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RoboCup Humanoid League Rule Developments 2002–2014 and Future Perspectives

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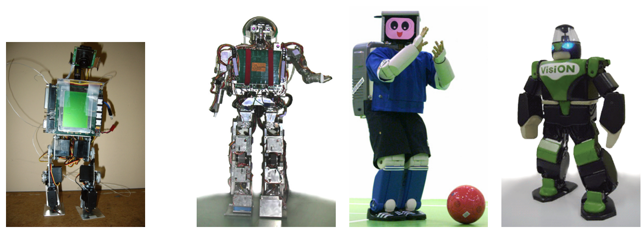
Abstract. This paper describes the major achievements in the history of the RoboCup Humanoid League from its start in 2002 to 2014. We provide a perspective for the future of the league with a strong push towards larger robots and FIFA-like playing fields. We also discuss some risks associated with these intended changes.

1 Introduction

RoboCup is an international initiative to promote science and technology through the organization of robot competitions and scientific meetings. The stated ultimate goal of RoboCup is: "By the middle of the 21st century, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official rules of FIFA, against the winner of the most recent World Cup." [1] Hence, many of the competitions focus on soccer as a challenge problem for artificial intelligence and robotics. However, RoboCup also includes competitions for domestic service robots, rescue robots, and industry-inspired mobile manipulators.

This paper describes the history and future perspective of the RoboCup Humanoid League. The history of the RoboCup Humanoid League can be broken up into several periods. The early years, where simple walking and kicking were formidable challenges, are introduced in Section 2. As described in Sec. 3, rapid improvements in mechanics, electronics, and perception and control algorithms resulted in much more capable human-like robots that were able to play soccer games, starting in 2005 for KidSize and 2010 for TeenSize robots. The third period of humanoid robot development, discussed in Sec. 4 resulted in robots playing as a team, where winning and loosing was more determined by the perception of the game situation, localization on the field, and team coordination than by individual robot skills. Section 5 describes how commercially available platforms provided teams with an opportunity to speed up their development and the impact of those commercial platforms on the competition. Section 6 gives an introduction to the major changes for the RoboCup 2014 competition in João Pessoa, Brazil. The future evolution of the RoboCup Humanoid League is characterized by a strong push towards larger robots, bigger teams, and more FIFA-like soccer rules and environments as shown in Sec. 7. Some concerns and issues with the current road map are discussed in Sec. 8. Sec. 9 describes the publications and workshops provided by the league. The paper draws conclusions in Sec. 10.

2 The Early Years (2002–2004)



Tao-Pie-Pie (2nd 2002/3) Nagara (1st 2002) HITS (1st 2003) VisiON (1st 2004)

Fig. 1. Early RoboCup Humanoid League Competitors

The Humanoid League is one of the youngest soccer playing leagues in the RoboCup competition. Its inaugural event took place at RoboCup 2002 in Fukuoka, Japan.

Building a fully autonomous humanoid robot that is able to play soccer games is still a challenging problem today, but it was clearly a blue sky—extremely ambitious with a high chance of failure—project in 2002.

At that time, some impressive humanoid robots developed by the Japanese industry like Honda Asimo and Sony Qrio existed. However, these robots were not available to the Humanoid League teams, but only showed demonstrations in controlled environments. Even if they would have been available for purchase, their price tag would have been prohibitive. One of the authors remembers that in 2003, a representative from Sony introduced the Sony Qrio - the successor to the widely successful Sony Aibo robot. In his speech, he was asked about the cost of the Qrio and stated that the cost would be about that of a car. Many researches were extremely excited, since the cost seemed very reasonable for such an advanced platform. When many members of the audience said that they would like to order one immediately, the Sony representative corrected himself by saying: "No. You don't understand. I mean a Ferrari".

In spite of the very ambitious goal, a hodge-podge of about a dozen teams entered the inaugural RoboCup Humanoid League competition in 2002 in Fukuoka, Japan (see Fig. 1. The robot designs varied from 20 cm to 180 cm tall robots.

There were also many other differences between the robot designs. Another platform that was commercially available during that time was the Fuji HOAP series of robots. Their cost was about $150,000 USD, but they were not able to act fully autonomously because they did not have sufficient processing power available onboard. So all vision processing etc. had to be done off-board on a PC. Another difference was that several other teams were unable to move autonomously under battery power and had to be powered externally. Some teams were even completely unable to act autonomously and used remote control to move the robot towards the ball.

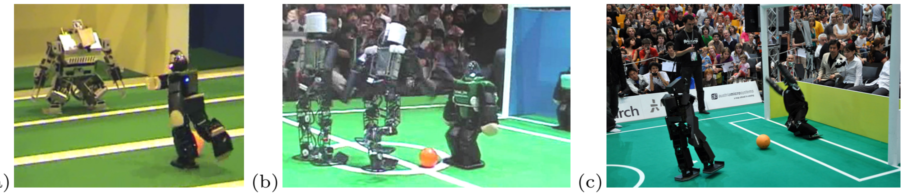
Due to these constraints, the first RoboCup Humanoid League competition consisted of three events: balancing on one leg, free style demonstration (a panel of judges graded a short free style demonstration by the team), and penalty kicks. To allow these robots with very different capabilities to compete in the same event, the RoboCup Humanoid League Technical Committee (TC) introduced performance factors in order to level the playing field. For example, the performance factor for remote controlled operation was 100%, so a goal scored with remote controlled robot counted 50% of a goal scored by a fully autonomous robot.

Apart from team Joitech that used the Fujitsu HOAP, all competitors developed their own hardware for the RoboCup Humanoid League and similar competitions (e.g., Japan Robo-One fighting robots). Since the Humanoid League TC realized that building your own robot was a significant challenge at that time and since it wanted to encourage teams to explore design ideas and build their own robots, commercial platforms were also penalized by a 20% performance factor.

The RoboCup Humanoid League TC was acutely aware of the fact that building larger humanoid robots was even harder than building smaller humanoid robots, but that to achieve the goal of 2050 large humanoid robots are of strategical importance. Therefore, the RoboCup Humanoid League TC separated the league into three size classes: small ($<$60 cm), medium (60 cm to 80 cm) and large ($>$80cm) robots.

The constraints of these early years influenced rule development in successive years and still influence the culture of the Humanoid League.

The performance of the Humanoid League robots developed quickly. By 2004, all robots acted fully autonomously and all processing was handled on-board. Therefore, the need for the performance factors vanished and they were removed from the rule book. The rules evolved to provide fair and entertaining competitions that could still act as benchmark problems for our research into developing capable fully autonomous soccer robots. The main tournament was now played as penalty shoot out. Standing on one leg was replaced by a Humanoid Walk competition, where robots had to footrace around a pole. Each year, a new technical challenge was introduced, in order to encourage development of new skills that were not yet applicable in the main tournament, In 2004, the technical challenges consisted of an obstacle walk, a passing task, and balancing across a sloped ramp.



(a) (b) (c)

Fig. 2. Some Humanoid League Finals: (a) 2004 Penalty Kick: Team Osaka vs. Robo-Erectus; (b) 2005 2 vs. 2 Soccer: NimbRo vs. Team Osaka; (c) 2009 TeenSize Penalty Kick: CIT-Brains vs. NimbRo.

The results of the individual competitions are aggregated into a Best Humanoid ranking. Since robots from the different size classes cannot be compared directly, the overall Best Humanoid Award, the Louis Vuitton Cup, is determined by voting of the team leaders, based on robustness, walking ability, ball handling, and soccer skills.

3 From Penalty Kicks to Soccer Games (2005–2010)

As teams improved the robustness and walking ability of their robots, it became possible to start 2 vs. 2 soccer matches for the small size class. After demonstration events during RoboCup 2003 in Padua, Italy, and RoboCup 2004 in Lisbon, Portugal, soccer matches were introduced as main KidSize (<60 cm) tournament in 2005.

The larger TeenSize robots (initially >65 cm, later the minimal size was increased to 100 cm) continued to play penalty kick, which was developed in 2007 to the Dribble and Kick competition. Dribble and Kick is played between two robots - a striker and the goal keeper. The striker robot starts in the center of the field and the ball is placed randomly on the striker's goal box. The task of the striker is to move back to approach the ball, dribble the ball across the center line and then kick the ball into the opposing goal.

In order to remove subjective judgment from the competition as much as possible, quantitative measures (e.g., goals scored) were seen as much more desirable by the teams. Therefore, the free demonstration event was removed from the competition.

Team VStone from Osaka, Japan, set a new bar for all competitors with their small robot platform. The robots were able to move quickly and stably across the playing field. Furthermore, the robots used an omni-vision system in the head of the robot, which allowed the robots a 360-degree view of the playing field. The VStone robots were extremely successful in the soccer competitions and won them two times in succession ([2], Fig. 2).

During this time, many formal and informal discussions were held among the technical committee and the participants. After several years, it became apparent that most participants felt that humanoid robots should be limited to human-like kinematics and human-like sensors. As a result of these discussions, the use of omni-vision was disallowed. Furthermore, active sensors (e.g., LIDAR, ultrasound, IR distance sensors) were also forbidden. This was not a major restriction, since from the beginning, color cameras were the most dominant sensor for perceiving the environment.

During these years, the performance of the larger robots also improved significantly. Partially driven by the availability of affordable high powered servos, the performance of the smaller TeenSize robots (80 cm to 120 cm and less than 10 kg) had improved to the point where 2 vs. 2 soccer matches became possible. There was a strong push from those teams to introduce soccer games for larger robots. But the largest (>120 cm) and heaviest robots were still too fragile to survive a fall. Furthermore, since some of the robots weighed more than 40 kg, they posed a real danger to other robots or participants should they fall. As a consequence, the larger robots were split again into two size classes: The smaller TeenSize robots (100–120 cm) started to play 2 vs. 2 soccer games in 2010, while the AdultSize robots (>130 cm) continued with Dribble and Kick competitions.

The rapid improvements in the robots' capabilities also led to an increase in the complexity and diversity of the technical challenges. The technical challenges introduced during this time includes: walking over uneven terrain, dribbling the ball around multiple poles, dribbling the ball trough randomly placed obstacles, and double passing.

4 From Individual Skills to Team Play (2008–2012)

In 2008, the number of players in the KidSize soccer matches was increased from 2 to 3 players per team. Furthermore, most teams had successfully solved the problem of locomotion and were able to walk stably over flat even surfaces such as hardwood floors or carpets. For these two reasons, the localization (where is the robot?) and the perception of the game situation (where are the ball and the other players?) became more and more important. Whereas individual robot skills (fast walking and strong kicking) were key to success in previous years, now team play and coordination became more important.

This was reflected in the rules, e.g. by placement disadvantages for robots which could not autonomously walk to their kickoff positions. Two teams from Germany (Team NimbRo [3], University of Bonn, and Darmstadt Dribblers [4], TU Darmstadt) were powerhouses during that period and won the competition several times.

The next wave of major rule changes aimed at making visual perception and localization more realistic. Additional landmarks in the corners of the field and later on the side lines were removed. In 2010, extra lighting on the field was removed, which resulted in much larger variability in brightness due to the influences of environmental lighting. The size of the playing field was extended, and detection of the goals was made more difficult: First the colored goal back walls were removed, leaving only the goal posts as landmarks, and in 2013 both goals were colored yellow [5].

The technical challenges now included throw-ins and high kicks. In the soccer matches, throw-ins are replaced by the referee putting the ball back into play without stopping the match, since a throw-in is an often occurring event that is a time consuming task for a humanoid robot. The throw-in challenge encouraged teams to use throw-ins by the goalie in actual games. The high-kick challenge also encourages the use of the third dimension in the games.

5 The DARwIn and NimbRo-OP Platforms (2012–now)

Fig. 3. Darwin-OP (left) and igus Humanoid Open Platform (right)

From its start in 2002, the number of participating teams had increased drastically over the years. So the number of participating teams in the KidSize class had to be limited to 24 and qualification for the RoboCup competition had become competitive. For qualification, teams had to submit a team description paper (TDP) and a video of their robot playing soccer. In that video, the robot needed to demonstrate the ability to perceive and approach a ball, line up with the goal, and to kick the ball into the goal. It also needed to demonstrate the ability to stand up after a fall from various positions (i.e., falling forward and falling backwards).

In 2011, the Korean company Robotis introduced the DARwIn-OP robot, which they had developed in conjunction with Dennis Hong from Virginia Tech [6]. A year later, a similar collaboration between Robotis and Sven Behnke from Bonn University resulted in the development of NimbRo-OP [7], a teen sized humanoid robot, which is now further developed together with igus GmbH (Fig. 3). The introduction of these platforms had a big impact on the Humanoid League. Instead of designing and building their robots from scratch, teams could now simply purchase a robot platform that was able to walk and kick a ball and recover from a fall out of the box. So it made qualification and entry into the league much easier for new teams. E.g., the DARwIn-OP had a large impact on the kid size league. Fig. 4 shows the Humanoid League teams participating in RoboCup 2013. In 2014, 50% of the KidSize teams that submitted qualification material used the DARwIn-OP platform or based their robot on it.

Many teams that built their robots from scratch felt that it was unfair that in spite of the fact that they had spent much hard work, time, and money on building their own robots, other teams could just purchase a robot and qualify for the RoboCup competition with much less effort. Other teams felt that only the performance of the robot should be the determining factor in qualification. The RoboCup Humanoid League TC discussed the issue and decided on a compromise. The stated policy for qualification is that teams that purchase a robot had to clearly highlight what advancements and improvements they had made to the out of the box system for qualification.

Fig. 4. Teams of the Humanoid League at RoboCup 2013 in Eindhoven, NL.

6 Brazil Ole Ola (2014)

At the end of the 2013 RoboCup competition, the RoboCup Board of Trustees issued a challenge to all leagues as they felt that progress in the leagues had been limited to incremental improvements rather than radical breakthroughs.

After discussions with the team leaders, one major change in the Humanoid League was an aggressive push towards larger robots. The 2014 competition [8] introduced radical changes in the sizes of the Kid, Teen, and AdultSize classes. For example, the maximum height of the robots in the KidSize was raised by 50% to 90 cm. Furthermore, the height limits of the Kid and Teen and the Teen and AdultSize classes were chosen with some overlap on the upper and lower limits. This allows teams to more easily transition into larger size classes, since they do not need to build a completely new robot. For example, a team could build an 85 cm tall robot and compete in the KidSize class in the first year and use the same robot in the TeenSize class the next year. Figure 5 shows some of the new generation of robots planning to participate in 2014.

Consequently, the field area for KidSize was increased by 125% to $6{\times}9$ m, and the size of the goals, and the size and weight of the ball were adjusted to accommodate the larger robots. To enhance team play, the number of players for the soccer matches was increased to four players per team.

The complexities of the challenges also increased. The dribble and kick competition for AdultSize robots will introduce two obstacles (representing opposing players) that must be avoided by the striker robot.

7 The Future of the Humanoid League (2015–2050)

The RoboCup Humanoid League continues its rapid advance towards smarter and more capable robots. The goal is to move quickly towards more realistic

Fig. 5. Humanoid Soccer Robots preparing for RoboCup 2014 in Brasil.

soccer matches. There are several extremely difficult problems that need to be overcome with respect to the environment, the players, and the matches.

One future direction of the RoboCup Humanoid League is to move to more human-like playing fields and environments. For example, in 2015 the RoboCup Humanoid League TC plans to reduce the colors in the environment even further and to move towards requiring shape or texture-based segmentation. The plan is to remove the yellow goal posts and to replace them with white goal posts. Furthermore, the orange ball might be replaced by a small version of a real soccer ball, that is a ball that is mostly white or gray with some texture to it.

Also, the playing surface might be changed from a carpeted floor to astro turf and eventually a real grass playing field. This means that active balancing and uneven terrain walking will become more important for the robots. As the number and speed of the robots increases, collisions between players are more likely to occur. The RoboCup Humanoid League TC might introduce push recovery challenges to test the ability of the robots to compensate for pushes from various directions.

In addition, corner flags similar to human soccer may be introduced. These changes combined will make the playing fields in the RoboCup Humanoid League scaled down versions of the FIFA soccer playing fields.

The progress in the TeenSize class has shown that it is now possible to have soccer matches for 80 cm to 120 cm tall humanoid robots. But the ambitious goal of the RoboCup Humanoid League TC is to introduce rules that move towards robots capable of playing against human players. To this end, the minimum height of the robots might be increased in stages from the current 40 cm to 140 cm.

As the capabilities of the robots increases, the RoboCup Humanoid League will play with larger and larger robots that become more and more similar to human players in their kinematics, dynamics, and sensing.

One technical challenge that could foster the use of the third dimension would be a header challenge, where a robot would need to score by using its head.

Lastly, the rules of the game have to be adjusted to match exactly the FIFA rules for human soccer. This requires that robots must be able to act fully autonomously during all aspects of the game (including kick-offs, substitutions, and free kicks). Furthermore, the games will include throw-ins and direct and indirect free kicks. It is interesting to note that this rule progression towards more human-like soccer is not always linear. For example, free kicks were included in the rules from 2004 to 2007, but slowed down the game significantly. Therefore, all free kicks were replaced by 30 second removal penalties similar to ice hockey rather than soccer. This made games much more entertaining and made the RoboCup Humanoid League one of the most exciting leagues in RoboCup. However, as teams improve the skills and capabilities of their robots, free kicks can be re-introduced while still resulting in exciting matches.

The number of players will be increased further in the following years. We start playing with 4 vs. 4 players in 2014 and will eventually reach 11 vs. 11 players in 2050. The RoboCup Humanoid League TC realizes that few teams will be able to afford 11 players and has also started to build the necessary technical infrastructure as well as amendments to the rules to encourage joint or mixed teams.

So to encourage more team collaboration, there have been several efforts directed at creating suitable communication protocols and infrastructure that will allow players from different teams to play soccer effectively. A good example for this approach is the RoboCup Standard Platform League. In the Standard Platform League (SPL) many teams have based their software on the yearly code-release of team B-Human ([9]). This resource has a great impact on the development of the Standard Platform League, since all teams must use an unmodified NAO robot and therefore the software can be used directly by other teams. Similarily, several Humanoid League teams have released their robots' source code and hardware designs ([10]). However, the benefit of those contributions is much less immediate. Firstly, teams use often different hardware designs, so inverse kinematics, walking gaits, device drivers, low level controllers need to be adjusted. Furthermore, even higher level functionality in the software (e.g., localization, vision, and behaviour coordination) are implemented using different and often custom middle-ware. There are now several initiatives to implement soccer robot middle-ware for important modules such as vision, localization, walking engine, and communication. The Robot Operating System (ROS) is a popular candidate to simplify inter-operability by software developed by different teams.

The other issue with the robots in the RoboCup Humanoid League are their robustness and energy efficiency. The use of compliance in control and construction of the actuators and links as well as soft materials on the outer shells will be necessary for improved soccer capabilities, such as running, high-speed kicks, robustness to falls, and safe robot-robot and human-robot physical interaction [11]. To test the robustness of robots drop test may be introduced.

The energy efficiency of the robots also needs to be greatly improved. Currently the soccer games in the RoboCup Humanoid League last only 20 minutes since robots cannot operate for much longer, due to the limited capacity of the batteries, the relatively poor power to weight ratio of the servo motors. Furthermore, few of the robots are able to use the inherent dynamics of the motion (e.g., the swing leg needs to be actively driven rather than swinging freely, because of the friction in the gear box) or are able to store energy in springs or other mechanics. To encourage teams to develop more energy efficient robots, the duration of the games will be increased in the coming years to ultimately match that of human soccer matches – 90 minutes per game.

8 Risks and Issues

This paper would be incomplete if it were not to include some words of warning for the future development of the league. The initiatives described in Sec. 7 are far reaching and ambitious. As such, it is clear that they entail a certain amount of risk.

The first issue is that moving to larger robots will greatly increase the costs associated with RoboCup participation for all teams. Larger robots require much more torque and thus much more expensive motors. Furthermore, large robots cannot be brought in check-in luggage and often must be shipped as cargo.

Combined with the ever increasing registration fees of RoboCup, this may lead to teams deciding not to participate in RoboCup. For example, several of the teams that participated in the RoboCup Humanoid League for many years (e.g., Tamkung University, Damshui, Taiwan, NCKU, Tainan, Taiwan, and FUmanoids, Berlin, Germany) will not participate at RoboCup 2014 for financial reasons.

For example, the number of participants in the TeenSize and AdultSize classes remained low with four to six teams each. The low number of participants was in spite of the best efforts of the RoboCup Humanoid League and the supportive attitude of the RoboCup Federation in general to promote large humanoid robots. One possible way to make soccer with larger robots easier would be the introduction of an affordable AdultSize platform. For example, Robotis Inc. is currently developing a large humanoid robot THOR-OP.

Another problem is that the move to larger robots will make entry for new teams much harder; the current road map does not provide a path for new teams. One suggestion discussed by the RoboCup Humanoid League TC was to keep the current KidSize league, but to require the best teams to move to a larger size class after two years. Another idea is to promote mentor teams where more experienced teams form joint teams with less experienced teams and provide them with technical support. A third possible way would be to include small humanoid robot competitions in the RoboCup Junior leagues. The issue may also be mitigated in the future by the general commercial availability of better and cheaper robot platforms that are more suitable to robotic soccer.

9 Humanoid Soccer Workshops, Schools and Publications

The Humanoid League does not only foster development through the organization of competitions, but has also a strong focus on advancing research via publications, workshops, and schools.

The team descriptions required for qualification are archived together with the other qualification material and the competition rules at the Humanoid League web page [10].

Members of the league submitted many high-quality contributions to the annual RoboCup International Symposium and major robotics conferences (e.g. IROS, ICRA), some of which were honored with Best Paper Awards. There is also a large number of journal publications originating from the league and two special issues of leading journals (Robotics and Autonomous Systems and International Journal on Humanoid Robots) appeared.

In addition, members of the league contribute heavily to the organization of and the submission to the annual Humanoid Soccer Workshop, which is organized since 2006 at the IEEE-RAS International Conference on Humanoid Robots, the flagship conference for humanoid robotics research.

Finally, since 2012, member of the Humanoid league have organized week-long humanoid soccer schools (see Fig. 6). These schools provide unique opportunities for about 40 researchers and hobbyists alike to learn from some of the leading experts in the field. But in contrast to scientific conferences and workshops, the humanoid soccer schools include practical components. A lot of time is made available to students to complete exercises and/or test their own ideas on real systems. The humanoid soccer schools also include a series of social events making it easier for researchers to socialize. The hope is that this will lead to closer collaboration between the teams in the future.

All these scientific activities ensure that (a) the research developed as part of the RoboCup initiative is widely disseminated to other researchers, and (b) that researchers participating at RoboCup learn about the latest research results from other humanoid robotics researchers. This means that especially new teams do not have to start from scratch and can learn from leading teams.

Amirkabir UT., Tehran, Iran, 2014

Drachenfels, Germany, 2013

Fig. 6. Participants of the Humanoid Soccer Schools

10 Conclusions

The paper describes the history of the RoboCup Humanoid League from its humble beginnings in 2002. It describes the historical evolution of its competitions and rules to provide the reader with an insight into the culture and traditions of the RoboCup Humanoid League. This will make it easier to understand the current state as well as future plans for the development of the RoboCup Humanoid League toward the 2050 goal.

The authors would like to thank previous and existing members of the RoboCup Humanoid League community for their input during many years of rule discussions and development. In particular, we would like to thank the other members of the RoboCup Humanoid League Technical and Organizing committees (Reinhard Gerndt, Luis F. Lupian, Marcell Missura) and RoboCup trustee Oskar von Stryk.

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