Bridging the Gap - On a Humanoid Robotics Rookie League

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Abstract. The 2050 robot-human soccer game is among the most prominent goals of RoboCup. All RoboCup leagues contribute to this goal, for example the Simulation Leagues with research on strategic game play, the Standard Platform League with stable walking and vision algorithms and the Humanoid League with mechatronics of bipedal robots. However, especially in the Humanoid League, the swift improvement in performance of the robots makes it significantly harder for newcomers to enter into this field of research. With robots increasing in size, with new challenges in mechatronics for bipedal robots and software increasing in complexity, the gap for new teams is widening on the course to the 2050 game. There have been many approaches to easy entry, such as the introduction of a two-league system in the Standard Platform (SPL) and Small Size League (SSL) or an 'educational challenge' at regional @home events. While the SPL and SSL approaches require fully developed hard- and software in order to compete, as the @home challenge, we propose an entry-level league with a reduced set of requirements to bridge the gap between the Junior level and advanced Humanoid League. We believe that the Humanoid League can only reach the 2050 goal if new researchers and universities can be attracted on a regular basis. Attracting new researchers requires an easy entry path for new teams, suitable for undergraduate students and universities with a limited budget. The 'Humanoid Rookie (Sub-) League' (HRL) will give new researchers and teams the time to gather experience and funds that are necessary to successfully participate in and contribute to the Humanoid League's development towards the 2050 game. This paper intends to spark discussion about the current state and the roadmap of the Humanoid League within the RoboCup community.

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1 Introduction

When the RoboCup Humanoid League started in 2002, the competition initially consisted of technical challenges only, exercises that were considered useful elements of a soccer game play [13]. In the following years, the challenges developed into 2 vs. 2 robot soccer games. The games raised considerable attention among researchers and led to the participation of 20 teams in the 2005 RoboCup Humanoid League. At that time, the two robots per team had a size of about 40 cm, the environment was color-coded and the surface was a flat carpet. Moreover, constraints on the robot's body parameters like height of the center of mass and foot size were very favorable for new teams to enter. The current rules allow 4 robots with a height between 40 and 90 cm for the kid size sub-league, 3 robots with a size between 80 and 140 cm in teen size and a single robot of 130 to 180 cm in adult size. However, most successful robots range between 70 and 90 cm. There is no more color-coding, except for the identification of robot teams. The games are now played with white goals on both sides and a regular FIFA-compliant ball. However, there is still a considerable gap between the current requirements in the league and the regular FIFA rule book: The current field size is 9 * 6 m with a playing period of two times 10 min. Aiming for the 2050 game, the field size must increase to about 100 * 60 m within the coming 30 years. Robots will need to reach a height of about 1.80 m or more, and an endurance of 45 min. While the walking speed of the current robots rarely exceeds 1.5 km/h, they must be able to run at a minimum of 15 km/h (sustained) to 36 km/h (burst) as the human competitors in the 2050 game are capable of. In addition, robots must be able to kick the ball at more than 100 km/h and have a vertical leap that is better than 50 cm to be competitive against the best human players. Note that we chose these physical skills since they are easy to measure and we believe that they are necessary, but not sufficient for world class soccer players. Many attributes such as speed with the ball, ability to change direction quickly, and to predict the play are of the utmost importance but too hard to measure experimentally. Table 1 gives an indication of the current value, the 2050 requirements and the required average yearly increase to reach the goal. However, requirements may not increase gradually but rather stepwise. For example the endurance requirement may jump from 10 to 20 min as a next step rather than increasing by 1.2 min every year.

Table 1. Necessary robot attributes for the 2050 challenge

Parameter	2018	2050	Required average Δ/Year
Height	40–180 cm	180–200 cm	≈1.5 cm
Endurance	10 min	45 min	≈1.2 min
Running speed	<1.5 km/h	>36 km/h (Burst)	≈0.9 km/h
Kick speed	<2.0 km/h	>100 km/h	≈3.3 km/h
Vertical leap	<1 cm	>50 cm	≈1.6 cm

The league already faces stagnation of the number of teams participating. We believe that a main reason is that teams fear both the cost as well as the hardware and software challenges connected to larger robots. New teams enter the Humanoid League almost exclusively through the kid size league and few of them eventually work their way up to teen and adult size, which supports this hypothesis. However, with the increasing level of difficulty in all sub-leagues, it is expected that even this entry-level will become too high for new teams, especially undergraduate student teams, in the very next years. As an evidence, the Humanoid League at RoboCup German Open was cancelled in 2018 after many years of successful competitions due to lack of new teams.

Figure 1 gives an indication of the planed evolution of the robot and the field size in the league as discussed within the league in 2014 [4]. The roadmap is driven by scientific challenges that the Humanoid League TC believes are crucial to accomplish the 2050 goal and that they hope to achieve by controlling the playing field and associated rules of the league. For example, larger playing fields naturally lead to improvements in the running speed of robots and their visual acuity. Furthermore, special scientific challenges are approached via technical challenges (e.g., the 2018 competition includes jumping and kicking a rolling ball challenges as they are crucial scientific goals, but are not currently beneficial in the soccer matches).

However, the increasing number of robots per team will put high demands on each team's logistics and budget. The Technical Committee already addressed this matter by introducing the drop-in games [10], which allows participants to attend the competition with only a single robot. It was inspired by the drop-in challenges introduced by the FIRA United Soccer competition (2011), and the Standard Platform League (where drop-in was introduced in 2013 [2], and later improved [1]). However, rather sooner than later, costs for research, components and equipment even for a single humanoid robot will reach a level that may be too high to be taken in one step. We propose a Humanoid Rookie League, which we will detail in the coming sections, to ease the path for new teams and to guide towards full participation. The HRL will combine elements of robotics and artificial intelligence education and research and shall enable undergraduate teams to develop a robot to participate in the league within the time frame of a year's project. The design follows research on robotics in education, e.g. [14] and [12]. The small rule set [3] will prioritize the principles of robotic entertainment and avoid complex regulations and requirements, such that participation and watching shall be highly attractive.

2 Soccer Leagues Development

As the abilities of the robots increase, it is clear that the amount of human interaction with the robots must be reduced for safety reasons alone. New teams must implement a large amount of code to simply fit into the league's infrastructure (e.g., listening and providing status updates to the game controller or automatic referee). Even though established teams publish their code base, this is still a

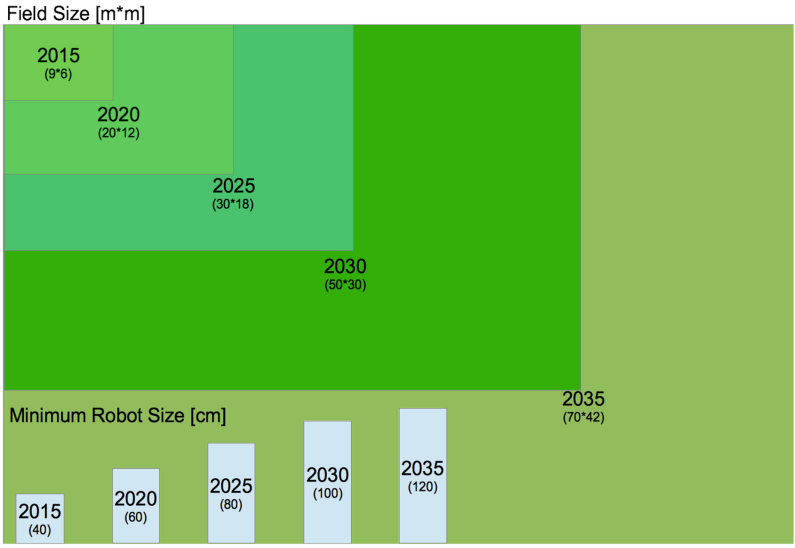

Fig. 1. Development of field and robot sizes as stated in the Humanoid League Roadmap from 2014 [4].

non-trivial work that is not at the core of soccer playing robots and thus of little interest to new teams, but still necessary to participate in the advanced leagues during RoboCup.

While league infrastructure is required in all leagues, the Humanoid League is at a great disadvantage when compared to the other RoboCup soccer leagues: Both in 2D and 3D simulation as well as in the Standard Platform League no hardware development is involved, which means that a good solution from a single team can be shared with all other teams and the league can make significant progress in this respect. Most teams in the Humanoid League use their own hardware and software, which makes sharing more difficult. There have been several attempts to use common middle-ware (e.g., ROS) or frameworks (FUmanoids player communication library [6]) to standardize at least some components in the Humanoid League. These attempts have not been very successful. For example, even though a lot of teams are interested in ROS, few teams actually implement it in their robots, first and foremost because updating a whole architecture takes considerable time away from implementing new features to keep up with the rule updates every year. The Technical Committee tried to foster a more collaborative approach within the league in the last years: In 2017, a drop-in challenge was introduced as a mandatory part of the competition for all teams participating in kid and teen size. While team collaboration increased *during* RoboCup, only few adaptations to hardware and software are actually made on-site. By announcing the drop-in teams in advance, the Technical Committee will make another attempt to strengthen the code exchange and development of a common code basis between the teams for 2018.

The increasing level of difficulty in the software development is only one of the development tracks in the Humanoid League. Similar to the Small and Middle Size League, the Humanoid League teams have to develop their own hardware, too. However, in contrast to the other hardware leagues, which

- use wheel-based locomotion,
- allow for non human-like hardware and vision-approaches and
- do rarely include rule changes which forces significant changes in the robot's hardware,

the Humanoid League imposes a very different level of hardware challenges on participating teams.

Even the Standard Platform League with the potential of easily exchangeable code faces a situation with few very advanced teams leaving the majority of other teams behind. The introduction of a Champions Cup creates an option for advanced teams to keep their games challenging, while still enabling new and less successful teams to play balanced games in the classical competitions [8]. A similar approach will be taken by the Small Size League in 2018 for the first time [5]. The idea of introducing a Rookie League, however, proposes a competition scenario at the 'lower' end of the performance range, because the 'higher' end is already defined by the 2050 challenge. A similar approach is followed by the @home Educational Challenge, co-located with the 2018 European RoboCup Junior [9]. Without the HRL, new teams will soon not be able to even meet the requirements for participating before putting in years of development effort and after significant investment. However, we strongly believe that new teams benefit from entering real competitions and networking with other teams during RoboCup events early on. Therefore, we need to provide a possibility for new teams to enter the Humanoid League and play against equally strong opponents while still developing towards the 2050 game for the experienced teams.

3 The Humanoid Rookie League

The user story of the Humanoid Rookie League is based on a group of undergraduate or early graduate students, interested in humanoid robotics and robotics soccer. They are assumed to have a yearly budget of a few thousand Dollars and some faculty support and should be able to design, build and program robots to enter the league within a time-frame of one year. With competitions organized at regional, super-regional and international level, the RoboCup Federation already allows for limited traveling budget of new-coming teams. Considering bipedal locomotion the core element of the Humanoid League, bipedal locomotion and kicking or driving a ball should be at the center of the Rookie League. At a lower, yet necessary level we see basic perception, localization with a local map and elementary planing. It is a core idea of the Rookie League that the rules and requirements of the league are simple enough as an entry point while simultaneously clearly guiding the development of a hardware platform and software base which can be used to compete in the regular Humanoid League within two or three years of participating in the Rookie League.

Fig. 2. HL Rookie League robot (left) and cardboard goal keeper (right).

3.1 Bipedal Locomotion

Constraints on the robots shall be reduced to the minimum. The regular league imposes restrictions on the center of mass (COM), height and foot size, just to mention a few. Except for the requirement of bipedal locomotion and a maximum size and weight, the Rookie League rules may not foresee any further constraints on the robot design. Avoiding or reducing the danger of falling, e.g. by sufficiently large feet, would allow to implement a robot with as few as 4 motors. Avoiding rules requiring to kick the ball, instead of just pushing it, would make robot design and control easier. However, locomotion on the difficult artificial turf used in the Humanoid League is still considered a significant challenge. Figure 2 shows a prototype of a basic 4-DOF bipedal robot for the HRL next to a FIFA size-1 ball. A game shall be played by robot teams of 3–6 robots, with each participant or participating team providing a single robot. Scoring and team building will be done according to the Humanoid League drop-in scheme [7], which awards points for scoring goals and supporting other robots. The range of number of robots per team allows for easy adjustment to the actual number of participants. In this case a competition with multiple games can be held with as little as 6 participating teams (forming 2 teams with 3 robots each). There are 10 different configurations of teams to play against each other with 6 robots, such that multiple games can be played.

3.2 Basic Perception

Color coding provides an easy way of identifying objects for a soccer scenario. Color blob detection is among the content of many entry-level computer vision courses. There are even integrated hardware solutions for color blob detection, like CMUCam (PixyCam) smart cameras. As in the earlier Humanoid League times, an orange colored ball, however, now a larger FIFA size-1 ball, shall be used. Coloring the goals is not suitable since this would require additional effort when using the goals of the regular league. Instead, a colored cardboard figure shall be placed in the goal (Fig. 2 right). Goal keepers shall be colored blue and red for the two different teams. This should ease orientation of the robots.

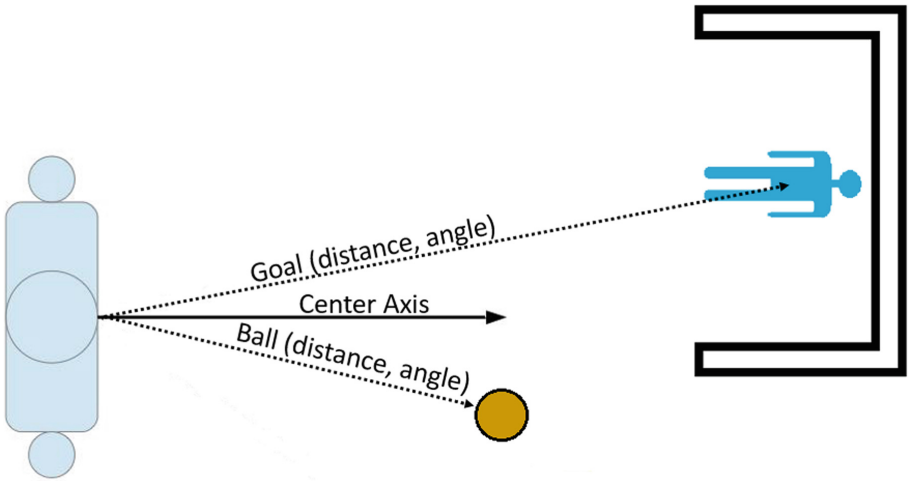

Fig. 3. HL Rookie League local map example.

Not having a dedicated goal keeper robot comes with multiple benefits. First, there is no need to implement a dedicated behavior and second, the drop-in scoring scheme becomes much easier and fair, since all robots follow the same behavior. Additional information on the environment can be derived from the fixed size of the objects, such that distances can be estimated with mono vision already.

3.3 Localization with Local Maps

Local, ego-centric models may serve as a very basic means of localization. This approach showed to be very easy to acquire for new coming students [11]. Figure 3 gives an example of a robot facing the ball and the opposing goal or more precisely the opposing cardboard goal keeper. From the position and size of the respective color blobs in the image, the position and distance relative to the own position can be estimated. A vector representation lays the base for easy calculations of positions and paths, as well as later decision making and planing.

3.4 Elementary Decision Making and Planing

Based on the local map as sketched in the previous subsection, basic decisions can be derived easily by adding and subtracting vectors. For example, in order to identify a suitable position for a goal kick, the robot may calculate the difference between the goal vector and the ball vector and extend it by an offset. After reaching the position the robot has to align to the goal and start driving the ball towards it.

3.5 The Playing Field

The Rookie League competitions shall be co-located with the regular RoboCup Humanoid League competitions. Therefore, the same playing field and goals should be used. If needed, the playing field may be reduced in size, e.g. to a single half, playing left to right and moving the goals to the touch lines or maintaining the playing direction with one goal moved to the center line. The field markings may require additional considerations. With a left-right playing direction in one half, temporary field lines may be drawn or taped within the free space between the lines of the current regular field, such that a rectangle of 6 m times 2.7 m without any otherwise misplaced goal box and center circle can be realized. With the main competition moving to larger fields, the free space will increase. Ultimately, the goal box of a full-size FIFA field, with up to approximately 5.5 m times 18 m could be used as afield for the HRL. However, with a strict local model based on the goals and the ball, it is possible for robots to play the game without evaluating field markings at all.

Similar to the field lines, the definition of the goals may impose some challenges. Making use of the same equipment was one of the objectives. However, eventually the main league will arrive at goals with a width of 7.3 m, such that they can not be used for the HRL. Instead we propose to make use of standard soccer goals as used for training purpose.

3.6 A Road Towards the Main Competition

While each challenge in itself is kept simplistic on purpose, the setup of the game allows for teams to advance their software and hardware development over time and step by step while still being able to participate in the league. For example, the white goals require more sophisticated vision to differentiate them from the white field lines. The hardware can be extended to using fully developed robots complying with the kid and teen size rules which poses additional challenges in the locomotion. Every year teams participate in the Rookie League they are encouraged to advance in one of the fields, so by the end of the three-year period they are allowed in the Rookie League their robots shall be advanced enough to participate in the regular kid or teen size league. While completely new teams are qualified to participate by default, teams have to demonstrate their advancements in a simplified application process for their second and third year in the Rookie League. This shall ensure that teams actually advance towards being compliant with the main tournament.

4 Draft Rookie League Rule Sheet

The guiding principles of the rules are fostering exiting games for participants and visitors and paving new robotics researchers a path to the RoboCup Humanoid League. Aiming for exiting games, robustness of the robots and the robot behavior, as well as minimal human robot handler interaction is crucial.

Attracting many new researchers shall be assured by introducing as few rules as possible to allow for easy implementation of the robot behavior and game play. At the same time they should avoid levering out the competitive advantage of more capable and robust robots. Appendix A shows an initial draft of the rules [3]. In order to guide the participants towards the main Humanoid League, we propose to allow participation to the HRL for a maximum of three years only In order to make robots more easy to handle, rules foresee a limitation to 1 m in size and 10 kg in weight. Robots may be started manually at the touch line, such that human robot handlers do not need to enter the field during start or restart. However, robots listening to the start command of the Humanoid League game controller may be positioned anywhere on the field as an advantage. For start and restart of the game a drop ball is carried out at the center point. The games continue until time is up, a goal is scored or until there is no further progress in the game (stuck game) for whatever reason. Typical scenarios for a stuck games could be robots not being able to find the ball or move it over a longer period of time e.g. because it is too close to a goal post or the goal keeper. Then there is a fresh start. The quality of the overall game play, whilst attempting to make sure that robust robots are not put at a disadvantage by other faster failing robots, is accounted for by restarting, if less than half of the robots of one of the teams are active and on the field. As stable locomotion is of paramount importance and restrictions are few, disallowing to pick up fallen robots, other than during a stoppage of the game, is considered a suitable rule to foster the development of robust robots. If the robot is in danger of damaging itself or others, standing, walking or fallen, it will be removed until next restart. As a default rule, significant authority is given to the referee. It is expected, that during implementation and the first trial run during a competition a few more rules need to be added.

5 Conclusions

The Humanoid Rookie League is an attempt to advance the RoboCup Humanoid League towards the 2050 game while still allowing new teams to easily enter with minimal requirements. It bridges the gap between a newcomer's budget of a few thousand Dollars and a 50.000 and more Dollars adult size robot. The HRL competitions provide motivation to new robotics students through manageable challenges and entertaining competitions. The Rookie League is closely linked with the overall league development and sets a clear path towards participation in the main competition after a maximum of three years. In this paper, we laid out the motivation for the Rookie League, presented the guiding principles and discussed a rule draft as a base for a broad discussion within the RoboCup community.

Appendix A

Draft of the RoboCup Humanoid Rookie League Rule Sheet

The games in the RC Humanoid Rookie League (HRL) are played as drop-in games for bipedal robots, with a minimal rule set. Every participating individual or group contributes a single robotic player to a robot team. Scoring is according to the HL drop-in rules. Individuals may participate in the Rookie league for a maximum of three years only and must not have participated in the Humanoid league before.

1. Field of Play

The HRL league is played on the fields of the RoboCup Humanoid League (currently 9 * 6 m). Cyan, respectively magenta cardboard figures represent the goal keepers. They are suspended from the respective goals cross bars, reaching the floor. Both figures have the same form. They are positioned by the referee, who may change their position during any stoppage of the game.

2. The Ball

The ball is a FIFA size 1 ball with orange colored surface.

3. The Number of Players

The teams consist of 3–6 randomly chosen robots and change during the tournament.

4. The Players

The robot players are bipedal autonomous robots that walk on two legs and drive a ball by pushing or kicking. The maximum size of the robots is 1 m, the maximum weight is 10 kg. Robots must bring red and blue team markers and must not use blue or red on any part that is not interchangeable. Robots may be started manually at the touch line of their team's own half. Robots that are started by the game controller may be positioned anywhere in their own half After positioning and possibly starting the robots, human team members must not interfere with the game play, except if explicitly called for by the referee. Robots need to be equipped with a handle to be safely picked up by a referee and an emergency switch off that is clearly marked and reachable. Pick-up of robots by robot handler and re-entry only is allowed during stoppage of the game.

5. The Referee

Each match is controlled by a team of referees with one head referee, who has full authority to enforce the Laws of the Game.

6. The Duration of the Match

A match is played in two half times of 10 min each with a break of 5 min.

7. Start and Restart of Play

The play is started and restarted by a drop ball at the kick-off point at the center. The ball is in play for both teams immediately. Goals may be scored immediately. A game is restarted for:

- second half time,
- after a goal was scored,
- after more than half of the robots of a team became inactive or removed after a (re-)start,
- stuck game.

For (re-)start of game robots may be placed and possibly manually started by a robot handler.

8. The Ball In and Out of Play

If the ball leaves the field of play, it is returned to field by the referee or an assistant referee, one meter into the field, perpendicular to the point where it crossed the line. There is no stoppage of the game.

9. The Method of Scoring

A goal is scored if the ball completely crossed the goal line between the two goal posts.

10. Fouls and Misconducts

The following cases are considered as fouls, resulting in a removal penalty until next restart of the game:

- any action posing the potential to significantly damaging a robot, including itself,
- leaving the playing field (field of play and surrounding green surface),
- any other significant offense, e.g. obstructing the game, as considered by the referee.

Robots potentially endangering humans by whatever activity are excluded from the game (red card).

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