On the Progress of Soccer Simulation Leagues

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Abstract. Soccer simulation league is one of the founding leagues of RoboCup. In this paper we discuss the past, present and planned future achievements and changes. Also we summarize the connections and inter-league achievements of this league and provide an overview of the community contributions that made this league successful.

1 Introduction

The soccer simulation league is one of the founding leagues of RoboCup [11]. From the first year of RoboCup it was played with teams of 11 versus 11 players. It is therefore the league that sets the standards for collaboration, team play and opponent modelling. It is also the league in which learning algorithms play a key role since the simulated robots are not subject to wear and tear.

After many discussions, in 2004 the league was split into the 2D and 3D Simulation branch. The goal has been to still have a league with 11 player teams, but add another league that keeps the strengths of simulation leagues, yet closes the gap to real robot leagues.

The rest of the paper is organized as follows: Sects. 2 and 3 describe the development and future of 2D and 3D soccer simulation. In Sect. 4 we point out the achievements and connections to other RoboCup soccer leagues and real soccer. Section 5 summarizes the wealth of contributions that made this league possible.

2 2D Simulation

2.1 History

The RoboCup Soccer Simulator (RCSoccerSim) is the official simulator for the 2D Simulation league since 1996. The official RoboCup competition was started in 1997, but the first 2D simulation competition was held in pre-RoboCup 96 in conjunction with IROS-96. RCSoccerSim was designed and developed by Itsuki Noda [19] and later developed and maintained by the RoboCup Soccer Simulator Maintenance Committee as an Open Source project. All software for 2D Simulation is freely available from the official site[1].

[1] http://sf.net/projects/sserver.

R.A.C. Bianchi et al. (Eds.): RoboCup 2014, LNAI 8992, pp. 599–610, 2015.
DOI: 10.1007/978-3-319-18615-3_49

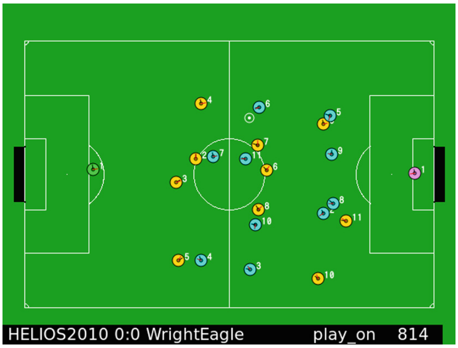

Fig. 1. A screenshot of 2D soccer simulator.

The 2D Simulation league is designed as a soccer competition which is played on a virtual 2D plane field (Fig. 1). All objects, such as the ball and players, are modeled as circle on a 2D plane, therefore players never jump and kick the ball into the air. The players' actuators are also simplified and very much different from real robots. However, almost all soccer rules are implemented and the simulator provides a completely distributed multiagent system which realizes full 11 vs 11 soccer games. The aim of these simplifications is to encourage RoboCup teams to concentrate on the research of teamwork.

With progress in a gameplay level, various rule changes have been made to push the progress by the league:

1998 Two important features were implemented. (1) A goal keeper was introduced. This special player possesses an additional action namely 'catch ball'. (2) An offside rule was implemented in the automatic referee. By introducing these features, the human soccer rules are almost fully implemented. Moreover, a stamina model was introduced. It imposes a resource model for the players. To perform actions, stamina needs to be invested and the model implements short-term expenditures with long-term recovery phases. This encourages the development of strategic resource management.

1999 The `turn_neck` command was introduced. This command enables players to change their head direction. As players' visible area is restricted, this command enables players to gather more environment information without interfering with body actions. In order to encourage teams to consider online adaptation, an online coach was introduced. The online coach can observe the whole field during a game and can send advice messages to players.

2000 The ball kick power was increased. This change accelerated the game pace. As a result, the competitions became more attractive.

2001 Heterogeneous players and player substitution were introduced. Teams still can use the default (homogeneous) player, but can select a heterogeneous player if necessary. Only the coach can substitute players during non-play on period. Because the physical abilities of heterogeneous player are randomly generated for each game, online coaches have to deliberate the player assignment according to their team strategy.

A new contest was added: the Coach Competition. In this competition the coach agent advises a team trying to improve its performance. To allow for universality of communication, a standardized coach language was introduced. The rules of this competition have changed frequently and in 2005 the coach task became that of identifying strategies (opponent modelling) instead of providing efficient strategies for the own team.

2002 In order to introduce new challenges related to communication, the length of auditory communication messages among players was shortened. Compensating this restriction, two new commands, `attentionto` and `pointto`, were introduced. The `attentionto` command can be used to focus players' attention on a particular player's auditory message. If `attentionto` is off, the player will hear one auditory message from each team selected randomly. The `pointto` command enables players to point to a spot on the field using a virtual arm and other players can see the arm direction. Players can send a location, and indirectly their intention to other players as a visual message. As the improvements of the dribbling skill progressed further, it became too difficult for defenders to block a smart dribbler. The new `tackle` command enables players to kick the ball in a range wider than the `kick` command succeeding with a probability based on the ball position relative to the tackling player yet causes immobility for a few cycles.

2003 An automatic penalty mode was added to the simulator. If the game ends in a draw, the automatic penalty mode may be started. As a RoboCup-based testbed for machine learning, a simplified scenario was implemented, the so-called Keepaway problem. In this game, the one team (the "keepers") attempt to keep the ball away from the other team (the "takers"). Details of the Keepaway task as well as some experiments can be found in [26].

2008 The number of heterogeneous player types was increased from 7 to 14. Assigning the default player type was forbidden except for the goal keeper, and assigning the same heterogeneous player type to several players was forbidden. Under the new rule, each player has to be assigned different player type. This means the player type assignment became more difficult. The range of the goal keeper's catch action was reduced to encourage teams to use more effective positioning of the goal keeper and defensive players.

2009 The stamina capacity model was introduced. This model restricts the total amount of stamina value for each player during the game. Until 2008, players could always recover their stamina. If the stamina capacity is exhausted, players never recover their stamina. As a result, they cannot run by their maximum power. In order to avoid this situation, players have to manage their stamina more carefully and online coaches have to consider the timing of player substitution according to the game situation and the players' tiredness. The dash model was extended to enable players to accelerate their body in 4 directions. Players can adjust their position more flexibly and quickly by using the extended model, but it requires more complicated planning for all move actions. In soccer games, players need to adjust their body direction in order to start the next behavior quickly. Under the previous dash model, players have to turn and dash to the target position, then turn their body to the desired direction. The new dash model enables players to adjust their position without turn action. However, there are tradeoffs, for example, between time and stamina cost.

2010 The tackle command was extended to introduce an intentional foul action. When the intentional foul action is performed, the success probability of action is increased but the player may be penalized. The foul detect probability is defined for each heterogeneous player type. In the current implementation, the foul detection depends only on the probability. If an intentional and dangerous foul is detected by the automatic referee, the referee penalizes the player by giving the yellow or red card. A new heterogeneous parameter that affects the goal keeper's catch range was introduced. Teams are still allowed to assign the default type player to the goal keeper in order to keep the Compatibility with previous team binaries. The dash model parameter was changed. Players are now able to accelerate their body in 8 directions.

2.2 Present and Future

Although the community held numerous discussions for introducing new features, no major changes were introduced since 2010. This does not mean the 2D Simulation league stops its progress. Gabel et al. evaluated the performance improvement of teams quantitatively [8]. They compared the performance of teams that participated in the competitions from 2003 to 2007 which has been possible, because no major changes were applied in that period. The results showed that newer champion teams would always overcome older champions.

Of course, new challenges that discover new research are always required. Although an online coach is available since 1999, online game analysis and online adaptation are still important research topics in the 2D simulation league. In the past few years, several teams started to prepare more than one strategy and switch them according to the opponent team. The role of online coach will become more important in next few years. With the improvement of online coach, the standard coach language will also be updated.

Another important topic is the collaboration with real human soccer. Because the 2D Simulation league focuses on the research of teamwork, 2D Simulation has begun to apply decision making techniques and game analysis techniques not only to 2D league but also to human soccer like in [1].

3 3D Simulation

In 2004 the 3D soccer simulation competition was born. Its main goals are those of the 2D soccer simulation, i.e., to keep the focus on multiagent system coordination research and to use the new 3D simulator to conduct research that cannot be performed using real robots, either because of time, money or hardware constraints. It adds the third dimension to the game seeking to make it more realistic and uses more realistic robot models and environment dynamics.

3.1 History

2004 The first RoboCup 3D Simulation Competition took place in 2004. This competition used the Simspark generical physical simulator platform [20] to build a 11 against 11 soccer game simulator called rcssserver3d. The simulation includes several innovations such as (obviously) the 3D model of the environment, but also the use of the ODE physics engine library to model and update the dynamics of simulated objects and a middleware for agent simulations, SPADES [23], that manages the distributed simulation, and ensures results do not depend on network or system load, and a new timing model, where agent thinking times are taken into account.
To keep the 3D environment in line with 11 vs 11 games, the 3D robot model used in 2004 was quite simple and its shape was a sphere, (Fig. 2). All actions were performed by applying forces either to the agent or to the ball.

2005 The 2005 rules and models were identical to the ones used in 2004. However, there were several changes inside the simulator to make it more efficient and to remove bugs. Big effort was also spent in the documentation of the new simulator as in its initial year, the documentation was quite scarce.

2006 The robot vision perceptor was changed to restrict agents vision to a limited field of view. To control the looking direction a PanTilt effector was added to the robot. A limited bandwidth broadcast communication model was also introduced in this year. Soccer rules were also changed to approximate FIFA rules, and an offside rule was added to the simulator. Optimizations made to the simulator turned it into a much more efficient application.

2007 In the 2007 competition, the robot model was changed from the simple sphere model towards the targeted humanoid robot model. The humanoid model used in 2007 was based on real humanoid HOAP2 from Fujitsu [3], which can be seen in Fig. 2. Each of the joints could be controlled setting the desired angular velocity. The new model introduced many new research challenges to the Simulation League, enabling this league to conduct research on humanoid robotics. The trade-off was that the number of players per team had to be reduced from 11 to 2, as the simulator could not cope with more than 4 humanoid agents in total, and the restricted vision was also changed to a global vision perceptor. The development of efficient humanoid skills became the most important point for the success of the team, making coordination research less important in this year. Nevertheless, this change was necessary to bring Simulation League research closer to the real robots and, as predicted, the number of players per team was increased in the following years making coordination essential again.

2008 With the introduction of Aldebaran's Nao Robot in the Standard Platform League, also 3D soccer simulation switched to the simulation of Nao robots. In 2008 games were played 3 versus 3. With this step, the 3D soccer simulation league again made a step towards narrowing the gap between soccer simulation leagues and real robot leagues.

2009 Saw an increase of the number of robots per team to 4 with the goal in mind to reach 11 vs 11 players eventually. The robots' omnidirectional view was replaced by a restricted view with a cone similar to real Nao robots.

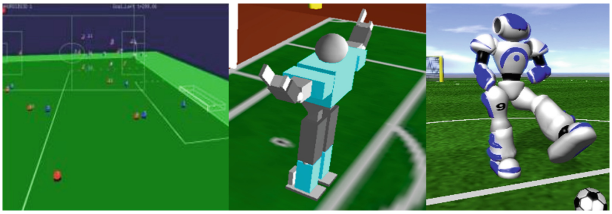

Fig. 2. Robot models used. Spheres (2003-2006), Hoap robot model [3] (2007) and NAO (from 2008).

2010 The major change for 2010 in Singapore has been the increase of teams of 6 simulated Nao players. Better hardware and software optimizations made it possible to increase the number of players and the field size accordingly. Also, to boost the development of simulation server and infrastructure, a 3D development competition was held.

2011 The last intermediate step to 11 versus 11 was taken in 2011 with teams of 9 versus 9 NAOs. Again the field size has been increased to keep the space per robot roughly the same. The visualization was done using a new visualizer RoboViz [25]. With a special 3D beamer and glasses the games could be watched in 3D in Istanbul.

2012 A major milestone has been achieved in 2012 simulating games of 11 vs 11 NAO robots for the first time. The soccer field size has been increased to represent the size of a real soccer field with respect to the size of the robots. As of 2012, both soccer simulation leagues were the only leagues with the full final team size played in 2050.

2013 A major strength of simulation leagues was first exploited in 2013 with the introduction of heterogeneous robots. In no other league it is so cheap to change robot models and use different variations of a robot model in one and the same game. The rational behind introduction variations of the NAO robot has been to shift from programming good behavior skills for a very specific robot to creating good algorithms for the behaviors to any similar robot, especially for walking. The exact robot models have only been published some days before the competition. Only teams that are able to adjust their algorithms and have the modified robots learning the skills succeed.

Also a drop-in player challenge was held in conjunction with several other leagues. Mixed teams with two players from each participant team played against other mixed teams put together from other participating teams. The challenge is to play with other players without a common strategy agreed upon. A couple of games with a changed mix of teams determined the winner.

3.2 Present and Future

For 2014, a new goal has been introduced in 3D soccer simulation: the league committed itself to work towards having the first running robots. In a running robots challenge, robots are evaluated for their run speed, but also on how much

Fig. 3. 11 vs 11 Nao robot game.

time both feet are off the ground. This is possible in 3D soccer simulation since the simulated Nao robots have slightly stronger motors than real Nao robots. Nao models with toes were introduced for this challenge to allow more human-like walking and running. The idea behind is to explore in a cheap way what hardware setups are required to make running with biped robots possible. While in 2013 the usage of heterogeneous robot models was optional, in 2014 teams are forced to use heterogenous robots. At most 7 robots may use the standard NAO type. The remaining 4 robots have to use 3 different variations of the NAO.

The main challenge for the future will remain to find a good balance between having a multiagent simulation for intelligent robotics research with ideally 11 vs 11 games and having a more realistic simulation in terms of real hardware. Having the 11 vs 11 goal achieved, concrete suggestions have been made for the later: a model for energy consumption and motor warming has been implemented and suggested, stiffness of motors, or more realistic noise models for sensors. Also a transition to new, more realistic simulators like gazebo is an option.

3D Simulation should also play a role in research for new robot models and hardware. This has started with the introduction of heterogeneous robot models including a model with toes. It is now continued with the running challenge in which teams for the first time can suggest their own robot model variations. And it should be further developed in the future to, for example, use new sensors and actuators if these sensors are biologically plausible and likely to be developed on real robots. Suggestions include linear actuators, touch suites and many more (Fig. 3).

4 Inter-League Achievements

Technologies that result from research in the Simulation League are often used in other RoboCup leagues. In some cases, the same institution creates new teams to compete in new leagues using the knowledge from a previous Simulation League team or starts its participation at several leagues simultaneously, this is the case, for example, of CMUnited (2D, Small, MSL, 4legged, SPL), Brainstormers (2D, MSL, 3D), FC Portugal (2D, 3D, Mixed Reality, 4legged, SPL, MSL), UT Austin Villa (2D, 3D, SPL), WrightEagle (2D, 3D, 4legged,SPL), Bold Hearts

(3D, Humanoid) or magmaOffenburg (3D, Humanoid). In other cases the technologies are adopted by completely independent teams from different leagues.

One of the major challenges in soccer is the positioning of the team in the field. Several positioning systems have been proposed in the Simulation League [2,4,14,21,27] and have been used in other leagues [10,12,27].

Simulation is a very adequate environment for the automatic development of behaviors. Several teams have developed machine learning to enhance their 2D and 3D teams. A very significant example is the research developed by the Brainstormers team, that has been applied in the Simulation League and also in the Middle-Size League [7,22]. Using humanoid models at the 3D Simulation league fostered automatic humanoid behavior generation research. The techniques that have been developed in the simulation league are mostly based on optimization and machine learning, either using model-free or model-based approaches and have had a strong impact on real robot leagues [5,6]. It is very interesting to see that, as referred to before, several 3D Simulation Teams have created teams that participate in the Standard Platform League or at the Humanoid League.

Teams that maintain a strong link to Simulation League research and developments have been very successful in other leagues. There are several examples of this kind of teams that became RoboCup champions in SSL (CMUnited, CMDragons), 4Legged (CMPack), MSL (Brainstormers Tribots, CAMBADA) and SPL (UT Austin Villa) (Fig. 4).

5 Community Contributions

More than in most leagues, soccer simulation leagues' progress is heavily influenced by community contributions. The main workhorses for 2D and 3D Simulation are the soccer simulators. Both have been fully developed and maintained by the community specifically to ensure independence from external vendors and so that the league retains the right to fully use and modify them as the requirements of the league progress. Around the simulators, a wealth of other software was created to visualize, analyze and comment games as well as run games or complete tournaments.

Simulator Development. The original 2D soccer simulator was proposed and developed by Noda et al. in 1997 [19]. Many people contributed to the development under the lead of Itsuki Noda, Tom Howard and later and until now by Hidehisa Akiyama. The simulator runs on Linux and has reached version 15[2]. A more detailed history of changes is provided in Sect. 2.1.

The 3D Simulator[3] was initiated by work from Markus Rollmann, Oliver Obst [20], Jan Murray and Joschka Boedecker who provided the Spark simulator as a generic simulator for 3D. It is based on ODE physics engine[4] to simulate physically realistic objects in 3D. The actual soccer simulation is a separate module based on top of Spark. It provides the robot models, soccer rules, automated

[2] http://sourceforge.net/projects/sserver/.
[3] http://sourceforge.net/projects/simspark/.
[4] http://ode.org/ode-latest-userguide.html.

Fig. 4. Debugging features of RoboViz [25].

referee and more. It proved its flexibility many times, for example whenever new robot types were used in the simulation. Today it provides the base for having heterogeneous robots types available in one and the same game.

Again many people from the community contributed to the server development under the lead of the aforementioned and later lead by Hedayat Vatankah.

Visualizers. To the public, the quality of the simulations is mainly associated with the quality of visualizing it. A couple of 2D visualizers are available for free for Linux and Windows, many of them adding debugging features and logfile replaying. 3D Simulation offers two visualizers, rcssmonitor3D and RoboViz [25][5]. The later is now used as main visualizer in competitions and by many teams for team-specific graphical visualization of real time debugging information.

Source Code Releases. It is a condition of participation that binaries of all teams are released after a RoboCup. This allows all teams to test against old teams and to perform scientific research including other team's binaries.

Source code release, however, is voluntary. Nevertheless, more than 15 teams have released source code libraries or fully functional agent code in 3D. Many teams in 2D based their code on source code bases from CMUnited 99, FCPortugal, UVATrilearn and Helios. The code is available for C++, Java, C#, Clojure, C, Prolog and Javascript. This way, new teams do not have to redevelop low level communication or geometrical transformations, but can focus on high level skills and decision making[6].

Benchmarks. Keepaway (see Sect. 2.1), a subtask of 2D Simulation has been a well established benchmark domain in the reinforcement community for many years [26]. The magmaRunChallenge is a currently developed benchmark tool

[5] https://sites.google.com/site/umroboviz/.

[6] http://wiki.robocup.org/wiki/Soccer_Simulation_League.

for the 3D running robot challenge in which robots are benchmarked for speed and the relative amount of time both feet are off the ground.

Miscellaneous. Many more contributions added to the success of soccer simulation league. To only mention a few: the league managers, a comprehensive set of scripts to run tournament rounds automatedly, a communication proxy that decouples the simulation from any network or simulation server performance issues in 3D, a framework to host a 2D tournament on a remote system, a couple of live commentary systems [9,18,28] or the ssil, an automated internet league.

6 Conclusion

In this paper we have summarized the past, present and future of the 2D and 3D RoboCup Soccer Simulation leagues as an excellent domain for multi-agent, machine learning and humanoid robot research. Due to its low cost, it is a good entry point for new teams into the RoboCup community. Many teams with roots in soccer simulation now participate in hardware leagues with some of them even winning other league competitions. The success of the soccer simulation league is due to the inpour of community contributions and the perseverance of the simulator maintainers which is an essential tool for mapping the path towards the Grand Challenge of 2050.

Appendix

(See Table 1)

Table 1. Table of Champions in 2D and 3D Simulation.

Year	2D champion	Country	3D champion	Country
1997	AT Humboldt	Germany	-	-
1998	CMUnited	USA	-	-
1999	CMUnited	USA	-	-
2000	FC Portugal	Portugal	-	-
2001	TsinghuAeolus	China	-	-
2002	TsinghuAeolus	China	-	-
2003	UvA Trilearn	Netherlands	-	-
2004	STEP	Russia	Aria [24]	Iran
2005	Brainstormers	Germany	AriaKavir	Iran
2006	WrightEagle	China	FC Portugal [13,17]	Portugal
2007	Brainstormers	Germany	WrightEagle	China
2008	Brainstormers	Germany	SEU-RedSun [29]	China
2009	WrightEagle	China	SEU-RedSun	China
2010	HELIOS	Japan	Apollo3D	China
2011	WrightEagle	China	UT Austin Villa [14,16]	USA
2012	HELIOS	Japan	UT Austin Villa [15]	USA
2013	WrightEagle	China	Apollo3D	China

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