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A Supporter Behavior for Soccer Playing Humanoid Robots

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Abstract. In this paper, an efficient behavior for a humanoid soccer robot supporting a teammate manipulating the ball is proposed and evaluated. This approach has been derived from human soccer tactics, requires only minimal information about the current state of the game and is therefore well suited for robots with directed vision and limited motion abilities like humanoid robots. The position of the supporter is chosen in a way to reduce the chances of the opponent team for scoring a goal and to increase the chances of the robot to take over the role of its teammate manipulating ball in case the teammate falls down or is being dodged by the opponent team. By different parameterizations more defensive or more offensive player tactics can be realized as well as adaptations to specific tactics and skills of the opposing robot players. The developed behavior was evaluated in a simulation based statistical analysis. Also an evaluation in games during RoboCup 2009 is given.

1 Introduction

In the RoboCup humanoid kid size league, teams of 3 two-legged robots play soccer against each other in a continuous, dynamic game. Within a team, usually one robot is the goalkeeper and two robots are field players. The field player which is in a better position for playing the ball is the striker, the other field player is called supporter. The robots can change roles at any time, if appropriate. This paper deals with the question of how the supporter should behave in order to contribute to the team's success. The goal is, that the supporter is able to continue an attack, if the striker fails, without obstructing the striker in any way. Particularly, the supporter should not approach the striker too close or cross the line between the ball and the opponent goal, to prevent blocking the striker's goal shots.

Compared to other RoboCup leagues, the implementation of tactical behavior faces specific difficulties. A two-legged walking robot has far more limited mobility than a wheeled system, like in the small size or mid size leagues. Further, the camera field of view is limited and can only view the area in front or sidewards of the robot by moving its head. This leads to specific, larger uncertainties in world modeling than with omnidirectional or overhead camera systems like those being used in the mid or small size leagues.

In this paper, a supporter behavior which accounts for the specific locomotion and vision abilities of humanoid robots is derived from human soccer tactics. The proposed behavior strengthens the defense by covering the own goal, but enables the supporter to continue an attack if the striker fails at the same time. The behavior requires only minimal information about the current state of the game: the teammate positions are required to negotiate roles. For the actual supporter positioning only the current ball position and sufficiently good self localization are required. The implementation consists of four states. The only required basic ability is approaching a position while avoiding obstacles. The developed behavior is minimalistic with respect to required computing power and motion and sensing capabilities, and is therefore very well suited for humanoid robots with directed vision.

The reminder of this paper is structured as follows: Related work is discussed in Sect. 2. In Sect. 3 first the basics of human soccer tactics are introduced, afterwards the possibilities for transferring the tactics to humanoid robot soccer are discussed. The developed behavior is presented in Sect. 4. In Sect. 5 the experiments in simulation and with real robots are described and the results are discussed. A conclusion is given in Sect. 6.

2 Related Work

Until now, most effort in the humanoid kid size league was put into the development of basic skills like locomotion, localization and perception, as well as the behavior of the striker, which usually approaches the ball and kicks or dribbles it towards the opponent goal. In most matches, it appears like the second field player does not add a significant advantage to the team in many game situations. Often, the supporter is either placed at a fixed position on the playing field, or it executes the same behavior as the striker, which leads to both field players approaching the ball and, in the worst case, obstructing each other.

A basic strategy for advantageous positioning of the second field player for humanoid robots is presented in [1], where the supporter always attempts to stay between the ball and the own goal. For the AIBO robots, in [3] the supporting robot is positioned close to the attacker to either recover a lost ball, or to be able to receive a pass. Similarly, in [7] the robots currently not controlling the ball are positioned either close to the striker, to support the attack, or at positions where they are likely to find the ball after it was out of bounds. In [4], in a simulation based on mid size robots, one robot is always positioned close to the striker, to act as backup. In [6], supporter strategies for the NAO robot are described; here a distinguishment is made between an offensive behavior that follows the striker, and a defensive behavior that supports the goalkeeper in defending the goal.

3 Transferring Human Soccer Tactics to Humanoid Robots

3.1 Human Soccer Tactics and Strategy

There are three important aspects in human soccer team play: formations, the style of play, and tactics.

Formations are used to define the distribution of the players on the field. A specific formation is described as $a : b : c$, where a denotes the number of defenders, b the number of midfielders, and c the number of strikers. Frequently applied formations are $4 : 4 : 2$ (4 defenders, 4 midfielders, and 2 strikers), and $4 : 3 : 3$ (4 defenders, 3 midfielders, and 3 strikers). Besides zone defense it is the purpose of the formation to provide depth and width in defense and attack. Width means having players to the left and to the right of the player currently playing the ball, to allow the team to move forwards quickly in attack and to keep the opponent from playing around the defender in defense. Depth means having a player behind the striker or defender currently playing the ball, in case the first defender gets dodged in defense or to have a play-to for a back pass if the forward player is stopped in his attack.

The style of play determines how the players act during play. Widespread styles of play are the counter-attacking style, the possession style and the direct soccer style. With the counter-attacking style the team waits for the opponent close to the own goal and tries to gain an opportunity of a fast counter attack. A team playing possession style soccer tries to keep possession of the ball for a long time through lots of passings until a good opportunity for an attack comes along. In direct soccer style, the ball is moved or passed towards the opponent goal as fast as possible, trying to score a goal with as little ball touchings as possible. This describes best what currently soccer playing humanoid robots do.

Tactics describe conceptual actions depending on the specific situation of the match. In soccer the basic tactical decision is to play offensive or defensive. Applying tactics depends on an overall understanding of the conceptional playing situation, including the current score, the opponents abilities and the position and movement of the ball, the teammates and also the opponent players.

3.2 Transfer to Humanoid Robots

As long as there are only two field players and one goalie in a match, it does not seem meaningful to apply formations to humanoid soccer robots. Different styles of play are also still difficult to achieve, because current humanoid robots are not able to control the ball (dribbling, passing) in a way needed to realize these styles. For the same reason it is difficult to distinguish between offensive and defensive situations, because almost never one team is really in control of the ball. Usually, if players from both teams are close to the ball, both are similarly able to kick the ball. As robot capabilities in these fields are getting better, applying tactics and styles of play will be a topic of future work.

From the suggested behavior for individual players not possessing the ball, it can be derived, that, no matter if the team is attacking or defending, it is important to place supporting players next to and behind the striker, to achieve width and depth in attack or defense. Because the passing abilities of humanoid robots are not yet reliable, width in attack and defense is considered to be more important. Therefore a good position for the supporter is diagonally behind the striker. In humanoid robot soccer this position has another advantage: When assuming that the ball is somewhere close to the striker, the supporter has a high probability of seeing the ball from that position. If the striker itself does not see the ball, and if localization confidence of both, striker and supporter, is above a given threshold, the communicated ball position is used as measurement update for the striker's Kalman filter. In that way, if the ball is occluded from the striker's point of view by an opponent or by the striker's own arms, the ball model of the striker gets updated with information coming from the supporter.

The best position of the supporter has to be identified with respect to the current situation of the match. Variables determining the current situation are the positions of the opponent players, the positions of the teammates, and the position of the ball. Perception capabilities of the robots are very restricted, therefore the players are not able to perceive the situation in the same way as a human does. Currently, opponents are only modeled as obstacles that have to be avoided. Further information about the opponents is not available, and therefore cannot be considered for behavior planning. It was chosen to position the supporter relative to the position of the ball, instead of relative to the position of the striker, for several reasons:

1. Just as opponents, teammates are observed only as obstacles, but additionally, each robot communicates its current position to its teammates. With this information, the supporter is able to calculate its relative position to the striker, but with two sources of error: the position error of the supporter's self localization and the position error of the striker's self localization. In the worst case, these errors sum up when calculating the relative position from supporter to striker. This error can be significantly large, and therefore positioning relative to the striker is not reliable.
2. The ball position is sensed directly by the supporter and therefore can be considered reliable enough. It can be assumed that the own striker is closer to the ball than the supporter, otherwise they would switch roles. Further, opponents can be assumed to approach the ball from the other side.
3. If the supporter positions relative to the striker, and the way between the striker and the ball is blocked (e. g. by an opponent), none of the robots will reach the ball, until the striker finds a way. If, however, the supporter positions relative to the ball, it potentially gets closer to the ball while the striker's way is blocked, and the robots can switch roles. In that way, the attack can be performed faster.

It is therefore reasonable to position the supporter diagonally behind the current position of the ball, instead of behind the striker.

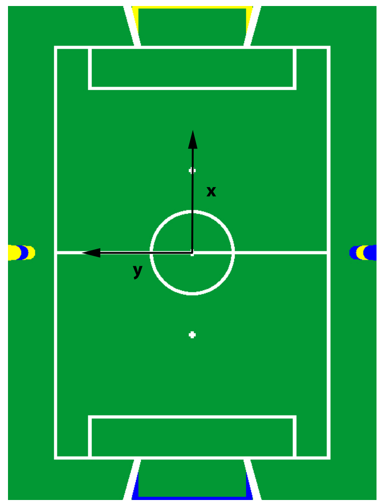

Fig. 1. The playing field with coordinate system for the team defending the blue goal.

4 The New Playing Supporter Behavior

Apparently, different strategies of the opponent team cannot be overcome with the same behavior, e. g. a team known to never kick the ball farther than 1m can be handled differently than a team being able to score goals from any point on the field. Therefore, an important issue when designing the new behavior was flexibility, to allow adaptation to different opponent strategies and capabilities.

The best position for the supporter has to be identified with respect to the current situation of the match. All positions in this section refer to a world coordinate system with its origin in the middle of the center circle, the $x-$axis pointing towards the opponent goal, and the $y-$axis parallel to the centerline, as it is depicted in Fig. 1. As described in Sect. 3.2, it is reasonable to position the supporter diagonally behind the ball. This position can be described, relative to the position of the ball, with an offset sidewards ($y-$direction) and backwards ($x-$direction). These two parameters can be controlled to achieve different variations of the behavior. For example, a larger $y-$offset is appropriate if the opponent is known to frequently play diagonal passes, while a smaller $y-$offset gives a higher probability of blocking direct goal shots. Likewise, a small $x-$ offset is suitable if the opponent only kicks the ball slightly, whereas a larger $x-$offset prevents that both, striker and supporter, can get dodged simultaneously.

The sideways shift should not always be fixed left or right to the ball, rather the supporter should be positioned on the side of the ball that is farther away from the closest touchline, and therefore is closer to the middle of the field. At this position the supporter has a high probability of blocking opponent goal shots. To avoid frequently switching sides when the ball is close to the middle, a hysteresis is used that causes the robot to stay on the current side. Overall, as shown in Sect. 5, this positioning leads to a high likelihood of the supporter

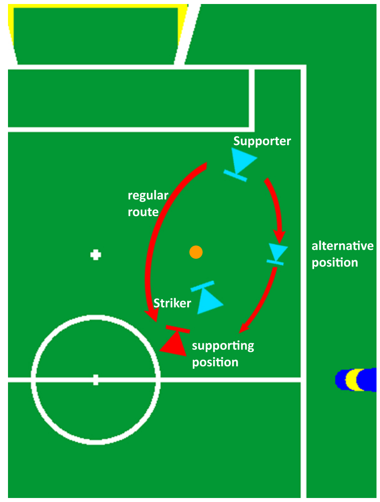

Fig. 2. Regular and alternative way to the desired supporting position.

standing between the ball and the own goal, and therefore being able to block opponent goal kicks. Additionally, if the striker fails (e. g. because of falling down, or the opponent dodges the striker), the supporter is likely to be in a good position to resume to the role of striker and scoring a goal. This is also shown in Sect. 5.

The special case when the supporter is closer to the opponent goal than the ball should be handled separately, in order to avoid the supporter crossing the line between the ball and the opponent goal on the way back, and therefore potentially blocking goal kicks of the teammate, as in Fig. 2. One possibility to handle this situation would be a distracting potential between the ball and the goal, and let the supporter walk along the potential field. However, this requires a high computation effort. A very simple, yet effective alternative is, to first send the supporter to an alternative position next to the ball, on the same side as the robot is currently positioned. The decision whether to select the left or right alternative position is based on the supporter's current position relative to the line between the current ball position and the middle of the opponent goal, as it can be seen in Fig. 3. The behavior control checks the signum of the angle $\gamma \in (-\pi/2; +\pi/2)$ between the vector from the ball to the supporter and the vector from the ball to the opponent goal. If $\gamma \geq 0$ the supporter is positioned to the left of the ball, else to the right.

Tactical decisions can be realized with two parameters x_{min} and x_{max} limiting the supporters longitudinal position. For example, for defensive behavior, the supporter should always stay in the own half of the playing field. This can be obtained by limiting the forward motion of the supporter to the middle line, i.e. setting $x_{max} = 0$. Conversely, to achieve an offensive behavior, the backward motion of the supporter can be limited to the middle line by setting $x_{min} = 0$,

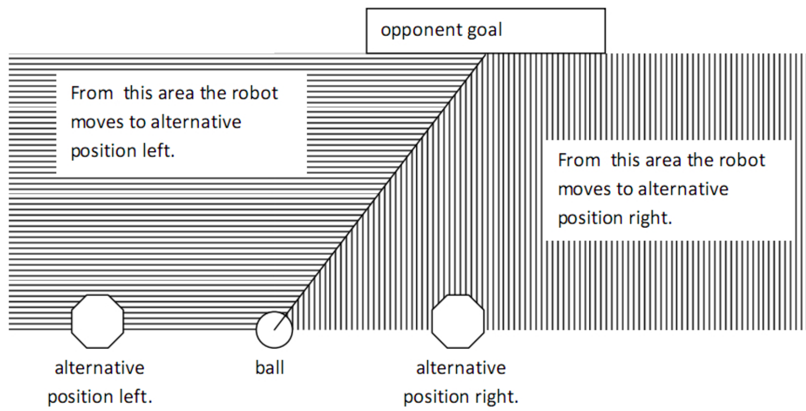

Fig. 3. Separation of walking left or right of the ball.

which leads to the supporter always being positioned near the opponent goal. Furthermore, the longitudinal limits can be used to forbid the supporter to enter the goal areas, to avoid committing an illegal defense or illegal attack foul.

In summary, the developed behavior can be controlled by four parameters, namely the offset of the supporter position sidewards ($y-$offset) and backwards ($x-$offset) to the ball, and the minimum and maximum limit x_{min} and x_{max} of the supporter position in the longitudinal axis. The behavior has been implemented as a XABSL [5] option, consisting of four states:

- Search Ball: Initially, and whenever the current ball position is unknown, the robot tries to find the ball.
- Position to Support Ball: In the most general case, the supporter goes to the position diagonally behind the ball, based on the current parameter settings.
- Position to Support near Middle: If the ball is near the longitudinal middle of the field, the behavior enters the hysteresis state to avoid frequently switching sides.
- Position to Support Alternative: If the supporter is closer to the opponent goal than the ball, it first goes to the alternative position next to the ball.

A visualization of the state machine, including the possible state transitions, is depicted in Fig. 4.

5 Results

The developed behavior has been evaluated in a simulation, because ground truth data of the robots' and ball's position is available. Furthermore, the videos of the relevant matches of RoboCup 2009 have been analyzed manually, to show the benefits of the new approach in a real situation.

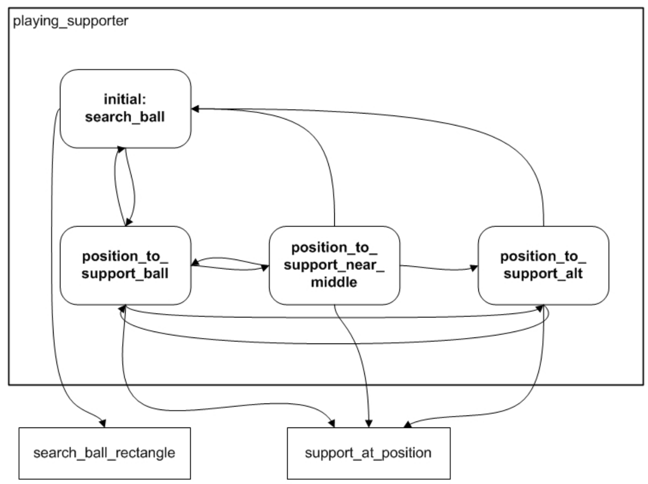

Fig. 4. The state machine for the supporter behavior.

For the experiments, a simulation based on [2] has been used. A screenshot of the simulation can be seen in Fig. 5. 44 halftimes of 10 minutes each have been simulated with one team playing with the new behavior against a team playing with the old behavior. For comparison, also 43 halftimes were simulated with both teams relying on the old behavior. The old behavior always positioned the supporter at a fixed distance in front of the own goal, away from the striker in $y-$direction. It can be assumed, that this behavior is not very effective. For the robots' motion simulation a kinematic motion algorithm was used, due to the limitations of computational power available. Therefore, no robot could fall over, which usually occurs frequently in real matches. However, the typical walking pattern was simulated, resulting in realistic shaking of the robots' cameras. The simulated camera framerate was 10 fps, also due to computing power. For a fluent game, independent of human influences, a script was used to replace the ball after it was kicked into the goal or out of bounds. During simulation, the position of the ball and of all robots was logged every second. Furthermore, the scored goals with associated timestamps were logged. Based on this data, it was possible to analyze different aspects that were influenced by the improved behavior. Over all halftimes for the reference data with both teams playing with the old behavior, the mean of the goal difference is 0.1395, while the mean for a team with new behavior against a team with old behavior is 1.7727. An unpaired t-test gives a P-value of 0.0001 , which is highly significant. As a second benchmark, the occlusion of the goal by the robots was calculated. For the new supporter behavior, the mean occlusion is 0.7750 m, compared with a mean of 0.6496 m for the old behavior. The entire goal width is 1.5 m. The t-test indicates that also this improvement is highly significant. The results are summarized in Table 1.

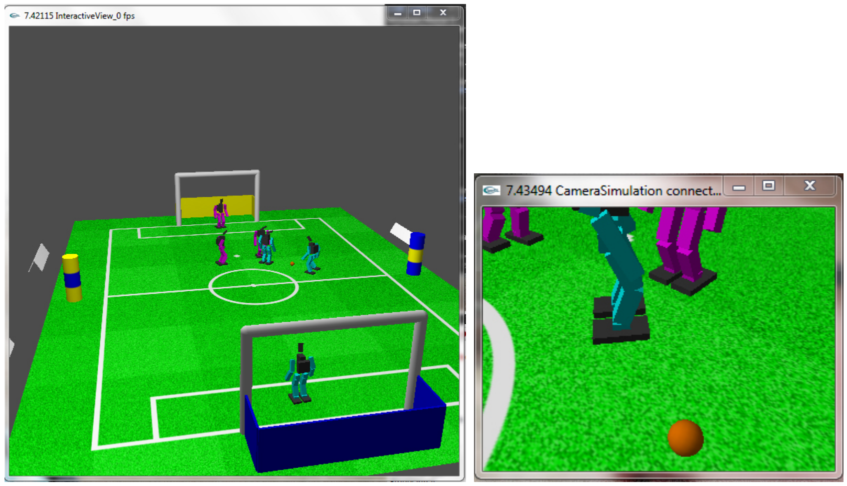

Fig. 5. Screenshot of the simulation experiments. Left: Match Overview. Right: Camera perspective of the cyan supporter.

Behav. team 1	Behav. team 2	Sim. halftimes	Mean goal diff.	Mean goal occl.
old	old	43	0.1395	0.6496
new	old	44	1.7727	0.7750
			highly significant	highly significant
			P = 1.1010e-004	P = 1.1623e-021

Table 1. Overview of the simulation experiments.

The improved supporter behavior has been used at RoboCup 2009. Only two of the matches (i. e. the semifinal and the final) were noteworthy, in all other matches the opponents almost never reached the ball or attempted to score a goal. Therefore, all other matches are left out of the analysis. Videos of the matches can be found at `http://www.youtube.com/user/DarmstadtDribblers#grid/user/23B57AD2A2A1D6BD`.

In the semifinal, the opponent team had a goalkeeper and two field players. Frequently, both field players tried to reach the ball simultaneously and therefore blocked each other. Therefore, there were only few opponent kicks, instead the ball was only moved slightly by the opponents by walking against the ball. This usually moved the ball less than 1m, and if the ball passed our own striker, this distance was a good hint on where our supporter should be positioned along the x-axis relative to the ball. The y-offset was chosen small (0.5m), on the one hand to avoid that the ball can pass between both field players, on the other hand because no diagonal passes were observed at the team's previous matches. The match ended with 7:2.

In the final, the opponent team had three field players and no goalkeeper. The robot that was closest to the ball always tried to approach it to score a goal, the other two were positioned at free space, one in the own and the other in the opponent half, to have a good coverage of the field. The opponents were dribbling most of the time, moving the ball approximately 1-1.5m, which gave an evidence for the x-offset. Like in the semifinal, the y-offset was chosen small to prevent balls passing between both field players, also in this match no diagonal passes were expected. The final score of this match was 11:1.

In both matches, x_{min} and x_{max} were set to the borders of the goal areas, to prevent the supporter of committing an illegal defense or illegal attack foul.

For the two relevant matches, the interesting situations are summarized in Table 2. Overall, there were 28 situations when the striker failed (i.e. got dodged by an opponent or fell over), and therefore a well positioned supporter was needed to recover the situation. If the supporter was able to play the ball before an opponent did, the supporter was considered to be helpful (+). If the supporter could not reach the ball or could not move it towards the opponent goal, it was considered to be not helpful (−). If no second field player was available, the situation cannot be rated (◦). Table 2 shows, that the team could benefit in many situations of the new supporter behavior.

match	striker situation	supporter +	supporter −	supporter ◦
Semifinal	got dodged	12	7	7
	fell over	4	1	3
Final	got dodged	7	3	1
	fell over	5	3	1
Total		28	14	12

Table 2. Analysis of the two relevant matches at RoboCup 2009. It can be seen, that the supporter frequently recovered a situation after the striker failed.

6 Conclusion

The development of humanoid robot technologies has reached a state where reasoning about high-level behavior development must be made. Indeed cognitive and mechanical abilities of humanoid robots are not enough developed to accurately reproduce human soccer tactics. However, with some adjustments key concepts of positioning and cooperation can be well transferred from human to humanoid robot soccer behavior. The proposed behavior is minimalistic with respect to required computing power, motion abilities and perception, and is therefore very well suited for humanoid soccer robots.

The behavior described in this paper was evaluated in simulations and has shown to yield significantly better results than the old behavior, regarding goal difference and goal occlusion. The results at RoboCup 2009 show that also in real matches with opponents with different tactics the improved supporter behavior is efficient and contributes to the overall team success. During RoboCup 2009 it was possible to adjust the behavior to observable characteristics of the opponents robots and playing style. Behavior parameters where set mainly regarding the walking speed of the opponent robots and the range of their shots. It has shown that hand-tuned parameters worked already well in practice, however, for future work, reinforcement learning techniques can be applied to find better parameters.

Further, refinement of the behavior will come along with improvements of the mechanical abilities like passing and ball control, opponent robot modeling, a larger playing field and a rising number of field players.

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