The Humanoid Leagues in Robot Soccer Competitions

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Abstract

This paper describes two major humanoid robotic competitions: the RoboCup Humanoid League and the FIRA HuroCup, which were both introduced in 2002. Even though both competitions have the final goal of creating a team of robots that can compete with humans in a soccer math, the two associations focused on different intermediate goals. RoboCup focused on interesting soccer matches between teams of robots as soon as possible, whereas HuroCup emphasizes versatility and robustness through a series of 8 events for a single robot.

Figure 1: Posters of both RoboCup and FIRA world championships in 2002.

1 Introduction

Initially suggested by Alan Mackworth in 1992 [Mackworth, 1993], robotic soccer is the one of the most popular challenge problems for intelligent robotics. Researchers in both Korea and Japan took up the call to use robotic soccer as a challenge problem for AI, which resulted in two associations: the FIRA (Federation of International Robot-soccer Associations) founded in 1996 and the RoboCup founded in 1997, [FIRA and RoboCup, 2009]. The rules and leagues for both competitions evolved into two distinct directions. By today each association focuses on slightly different challenges. Thus, each one may be suitable for different research groups. The aim of this paper is to introduce and compare both competitions to potential participants, the different philosophies, show their history, the present differences and finally maybe help those potential participants to conclude which type of competition suits their interest best.

When RoboCup and FIRA started the computer deep blue had just beaten the best human chess player, many researchers had previously realized that computer chess and other games constitute a very limited domain when compared to real world robotics applications. For example, in chess, a single agent moves selects discrete and deterministic actions (i.e., legal actions in chess and a legal move will always result in the same successor state) to move the system through a set of fully specified states (i.e., the position of pieces of the chess board) to achieve a single fully specified goal (i.e., putting the opponent into check mate). This contrasts significantly to real-world robotics applications and robotic soccer, where multiple agents must generate continuous actions, that may fail for some unknown reason. Only partial information about the system is known, since the sensors of the robot can only measure certain aspects of the environment. Furthermore, the robot must choose between several soft goals, such as getting into a good shooting position or blocking an opponent.

Kitano [Kitano *et al.*, 1997a; 1997b] boldly announced that the goal of RoboCup is to beat the human soccer world champion by 2050 with a team of humanoid robots.

Initially, the RoboCup and FIRA competitions did not include leagues of humanoid robots. The approaching establishment of the Humanoid League (HL) had been announced for the RoboCup already in 1998 [Kitano and Asada, 1998]. Still the league was not started until 2002, when the RoboCup was organized in Fukuoka, Japan. A month earlier, FIRA hosted the first humanoid robot competition. The reason was obviously that the walking in biped robots was and to some extend still is a technical challenge. In our current contribution we briefly outline the history of the humanoid soccer competitions in both associations. Further we give an overview of the current rules and challenges in all competitions. We then describe the typical current hardware design of robots. Finally it is discussed which competitions are most suitable for which research interest.

The remainder of the paper is organized as follows: Section 2 describes the history of the humanoid league at RoboCup, two related leagues of RoboCup are described in section 3. The FIRA HuroCup event is described in section 4. The paper concludes with section 5.

2 History of the humanoid robot leagues at RoboCup

Here we give a brief overview. For a detailed description we refer to earlier publications [Mayer and Asada, 2008].

During the first three RoboCups events that included a humanoid robot event (2002 Fukuoka, 2003 Padova, 2004 Lisboa), a broad range (from ca. 240cm to 11cm [Baltes *et al.*, 2003]) of robot sizes were brought to the competitions. Still the number of participants was small (around a dozen teams). The number of trophies was around the same number which caused considerable complaints from other leagues. 2004 the robot of Team Osaka (for a later team description see [Matsumura *et al.*, 2007]) showed a design that soon set a new standard (see Sect. 1) and proved that it would soon be possible to play regular soccer games with humanoid robots.

For the RoboCup competitions 2005 many changes were introduced into the competition specializing the technical constraints (compare the rules of 2004 [Zhou, 2004] to the current rules). For example, the height of the robot was clearly defined to exclude antennas etc.) Initially introduced performance factors were abandoned, and external processing as well as remote control, which was allowed in RoboCup until 2003, were banned from the competition. Thus, processing of sensory information, behavior processing, etc. has to be completely self-contained within the platform. A maximum ratio between foot size and height of the center of mass had been introduced in order to encourage dynamic walking. The number of size classes was reduced from 3 to 2, of which the smaller class was called Kidsize class($<$ 60cm) and the TeenSize class for larger robots. The total number of competitions remained the same, however, the free style competition was replaced by the regular 2 on 2 games in the KidSize class. In the TeenSize class the conductance of 1-1 games was discussed, but could not be carried out. One aim of the technical committee was and still is to lead the development towards current research problems. Dynamic walking and stability have been the most important issues then and still are up to now. One of the technical challenges in fact was a rough terrain challenge, which was included in the 2005 and 2006 events.

The rules had been further refined for the competitions in 2006 and 2007 in many aspects, in particular with respect to the conductance of the 2 on 2 games. Also the footrace competition was introduced to the TeenSize class in order to have an equal number of competitions in the Teen- and KidSize classes. The rules of 2005 and 2006, and the example of relatively cheap and powerful robots gave a new perspective to many interested members of the RoboCup community and also students, researchers and others from outside who were interested in setting up a team. In 2005 a total of 20 teams from 9 nations and regions participated. This was about twice the number of the year 2004. For the first time a qualification process had to be introduced. Several teams had some background from other leagues and took the advantage to customize their software rather successfully for the new league. Team Osaka received the Best Humanoid Award from 2004 - 2008. At RoboCup 2007 in Atlanta a total of 29 teams participated, of which 22 were from the KidSize class and 7 from the TeenSize class. The technical level of the participating teams increased significantly. Further increases have been seen in 2008. Since by the organizers each league is restricted to 24 participants, the increase in numbers has happened in the TeenSize recently, where about 16 teams qualified for the RoboCup in 2009.

In the first years quite a variety of different types of humanoid robots participated. Fig. 3, upper half, shows the histograms over the heights of the participating robots in 2002 – the first year of the Humanoid League, and 2005 – which was the first year of the 2 on 2 competitions. In each graph, the plotted Gaussian distribution shows the same mean and variance as the data-set of the respective histogram. In the top pair of graphs one can see the histogram of heights of *all* robots that participated in 2002 and 2005. Robots of the year 2005 showed a significantly smaller variance in size than the robots that participated in the first year of the Humanoid League[1].

Using only this one parameter one can clearly see a developmental and convergent process towards robots of sizes between 40-60 cm. More and more robots participating in the RoboCup Humanoid League are exclusively manufactured for this event. The convergence is partly caused by the rules in the KidSize class that allow a maximum height exactly at the size of 60 cm, but mainly it is due to constraints that come with considerations of the mechanical design and costs: Taller robots face the problem to handle a high center of mass during walking. Shorter robots have to deal with the fact that there is not much space for the actuators and the electronics. The convergence process happens mainly in the KidSize class, where the typical design concept of the robots' hardware consists of the features outlined in Table 1.

3 Competitions of humanoid robots in other RoboCup leagues

Currently, in addition to the KidSize and the TeenSize competition two additional competitions have been started that include humanoid robots which should be mentioned briefly.

The first is the Standard Platform League (SPL, further information is available from the SPL webpage [SPL, 2009]). In this league the teams buy the same hardware and completely concentrate on the design of the behaviors. The SPL evolved from the former 4-legged league which previously used the Sony Aibo dogs. The SPL uses the Aldebaran NAO (see Fig. 4) robot as their common platform. This robot is a humanoid with 22 degree of freedom.

One further step is the 3D Soccer Simulation League (3DSocSim). There a common simulation server is used that has been provided by the organizers of this league [SimSpark, 2009]. One of the first leagues of RoboCup was the two-dimensional soccer simulation league. The actual hardware

[1]Only those robots were counted that showed movement at all during the competition.

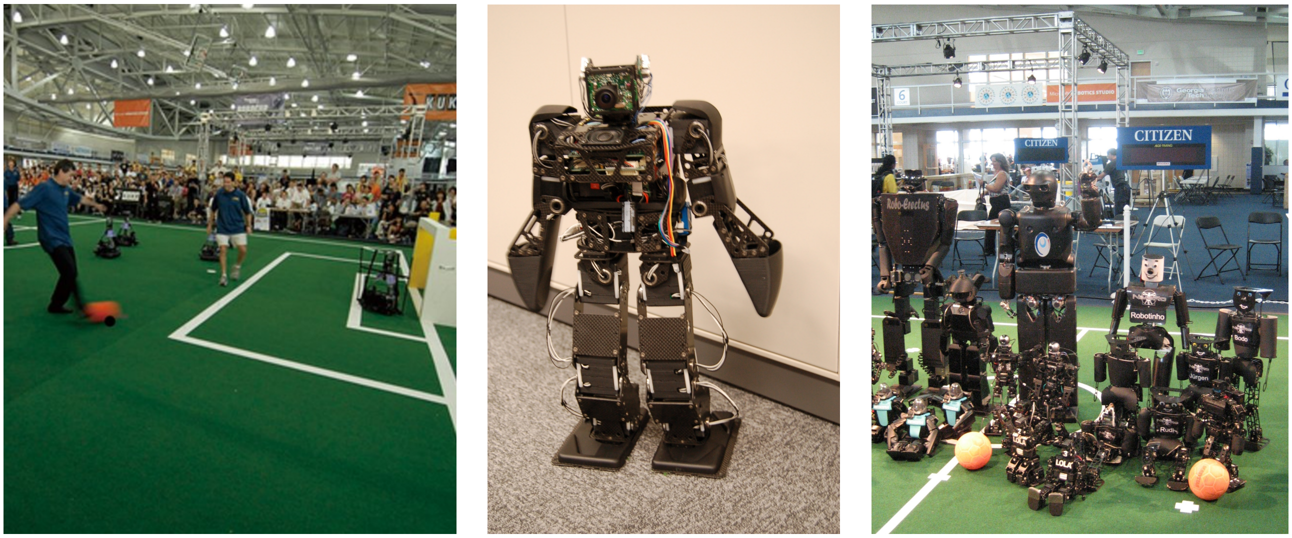

Figure 2: Left: The first game human versus robot in Atlanta 2007 (still instead of humanoid robots wheeled RoboCup Middle Size robots are used. Middle: Typical RoboCup KidSize Robot (VStone Vision Tryze without plastic cover). Right: Participating robots at the RoboCup.

- High performance servo motors like the Robotis RX-64. In particular many teams switched to digital intelligent servos that can be linked together in a daisy chain which greatly simplifies the cabling of a humanoid robot, with its 15-25 degrees of freedom (DOF). The power to weight ratio of these servo motors seems optimal for the current heights.
- Small reliable mini PCs (e.g. handheld computers, industry one board mini PCs, like PINON PNM SG3F): In order to process the vision stream of about 15 frames per second at a resolution of 640x480 a 600-800 MHz processor is sufficient. One team even uses mobile phones for their high level control.
- Micro-controller: these are necessary for real time control of the servos.
- Sensors: camera (often webcams or advanced connected via USB) and attitude sensors (gyro, acceleration sensors). Except for the feedback from the joint angles most robots usually do not use additional sensors. In fact, the rules restrict their usage to ̈human-like ̈sensors.
- Wireless network (IEEE 802.11): permitted to be used for communication between the robots and in order to send start and stop signals to the robots. However, wireless networks are not reliable during RoboCup. A fall back solution is highly recommended. The rules state that the robot has to be able to perform even if the wireless network is not working.

Table 1: Present common design features of both RoboCup KidSize and FIRA HuroCup

of the simulated robots, the actuators and also the perception are simulated on a relatively high level of abstraction as opposed to the robots in the current hardware leagues. The motivation for the high level of abstraction was the desire to create a league where participants can concentrate mainly on coordination and cooperation of robot teams. The rationale was that in the (quite far) future, many "lower level" problems of the hardware leagues would be solved, leaving cooperation among agents in a team as main challenge. In fact, two-dimensional soccer simulation league helped to address many different open problems of creating cooperative multi-agent systems.

Because some participants got tired of the simplified model of 2D simulation league, a three-dimensional physical simulation was created. The three-dimensional physical simulator used in Soccer Simulation League addresses additional classes of problems:

- Articulated agents create the problem of coordinating several actions of the same agent among each other, as well as with global team behavior.
- Decision making procedures have to deal with a much higher complexity of the decision space, compared to 2D Soccer Simulation League.

The 3D Soccer Simulation League evolved from rather simple beginnings to a simulation of realistic physical simulation of the Nao robot (see Fig. 4).

Currently, the development in 3DSocSim League leads towards realistic humanoid robots, which already can be controlled by a lower level interface. However, controllers for these robots have to be developed in order to provide an easy-to-use interface.

As a result, humanoid and simulation league have more common qualities. This way, a closer relationship between Soccer Simulation League and Humanoid League becomes

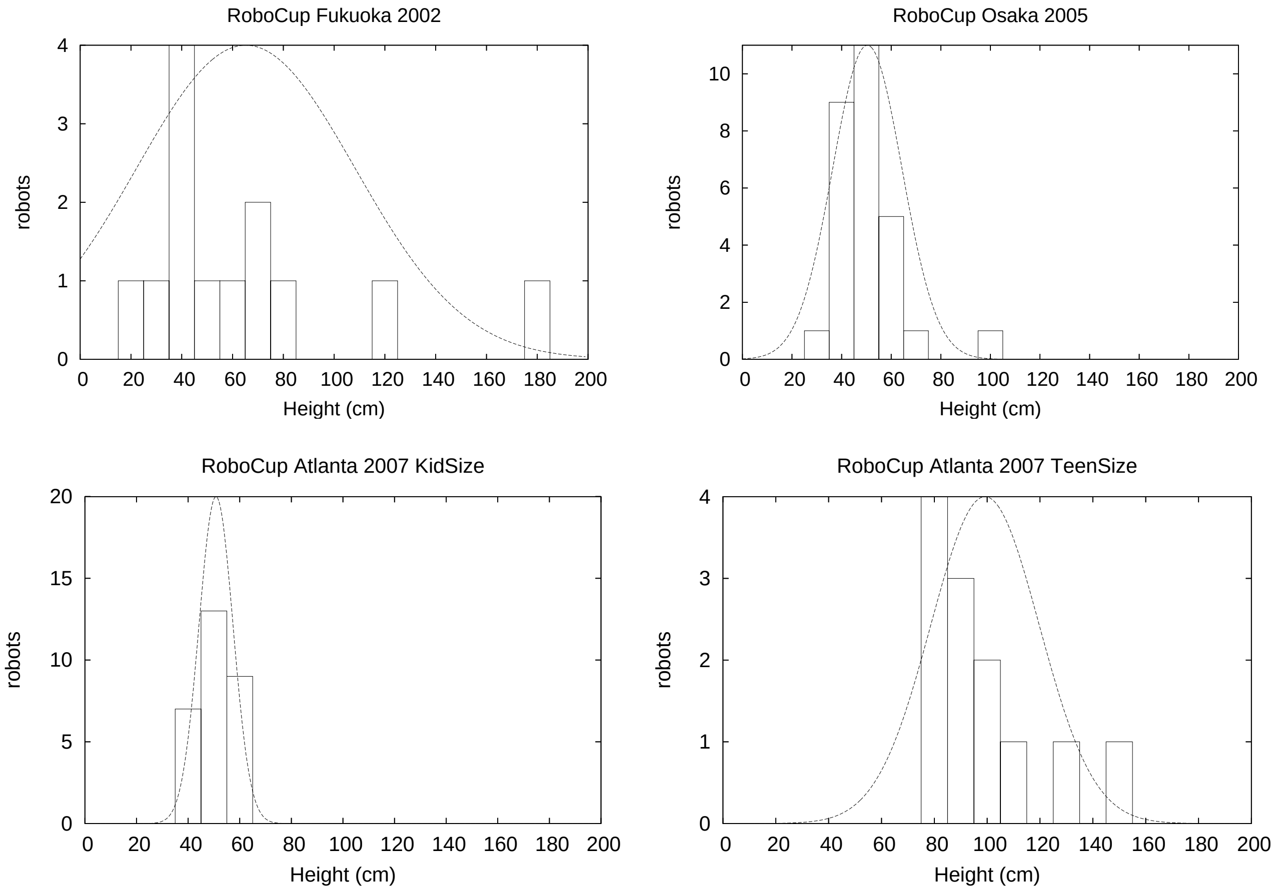

Figure 3:
Histograms of the heights of robots that participated at several HL competitions between 2002 and 2007 taken from [Mayer and Asada, 2008]. The upper line shows histograms of the heights of robots in the competitions in the year 2002 and 2005. The lower line shows the histograms of 2007 KidSize class ($< 60cm$) and TeenSize class ($> 80cm$) separately. Please note that some teams participated with several robot types. Thus, the number of teams differs from the number of participating robots.

possible, which promotes a faster progress in both leagues. For this purpose the 3D2Real project had been proposed [Mayer *et al.*, 2006]. The goal that had been envisioned was to have the finals of the simulation league using real robots.

4 HuroCup: Improving robustness through breadth

One of the dangers of focusing too much on a specific competition as a research benchmark is that teams develop narrow special purpose solutions such as extremely powerful golf ball launching devices.

The FIRA association has always emphasized the fact that robotic competitions must be seen as research benchmarks [Baltes, 2000], since no real world applications for humanoid robots are still extremely limited.

To deal with the problem of narrow special-purpose solutions that may beat flexible, robust approaches the FIRA organizers decided to emphasize the latter qualities by continuously broadening and updating the challenges involved

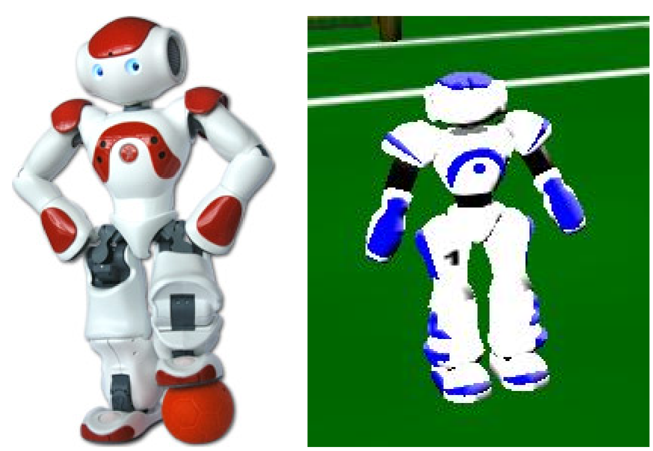

Figure 4: Real and simulated Nao robot for the RoboCup SPL and 3DSocSim Leagues.

while still keeping them manageable for a competition setting. The challenges involved in this go beyond just developing the events that stress versatility, adaptability, and flexibility: organizers must ensure that the rules preclude any easy ways to get around these qualities and must also ensure that teams understand the spirit of these rules.

As an example of what we feel is the way a competition must be designed to be effective evaluators for AI systems by promoting robustness and adaptability, this section describes the development of the current FIRA HuroCup competition for evaluating humanoid robots.

The FIRA HuroCup is the oldest intelligent humanoid robot competition, with the inaugural competition taking place in June 2002 with five teams. Since the HuroCup event is organized as part of the Federation of International Robosoccer Association, the initial plan was to develop a soccer competition for humanoid robots.

However, it became quickly apparent that soccer did not provide a good benchmark problem for humanoid robots at the moment. Since soccer was played on a flat surface, many teams quickly developed efficient walking gaits and kicks for this surface. The main challenge then was to develop localization (where is the soccer player on the playing field) and mapping (where are the other players and the ball) methods for the players. However, localization and mapping are not specific problems for humanoid robots and research in these areas can be done without much change with wheeled or other walking robots.

However, as shown below, there are many fundamental research problems for humanoid robots that are still open problems. Therefore, the HuroCup committee decided to focus on the open research problems that are more specifically associated with humanoid robots. The main open research problems in humanoid robotics fall into several areas:

Active Balancing humanoid robots must be able to walk over various even and uneven surfaces. They also must be able to adapt their walk to changes in the weight and balance of the robot (Lift and Carry, Weight Lifting),

Complex Motion Planning humanoid robots can perform many different actions. The sheer number of these movements mean that they can not all be preprogrammed. Instead a humanoid robot must be able to plan new motions on-line (e.g., a new motion to lean over a barrier to operate a light switch or to pick up a box from under a table),

Human-Robot Interaction a humanoid robot must be able to interact naturally with a human which entails that it is able to understand speech, facial expressions, signs, and gestures as well as generate speech, facial expressions, and gestures.

Because one of the advantages of the humanoid form is its robustness and applicability to a wide variety of problems, some of these areas are naturally associated with robustness and breadth (e.g. walking vs. walking on uneven terrain vs. walking while carrying a load). Since this is a competition evaluating research, the researchers involved have a vested interest in leveraging this wide applicability, in their own research and to the public. Self interest along with many of the peripheral motivations of robotics competitions can thus also be used as an advantage in encouraging breadth and robustness.

In deciding on challenge events, the members of the HuroCup committee looked for those that would specifically advance research in these areas, as well as considering what would most encourage robust solutions and work well in a public challenge environment. To avoid exploiting rules in one large challenge environment attempting to encompass all humanoid skills, the committee instead focussed on dividing the FIRA HuroCup into a series of events that test a subset of interacting humanoid skills. Scores in the individual challenges are summed, so that in order to do well in the HuroCup, a single robot must perform and score well in a range of events. Thus, any special hardware development that focuses on doing well in one type of activity becomes redundant in others that do not require that specialization. Such additions can also be severely detrimental in two ways. First, in the limited time available in and around a competition, additional hardware and control that serves no purpose in some events draws support and resources away from the limited pool available to a team as a whole. More directly, the addition of such equipment may be directly detrimental to the performance of other events (e.g. arm modifications requiring adaptive balance adjustments that make some fine body movements more difficult).

All HuroCup events require a fully autonomous robot that has all sensing and processing on board. No interaction from a human is allowed. HuroCup 2009 consists of the following eight events, some of which are depicted in Figs. 5 and 6:

Sprint the humanoid robot must walk a distance of 3.0m in a straight line forwards and then backwards. This means that a robot must possess at least two fast walking gaits. This event is really intended as a starter event which allows beginning teams to score some points. The other HuroCup events are difficult and many teams do not manage to score any points in those.

Obstacle Run the humanoid robot must cross a 3.0m long region to reach the end zone without touching any of the obstacles. There are three types of obstacles: walls, holes, and gates. A robot must not step into a hole, but can crawl through a gate to reach the end zone.

Penalty Kick a humanoid robot tries to score against several goal keepers. This event is to include soccer related activities in HuroCup and is also considered relatively easy by most teams. In contrast to human soccer, the ball is placed randomly in an area in front of the robot.

Lift and Carry Lift and Carry was introduced in 2004. A robot must carry an increasing number of weights over an uneven stepping field. The stepping field is colour coded so that the robot can recognize steps. This is an advanced challenge and many teams have problems with it (See Fig 7).

Weight Lifting The weight lifting competition was introduced to provide a slightly simpler active balancing challenge than Lift and Carry. A robot must lift as many CDs as possible. However, since we did not want to test

Figure 5: The obstacle run (left) and marathon at HuroCup (from the HuroCups 2007 and 2008).

the shoulder motor strength, the robot must walk 30cm with the weight low and then 30cm with the weight above its head. This means the centre of mass of the robot changes drastically, but predictably and the robot needs to compensate.

Basketball A humanoid robot must pick up a table tennis ball randomly placed in front of the robot and throw it into a basket.

Marathon A humanoid robot must cover a distance of 42.195m as fast as possible without being allowed to change its batteries. The event was the first HuroCup event that took place out-doors, which means that teams must cope with more uneven surfaces and lighting conditions.

Climbing Wall a humanoid robot must climb up a wall where foot and hand holds were placed randomly. This is a new event in 2009.

The combination of events were chosen precisely because the subset of humanoid motions they rely on represent most of the range of activity expected of a humanoid. To do well in a dash, for example, a robot must have a fast start, but need not have fine control once it is moving. On the other hand, completing the marathon (Fig 5) requires following a lined track over a long period of time.

The events are constantly updated to reflect the current state of the art. In 2009, for example, the climbing wall event was added, but major changes to other events were also introduced. The robot must pick up the weight lifting bar whereas in 2008, it could start with the bar in hand. The distances for the sprint and obstacle run were increased from 1.2m to 3.0m. The stepping obstacle was replaced by an hole obstacle in the obstacle run. The marathon will now performed outdoors. The maximum size of the robot was increased to allow more space for the extra sensors needed to perform these tasks and infra-red sensors are not allowed any more.

The various challenges of HuroCup are extremely difficult and there have been no affordable large sized robots that were able to perform all of these tasks until recently. In 2009, we expect the first teen sized humanoid robots to take part in the HuroCup competition.

5 Discussion

Even though the RoboCup and FIRA competitions have similar long term goals, the different philosophies have led to vastly different competitions.

The robot soccer competitions in both associations serve different communities as benchmark for potential solutions of various research problems.

The RoboCup KidSize League requires each team to supply their own robot hardware and software. This is interesting for those research groups who are interested to work out the hardware and at the same time have the capacity to develop their own software environment. The rules of the KidSize league are relatively stable which makes it easier to plan a participation over years. For the media this league is the most attractive league of all robot soccer competitions. The games in the finals are already pretty advanced.

HuroCup strongly emphasizes robustness and versatility through a series of events that direct research in active balancing, complex motion planning, and human robot interaction. The competition still focuses on challenges for a single robot, which reduces the cost for teams, since only one instead of three or five robots are needed.

The TeenSize league has been used by various research groups with tall robots as a benchmark for their devices. Thus, the focus here is more on specific problems of these

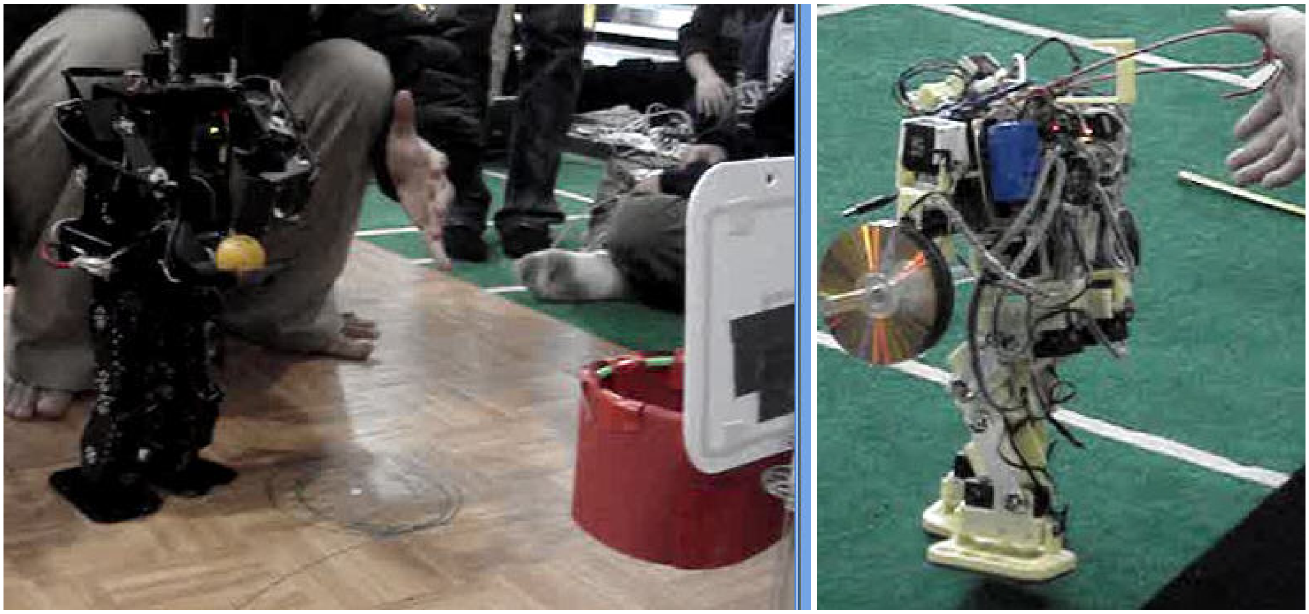

Figure 6: Basketball (left) , and weightlifting (right) competition.

robots. In recent years, the teen sized robots have had great improvements. For example, in 2008, the teen sized robot was able to fall down and stand up on its own for the first time.

The main appeal of the SPL league is that all teams use the same hardware. In fact, any modification to the hardware is disallowed. This makes this competition especially suitable for researchers interested only in software development, yet still use real robots in their research.

One of the problems of making Soccer Simulation League closer to humanoid robotics is that solely researching high level coordination and cooperation becomes intractable, when lower level controllers have also to be implemented by everybody. One of the advantages of the 2D simulator however was the possibility to research cooperation in a team quite easily. In order to keep the advantages of the 2D simulator while adding new possibilities for the additional research problems listed above, two different levels of interfaces should be provided for users of a Simulation League Simulator: one high-level interface granting the possibility of researching high-level coordination only. This way, existing approaches can be transferred to the domain of robotic soccer easily. The lower level interface has to provide full control over all features of the simulated robots, so that developers can research and take care of dependencies between lower-level and higher level control.

There are also some organizational differences between RoboCup and FIRA, which clearly can be seen from the images above. RoboCup emphasizes a good public image and therefore provides great looking facilities and playing fields, many of which are destroyed after the event. This makes RoboCup a very expensive event, which results in high registration fees. One analogy one could make is that RoboCup is like the Oscars (very high production value), whereas FIRA is like the Sundance film festival (much lower production value, but still some very interesting movies).

In contrast, the organizers of the HuroCup event had to organize the competition with very little financial support. In fact, the playing fields deliberately use cheap commonly available household items such as binders, batteries, and CDs. This has the great advantage that the cost of the event is cheap. Registration fees for FIRA are usually 1/3-1/2 of the RoboCup fees.

In summary, all events provide an interesting challenge for researchers and a wonderful learning opportunity for students. We hope that this papers gives a background into the different associations, their philosophies and focus, and their future directions, which will allow researchers to select a suitable competition to match their research goals and expectations.

Acknowledgments

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Figure 7: Lift and Carry (left) , and Climbing Wall (right) competition.

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