Is that Robot Allowed to Play in Human Versus Robot Soccer Games

Laws of the Game for Achieving the RoboCup Dream

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Abstract. Many RoboCuppers share a dream: a team of fully autonomous humanoid robot soccer players that is capable of playing soccer games against human players by 2050. The demonstration of a human versus robot soccer game at RoboCup 2007 was an exciting display of the progress that has been in RoboCup community since 1997 in terms of the robot's autonomy, sensing ability, and physical features. This game also uncovered several new issues. For example, do human soccer players play games against robots in the same way that they would if they were playing against human players?

In this study, we investigate the features of RoboCup soccer leagues and examine whether these features are necessary and sufficient to realize the dream of RoboCuppers. We compare the current RoboCup soccer leagues to human soccer leagues and discuss metrics that indicate the similarity between robot soccer games and human soccer games. In other words, we discuss our progress toward realizing the dream. In addition, we propose amendments of laws for human and robot soccer that will deal with human-related issues and facilitate research toward achieving the dream.

1 Introduction

Many RoboCuppers share a dream: a team of fully autonomous humanoid robot players that is capable of winning a soccer game against the winner of the most recent World Cup while complying with the official FIFA rules by 2050 [15]. In RoboCup 2007, the first robot versus human soccer game was played between robots from the Middle Size League (MSL) and humans [19]. The game excited RoboCuppers but also brought about the fact that the RoboCup dream implicitly assumes that robots will be able to run as fast as humans and kick the ball as well as humans. The MSL uses the size 5 soccer ball, which is also used in human games. This was one of the factors that made the exhibition games possible. Other factors like the field size, floor and lighting conditions, and mechanical specifications of the robots, such as speed, size, and shape, are also important in realizing robot versus human soccer games.

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With each passing year, these factors have become increasingly similar to those that are used in human soccer games. The progress of the RoboCup soccer leagues were reported and issues to achieve the RoboCup dream have been reviewed [10,18]. Most of the issued that were reviewed were technical ones. On the other hand, safety to human players and abilities of robot players were questioned: Are they allowed to have omnidirectional visions? How much power is allowed to for kicks? However, these questions have not been discussed further, and the safety of human players in human versus robot soccer games remains unsettled.

Human players seem to be apprehensive about robots approaching at full speed as an iron block, and tend to be extra careful in order to avoid injuries due to the robots in the human versus robot soccer game. The robot's movements can potentially injure human players. This factor has prompted us to consider the themes presented in this paper. Player safety is important in soccer games and must be ranked as the highest priority in the event of robot-human contact. This leads to the following questions:

Q1: Can we realize our dream given the present league rules?
Q2: What challenges should we consider and promote in order to achieve our goals for robot versus human soccer games?

We believe that now is a good time for us to examine our approach and to clarify what must be done in order to realize the RoboCup dream by 2050. In this study, we compare the RoboCup robot soccer leagues to human soccer leagues, describe issues in the existing laws of the games, and propose new laws for human versus robot soccer games, which will enable us to achieve the RoboCup dream. Section 2 describes robots from other fields and the rules that were initially established for the use of those robots. Section 3 discusses differences in the perspectives of humans and robots with robot soccer. Section 4 discusses our proposals for amending the laws of the games in order to realize the dream and related challenge issues. Finally, Sect. 5 concludes the paper with a summary of our proposals.

2 Background and Related Works

We expect robots to eventually become a pervasive part of our lives. For example, in the automotive fields, Google has been presenting and testing driverless cars in many cities since the success of the DARPA Urban Challenge [1,5]. Driverless cars have been presented at exhibitions, while laws and guidelines for driverless cars have been drafted [6]. There are numerous issues that need to be resolved for us to use the driverless cars. For example, who is to blame if the driverless car is involved in an accident? Should the automaker that designed the technology, the car's owner, or a passenger accept responsibility?

For the standardization, terms such as "service robots" and "mobile robots" are being defined, and co-ordinate systems for mobile service robots are being discussed [12,13]. With regard to safety, protective measures and system requirements are being examined. This involves considering the possibilities of incorrect autonomous actions, contact with moving components, stopping and speed/force restriction. In ISO 8373 standards for robots and robotic devices, it is clearly stated that the robot shall either be designed to ensure either a maximum dynamic power of 80 W, or be designed to maintain a separation distance from the operator. The ISO statement is clear for designing robot soccer players, however human soccer players cannot sense how much force we apply.

At the beginning of the RoboCup initiative, Kitano et al. said that RoboCup poses significant long-term challenges that will take a few decades to meet. Due to the clarity of the final target, several sub-goals can be derived, which in tern lead to short-term and mid-term challenges [14]. The three short-term challenges involve synthetic agents, physical agents and infrastructure challenges. For the synthetic agent challenge, learning, teamwork, and opponent modeling challenges were proposed. For phase I of the physical agent challenge, the following three challenges were set [8]:

1. Moving the ball to a specified area with no, stationary, or moving obstacles,
2. Receiving the ball from an opponent or teammate, and
3. Passing the ball between two players.

The robot versus human soccer game at 2007 showed that these challenges have been achieved to some extent [7,16,19]. Stone et al. presented a paper on robot soccer followed by the 2007 human robot soccer game [17]. The topics covered a range of issues: the physical size of robots that are not bigger than human players, confidence of human players that they are not more likely to sustain an injury than were playing with people and funs who enjoy soccer game, rules that are suitable human and robot players and so on.

We also wondered whether the human players were apprehensive that robots would injure by playing with robots. This feeling applies to other leagues that have interactions with human and robots. In the RoboCup@Home league, robots showcase their abilities in homes, shopping malls, and public parks rather than in RoboCup competition venues. Robots soccer leagues are conducted in accordance with the official FIFA soccer rules. The robots are designed with considering not injuring human. Following Asimov's Three Laws of Robotics may express one of design guidance [9].

1. A robot must not harm a human. And it must not allow a human to be harmed.
2. A robot must obey a human's order, unless that order conflicts with the First Law.
3. A robot must protect itself, unless this protection conflicts with the First or Second Laws.

Soccer players compete with their opponents to gain control of the ball. Haddadin et al. discussed contact plays from physical human-robot interaction and studied joint elasticity to kick the ball for human-level soccer [11]. In addition to developing such mechanisms, we believe that rules similar to the Three Laws of Robotics are required to ensure the safety of human players.

3 Differences Between Human Versus Human and Human Versus Robots Soccer Games

3.1 Comparisons with Physical Aspects of Human Soccer Games

The human versus robot demonstration game involved five players per team. Table 1 lists the specifications of three different soccer games. The first category is for human soccer games. The table list data for leagues in the professional, junior high schools, and elementary categories. The second category are data for futsal that is played on a smaller field and mainly played indoor and blind soccer games. The third and fourth categories are data from RoboCup soccer games from real robot leagues and simulation leagues, respectively.

Parameters such as field size, running speed of players, and ball size indicate how close we are to achieving the RoboCup dream. The values in Table 1 are standard values or are taken from the rules and manuals of the leagues. For MSL and the Small Size League (SSL), the field sizes in 2003 and 2010 are listed to indicate the progress in each league. W, D of P_{size} denote the width and depth of players, respectively and H denotes the height of human players. The following metrics were set in order to normalize the game specifications.

Table 1. Comparison of parameters of human and robot soccer Games.

Leagues	Field Size ($m \times m$)	Players	Metrics					
			P_{size} ($W \times D(\times H)cm$)	P_{speed} (m/s)	P_{number} ($m^2/player$)	P_{space}	P_{grid}	P_{time} (s)
Human full-size games *1								
Professional	105 × 68	11 vs. 11	50 × 30 × 180	9.09	325	210 × 227	2,164	12
JuniorHighS.	70 × 50	11 vs. 11	30 × 20 × 130	6.25	159	233 × 250	2,652	11
ElementaryS.	68 × 50 (halfsize)	8 vs. 8	30 × 20 × 100	4.50	213	227 × 250	3,542	15
Human mini-soccer games								
Futsal	40 × 20	5 vs. 5	50 × 30 × 180	9.09	80	80 × 67	533	4
Blid soccer *2				8	80			5
RoboCup Real Robot League								
Middle (2010)	18 × 12	5 vs. 5	30 × 40 to 50 × 80	3.00	22	36 × 30	108	6
(2003)	10 × 5			3.00	5	20 × 13	25	3
Small (2010)	6.05 × 4.05	5 vs. 5	18 × 14	3.00	2.5	34 × 23	76	2
(2003)	2.8 × 2.3			1.00	0.6	16 × 13	20	3
SPL/Humanoid	6 × 4	3 vs. 3	10 × 5 × 58	0.10	4.0	60 × 80	800	60
RoboCup Simulation League								
2D	105 × 68	11 vs. 11	60 × 60	1.20	325	175 × 113	902	88
3D	105 × 68	11 vs. 11	140 × 96 × 210	2.00	325	75 × 71	241	53

$P_{number} = \frac{\text{Field Size}}{\text{Players}}$, $P_{space} = \frac{\text{Long Side of Field}}{\text{Player Width}} \times \frac{\text{Short side of Field}}{\text{Player Depth}}$, $P_{grid} = \frac{\text{P}_{\text{space}}}{\text{Players}}$, $P_{time} = \frac{\text{Field long side}}{\text{P}_{\text{Speed}}}$

*1: Students of Junior High and elementary school play soccer according to modified rules: for example cf http://www.usyouthsoccer.org/coaches/RulesSmallGames/

*2: There are three leagues: B1 and B2/3, for completely blind and fully sighted or partially sighted persons.

- P_{number} denotes the area size per player.
- P_{space} denotes the ratio of the field's long side to the player width and the ratio of the field's short side to the player depth. The numbers indicate the number of grids necessary to represent the movements of players.
- P_{grid} denotes the number of grids allocated to one player. This number corresponds to the size of area that agents use to monitor the changes in environments for playing soccer games.
- P_{time} denotes the time taken by a player to run from one end line to the other. This is related to the mobility and stamina of players.

P_{size} and P_{speed} are different for the three levels of human soccer leagues: professional, junior high school, and elementary school. The relative parameters, P_{space}, P_{time}, and P_{grid}, of the three levels of human leagues have a similar order of values. This implies that the rules are set such that the settings of games match the physical abilities and sizes of human players. The values for

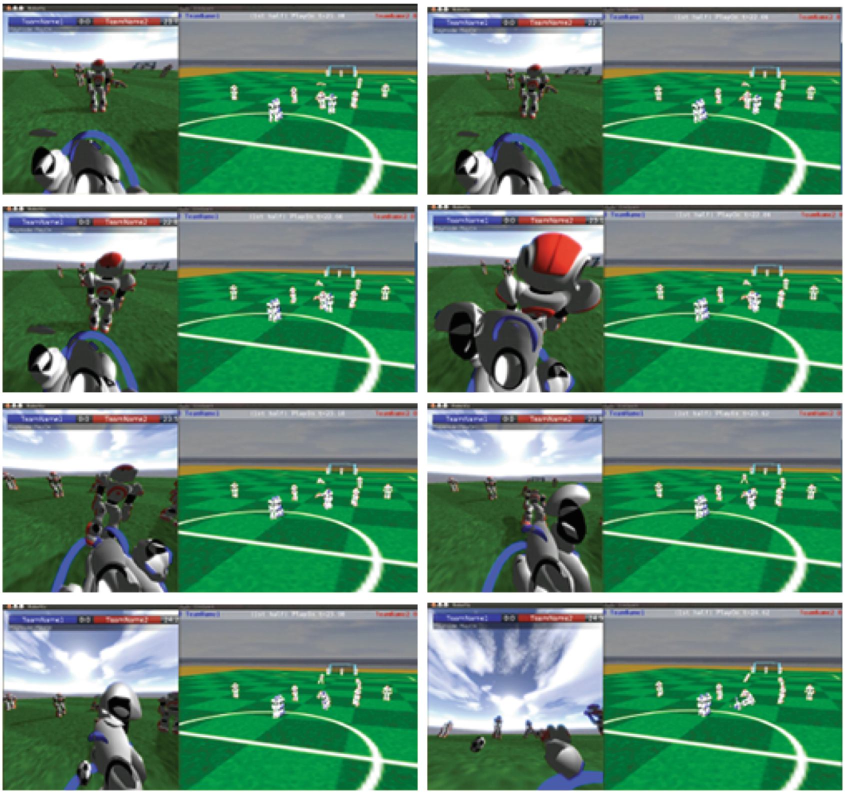

Fig. 1. Pictures from local(left) and global(right) vision Systems. In a zigzag way from the left top screen shot to the right bottom one, they are snapshots of collision between two robots. The last picture was taken as the robot was falling backwards and most of the visual information is from the sky.

Table 2. Potential amendments of rules and time schedule to achieve the DREAM.

(a) Potential Rule Changes

FIFA LAWs	categories of rule amendments and others
1 The Field of Play	INP
2 The Ball	
3 The Number of Players	INP
4 The Players' Equipment	ESH
5 The Referee	
6 The Assistant Referees	CRT
7 The Duration of The Match	
8 The Start and Restart of Play	kick-in instead of throw-in in Futsal
9 The Ball In and Out of Play	
10 The Method of Scoring	
11 Offside	no offside rule in Futsal
12 Fouls and Misconduct	ESH
13 Free Kicks	
14 The Penalty Kick	
15 The Thrown-in	CRT
16 The Goal Kick	
17 The Corner Kick	

(b) Expected Schedule of Events to 2050

year	event
1997	start of RoboCUP
2007	1st Human vs. robot soccer games
2013	
2015	Draft of RoboCup Soccer Rules for human versus robot games
	<Transitional phase>
2020	Competition compliant with RoboCup Soccer Rules
2030, 2040, 2050	<Major updating of Rules per decade to Achieving Dream>

Futsal games rank between human soccer leagues and RoboCup soccer leagues. This provides a good example for determining the rules for RoboCup soccer games and working toward achieving the dream.

3.2 Local-Global Vision as an Example of Difference in Sensing Ability

In the early stages of MSL, all teams used video cameras. Now all teams use omnidirectional vision systems and laser range finder systems. In the SSL, two types of vision systems were used at the beginning. Some teams used video camera systems mounted on robots and other teams used a global vision system that provided a bird's eye view of the game. After the first a couple of competitions, all team used the global vision system. At present, vision cameras are set over the field by rules and the images from the cameras have been provided to teams.

Figure 1 shows images taken in a 3D simulation soccer games. In this league, individual robot players receive information around them from a server. The pictures on the left are pictures that contain the same information from the server. These pictures are obtained from a camera that is virtually attached to a player. The right pictures are images of global vision system that are displayed to spectators.

The local vision that human use is clearly inferior to the global or omnidirectional vision that robots use. In the case of Fig. 1, different commands are generated 46 times during 300 steps between using sensing data from global and local vision systems. This issue presents us with questions about extra sensing abilities that are available to robots and whether they should be permitted in human versus robot soccer games.

4 Proposal to Achieve Human Versus Robot Soccer Games

4.1 Rule Amendments and Time Schedule

The FIFA Laws of the Game include seventeen laws that address subjects ranging from field to plays to the corner kick. Burkhard et al. compared the FIFA rules and RoboCup rules and showed the main differences are the playing field, the number and skills of players, etc. They also pointed the difference of field size and the number of players would be used to measure the progress of robot soccer [10].

The FIFA Laws of the Game empower a referee to interpret the rules at his/her decision and the referee has full authority to control a match to which he/she is assigned [3]. For example, a direct free kick is awarded to the opposing team if a player commits one of seven offenses in a manner that the referee considered to be careless, reckless or using excessive force. One of the seven offenses is pushing an opponent. The interpretations of the FIFA Laws of the Game vary from one referee to another. It is interesting to note that the latter half of these laws includes a section about their interpretation and a section about guidelines for standardizing referees' decisions.

The left column of Table 2 (a) lists the seventeen laws. The right column of the tables lists the laws that we think will need to be amended in order to achieve the dream. We believe that laws 1, 3, 4, 6, 12 and 15 are potential ones to be amended and they are categorized to three groups:

INP(Introduction of New Parameters based on metrics) - Law 1 and 3 -:
It is a goal to play soccer games at fields fully compliant with the FIFA rules, however it takes a lot of space and money for teams. The metrics in Sect. 3.1 describe the features of human soccer games. Field size and the number of players need to be different from those specified by FIFA, but the metrics calculated from them should be similar to values for real soccer games, as listed in Table 1.

ESH(Examination from Safety of Human players) - Law 4 and 12 -:
We believe that there are two categories of issues related to safety. The first category deals with technical issues, which are concerned with how well the robots play. The second category deals with the mental approach of the

human players. These issues are concerned with the risks of injury and how those risks affect the way that human players play the game.

CRT(Challenge Research Themes) - Law 6 and 15 - :
In SSL league and simulation leagues, programmed computers have refereed games. For this discussion, we will assume that the referee is human and that one of the assistant referees is a robot that has the required software installed. The robot referee checks not only goals but also offside infraction in order to help human referees [2]. In humanoid leagues, throw-in-lay has been challenged [4].

Rule revisions influence research themes of participants and the operations of the RoboCup soccer leagues. Before anything else, RoboCuppers share what really needs to achieve the dream from the viewpoints of technically themes to safety of human players. Table 2 (b) shows our proposal how to proceed further discussions and rule changes.

- By 2015, a draft of RoboCup rules for human versus robot games will be presented. During the subsequent five years, every league will be required to change their rules to comply with the RoboCup 2015 rule set.
- From 2020, games will be played according to the 2015 rules. And the rules will be updated once per decade to achieve the dream.

4.2 What Should Be Considered in Order to Gain Acceptance from Human Teams

Soccer players compete with their opponents to take the ball. This implies real tackles, collisions and fouls between humans and robots. Law 12 (Fouls And Misconduct) prohibits players from making severe body contact that would hurt opponents or themselves. It does not seem feasible for robots to apply Asimov's Three Laws of Robotics to soccer games. We believe that laws similar to the Three Laws of Robotics are needed in order to provide human players with sense of ease to play games with robots. The following issues should be considered in examining the amendment of laws.

1. Equality of Physics:
   According to the action-reaction law in physics, the same force acts on both a human and robot when they collide with each other. This leads to the conclusion that the mass, speed, and acceleration of robots should be restricted to those comparable to human players. Skin and muscles make collisions between human players softer than those that would occur with robots having protective shells made of metal or plastics. Collision mitigation should be taken into considerations when setting the rules of robot soccer.
2. Ease of Playing:
   Players predict the next movement and action of opponents when they play games. Omnidirectional vision systems and movement mechanisms cause robots to move in ways that are distinctly different and also unpredictable. As a result, humans players often do not have a clue about what the robot's

next movement will be. This makes human players feel uneasy when playing with robots. It is important for human players to feel at ease while playing against robotic opponents.
3. Communication and Accountability:
In the unfortunate cases where human players get injured, the players are required to describe the situations to a referee or show that the play was not an intentional one. This includes not only communication to the referee but also explanation of which player did what kind of plays and where. The need for an account for one's own play and related plays requires robots to generate and record log data in text form. The data corresponds to memory of human players and other players recorded at consecutive steps are identified each other.

4.3 Challenges in Human Versus Robot Soccer

As we have described, human versus robot games and robot versus robot soccer games have different features. From a viewpoint of human versus robot soccer games, it is important to get acceptance form a human teams to play with robots. For the above second and three issues, followings will be agenda to be discussed:

1. Clue-giving Mechanism:
The direction of the gaze or body is an important factor that we use in the predictions of others' movements. A robot should have a mechanism to give clues about its future motions that will let human players predict the next motion of the robot. The direction of the face, body, or camera of the robot should be linked to the next motion of the robot for predictability and ease of playing.
2. Hostile (unfair) Play and Summarizing Ability:
Blocking an opponent player may be judged as a foul. A player with a captain's band can appeal a refereeing decision. An appeal should address the 5W1H questions(who, what, when, where, why and how). When a human player gets hurt, the robot player (or designer of the robot) explains that the plays are not intentional. This requires a textual summarization of the sequences of recorded plays in a natural language.

5 Discussion and Summary

The RoboCup community has been working toward achieving the dream of seeing robots playing soccer games against humans using the FIFA rules. The demonstration games between robots and humans that started at RoboCup 2007 and have continued showed that robots can play soccer games with humans at the level of an elementary school team. Honestly, one of authors was drawn strategically into what the robot teams of RoboCup 2014 champion would do next to human players as a spectator. The game uncovered several new issues regarding safety and the mental approach of the human players. Soccer is a contact sport and humans get injured sometimes during games. At robot-human soccer games, we expect robots to play competitively. Robots will be penalized by referees when they injure human players even if unintentionally.

This paper surveys issues on human-robot interaction from the view of human safety to realize our dream and raises the following questions:

Q1: Can we realize our dream given the present league rules?
Q2: What challenge should we consider and promote in order to achieve our goals for robot versus human soccer games?

This paper introduces various issues and themes that we must discuss in order to achieve the RoboCup dream in a concrete manner. We hope that this paper makes will serve a starting point for discussions about rules for human-robot soccer games and setting metrics that show how the leagues reach to the dream. And these outputs are assumed to support common functions of service robots that will coexist with us and will assist us in daily life.

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