and human-robot interaction. The more educated, experienced, technically sophisticated user will have an easier time interacting with technology — robots — than users without such experiences.

Our hope is that not only will RoboCupJunior Rescue help to attract a broader range of students than just the soccer and dance challenge alone, but also will serve to teach young students about this socially significant application for robotics.

The fifth annual international RoboCupJunior event will be held in Lisbon, Portugal in early July 2004. For further information about RCJ Rescue as well as the soccer and dance challenges, refer to: `http://www.robocupjunior.org`

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