The Attempto Tübingen Robot Soccer Team 2006

Patrick Heinemann, Hannes Becker, Jürgen Haase, and Andreas Zell

Wilhelm-Schickard-Institute, Department of Computer Architecture,
University of Tübingen, Sand 1, 72076 Tübingen, Germany
{heinemann, hbecker, jhaase, zell}@informatik.uni-tuebingen.de

Abstract. This paper describes the Attempto Tübingen Robot Soccer Team 2006. After radical changes in the software and hardware we present a team of six new omnidirectional robots in 2006 together with promising innovative algorithms. Apart from the ability to play at changing illumination we present effective methods of ball interception and efficient path planning around dynamically moving objects using sophisticated tracking algorithms. This paper introduces the robot hardware and some of these algorithms.

1 Introduction

The software of the Attempto Tübingen Robot Soccer Team has undergone a radical change over the last three years. From a laser-based system, using a very accurate, however, heavy weight laser scanner as main sensor, we migrated to a camera-based system, using an omnidirectional camera. As the fundamental algorithms for the performance of the whole system, like object detection, landmark detection, and self-localization, had to be developed from scratch, the team had some problems in reaching the finals in 2003. Nevertheless, we showed in the technical challenge at the world championship in Padova 2003, that our high-level control code was still good enough, to win the technical challenge by dribbling the ball around static obstacles and playing with a non-colored standard FIFA ball [8]. In addition to the drastical change in parts of the software, the upcoming use of very fast omnidirectional robots forced us to change our hardware as well. In order to stay competetive, we replaced our differential drive Pioneer 2 robots from ActivMedia with a maximum speed of only $1.6\frac{m}{s}$ by custom-built omnidirectional robots with $2.6\frac{m}{s}$ speed. The first prototype of this new generation of robots was used as goal keeper in the competitions of 2004. Combined with a very efficient high-level control, this goal keeper was regarded as one of the best goal keepers in the world championship 2004 at Lisbon and was consequently elected into the all-stars match.

Meanwhile, we have built a team of six omnidirectional robots and implemented robust algorithms for object and landmark detection using the omnidirectional camera system [4] as well as a novel approach for an efficient and reliable self-localization [1, 2]. Both algorithms rely on the nearly constant lighting on current RoboCup fields by using a static look-up table mapping the image colors to the color classes used in RoboCup. With these color classes, objects and landmarks can be easily distinguished and extracted from the image. As future RoboCup matches will take place under changing and finally natural lighting, we recently developed an extension to the object and landmark detection algorithm that automatically adapts this look-up table online to a changed illumination [5]. Thus, our basic algorithms already fulfill future requirements and serve as a good foundation for improving the high-level algorithms in our software system.

One of the main features of our high-level software is still the accurate model of the robot's environment including the velocity of the objects resulting from a robust tracking over time. Several approaches for tracking objects were implemented and tested over the last years [3, 6]. Recently, we developed robot control algorithms that are incoporating the velocity of the objects for ball interception as goal keeper or pass receiver and for path planning. Details of these algorithms are presented in the remainder of this paper, which is organized as follows: the next section gives an overview of the hardware used by our team for the 2006 competitions. Section 3 presents a path planning algorithm based on time variant potential fields that efficiently plans paths around moving obstacles. In section 4 we explain a novel behavior of our goal keeper used to intercept a kicked ball.

2 Hardware

The Attempto Tübingen Robot Soccer Team will participate in the RoboCup competitions 2006 with a team of 6 custom-built omnidirectional robots. Driven by three 60W motors each robot reaches a maximum speed of $2.6\frac{m}{s}$. Apart from the wheel encoders, the only sensor on these robots is an omnidirectional camera system, comprising a 50fps perspective camera with a resolution of 580×580 pixels and a hyperbolic mirror. The images of this camera system are sent via FireWire to the Pentium-M 2GHz onboard PC with 1GB RAM running all neccessary control processes. The software algorithms running on this computer are optimized to run in a global 20ms cycle, enabling the robot to be extremely reactive. All field players of the team additionally contain a custom-built electromagnetic kicking device that can accelerate the ball to a speed of up to $10\frac{m}{s}$. As a special feature, the robot can control the kicking strength of this device in real-time, in order to pass the ball to a team-mate instead of kicking it at full strength. Communication among the robots and with the referee-box is realized over an external IEEE 802.11 a/b/g wireless LAN client.

3 Path Planning based on Time Variant Potential Fields

Planning collision-free paths is one of the basic skills for a mobile robot performing a goal-oriented task. Especially in highly dynamic environments such as RoboCup there is a need for smooth navigation avoiding the cooperating and competing players. Today, robots in RoboCup are moving at speeds up to 5 m/s. Navigation thus requires real-time path planning considering the movement of the obstacles. Yet, the majority of the teams in the RoboCup middle size league competition of 2005 were actually completely unaware of the speed of the other robots [7]. To the best knowledge of the authors no team incorporates moving obstacles in their path planning algorithms. In this section we present a new method of path planning for the RoboCup domain that extends the approach introduced by Weigel *et al.* [9] to time variant potential fields that consider the movement of the obstacles over time. Using this method results in smoother paths and less collisions for several scenarios that frequently occur in RoboCup.

As our method is an improvement of the path planner of Weigel *et al.*, a brief overview of this planner is given first. The approach of Weigel et al. is one of the most efficient approaches for path planning in the RoboCup domain. It uses a combination of grid-based path planning and potential fields. The potential field at position (x, y) consists of an attractive force $f_{att}(x, y)$ towards the target position and repulsive forces $f_{rep,i}(x, y)$ from the obstacles $o_i = (x, y, v_x, v_y)_i$

$$P(x, y) = \left| f_{att}(x, y) + \sum_i f_{rep,i}(x, y) \right| \tag{1}$$

If the robot follows the gradient of the potential field $g(x, y) = \nabla P(x, y)$ this results in an effective path towards the target. To reduce the computational costs for evalutating the whole field, the gradient is approximated on an equally spaced grid by evalutating the potential field locally at adjacent cells. If the robot starts in grid cell (u, v) the gradient is

$$g(u, v) = \frac{1}{\alpha} \langle P(u+1, v) - P(u-1, v), P(u, v+1) - P(u, v-1) \rangle \,, \tag{2}$$

where α is the distance between two cells. Then, the next waypoint of the path is the next grid cell following the direction of the gradient. To overcome the problem of local minima a local search along the grid is done if the planned path enters the same grid cell twice. The main advantage of the approach, however, is the idea to plan the path backwards from the target to the robot to avoid heading directly into an obstacle and then following a curve around it. If the path planning is reversed, the robot directly enters a trajectory that leads around the obstacle. However, the path planning is not only based on the gradient for the current position of the robot but is done for the whole path from the goal backwards to the robot. Nevertheless, the method is able to compute paths in real-time which means 50 times per second on our robot hardware. With the continuous replanning this approach generates very efficient and smooth paths for slow moving obstacles. Unfortunately, there are many situations where the planned path is inefficient because of unconsidered movement of the obstacles (cf. figure 3).

Our improved path planning method extends this approach to cope with such situations. For that, the position of the obstacles is no longer static for the whole planning process. Instead, whenever the next grid cell is reached in the planning process, the obstacles are moved to a new position

$$o_i(t+\tau) = (x(t+\tau), y(t+\tau), v_x, v_y) = (x(t) + \tau v_x, y(t) + \tau v_y, v_x, v_y) \,. \tag{3}$$

Here, τ is the time the robot needs to reach the next grid cell, which depends on the maximum speed of the robot. This process results in a time variant potential field reflecting the changed obstacle situation in each planning step. Planning in this time variant potential field avoids paths that interfere with the predicted trajectories of the moving obstacles.

As the original method included backwards planning from the target to the starting point of the robot, the proposed algorithm must know the time T the robot needs to reach the target a priori to predict the obstacle positions. However, T depends on the planned path, which is unknown before the planning. To overcome this problem the algorithm calculates the minimum time T_{min} depending on the Euclidian distance from the start to the target point and the maximum robot speed. This time is always an underestimation of the time needed to follow the resulting path. Using this a priori estimation a path is planned and the time the robot actually requires to follow this path, the a posteriori time, is compared to the a priori estimation. If the difference between those two times is lower than a given threshold the planning is finished, otherwise the planning iteratively continues with the a posteriori time from the last iteration as a priori estimation for the next iteration.

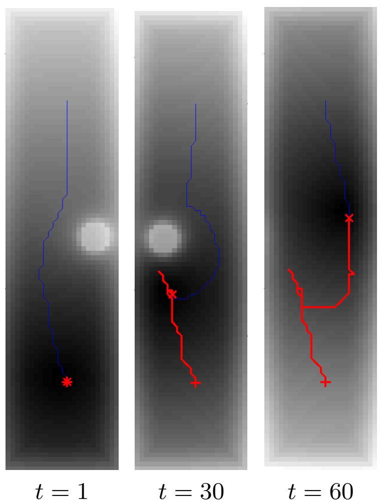

Fig. 1. Conventional path planner

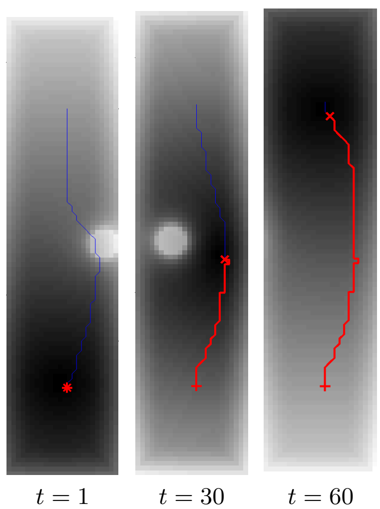

Fig. 2. Path planner based on time variant potential fields

First experimental results of the algorithm show, that the iterative path planning process needs very few iterations to converge to a reasonable path avoiding the trajectories of the moving obstacles. Figure 3 shows paths planned in a simple simulated scenario. The robot starts in the lower middle of the field marked with a red plus sign, while the target point is in the upper middle. An obstacle moving at a constant speed crosses the direct path to the goal. A conventional path planner based on the approach of Weigel et al. fails to plan an efficient path avoiding the moving obstacle, shown in the three snapshots on the left after $t = 1$, $t = 30$, and $t = 60$ cycles. The current position of the robot is marked with a red cross, the planned path is the thin blue line and the real path travelled by the robot is shown as thick red line. As the conventional path planner does not consider the movement of the obstacle, it nearly collides with the obstacle at $t = 30$ and has to drive away from the target to avoid it. The three snapshots show the same scenario and the path planned with the novel approach. Here, the robot clearly avoids interfering with the obstacle and plans a very efficient path to the target right from the beginning. For this path only a single iteration was necessary to estimate the time needed to follow the path with an accuracy of less than 100 milliseconds, thus resulting in a very fast path planning approach comparable to the standard potential field path planners.

4 From Passive to Active Defense of the Goal

Many goal keeper robots that played in recent RoboCup competitions have a fairly good defensive behavior moving sidewards on the goal line or on a half circle in front of the goal. The main control parameter for the position of the

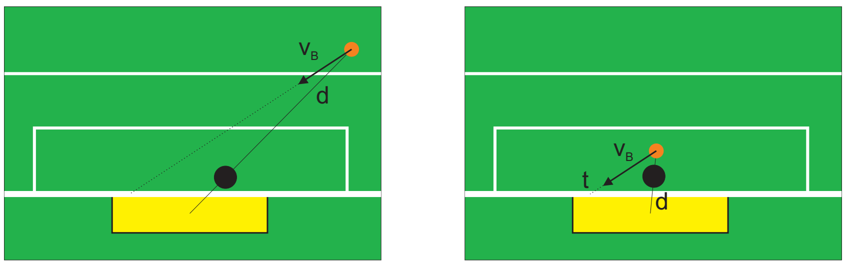

Fig. 3. A typical goal keeper reacting to a shot as if the ball was not moving. It only tries to minimize the angles under which the ball can be shot into the goal.

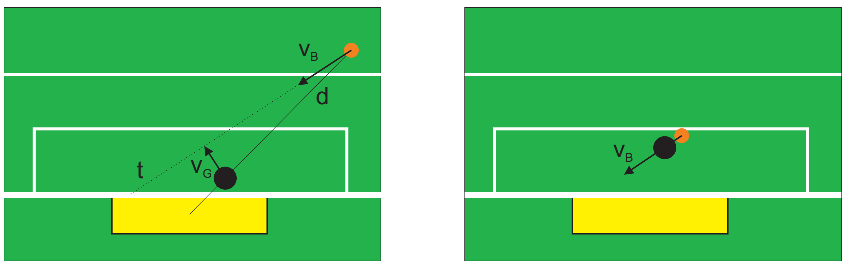

Fig. 4. By incorporating the velocity of the ball, the proposed behavior reacts with an active defense of the goal trying to intercept the ball on its predicted trajectory.

goal keeper on these lines is the position of the ball. Typical keepers try to minimize the angles under which the ball can be shot into the goal avoiding the goal keeper. This can be reached if the keeper takes a defense position on the line d going through the ball and the middle of the goal (cf. figure 4). In cases where the ball is shot in the direction of the farer goal post, however, this behavior is too static until the ball is directly passing the goal keeper. Considering the delay from perception to reaction of the goal keeper and its maximum acceleration, such situations will result in a goal in most of the cases.

Yet, these situations can be handled more successfully if the velocity of the ball v_B is detected through a good object tracking. Then, the goal keeper is able to predict the trajectory of the ball t and can actively defend the goal by moving into the trajectory to intercept the ball (cf. figure 3). Even considering the reaction time of the goal keeper and its maximum acceleration, there is a high chance of intercepting the ball, as the goal keeper moves perpendicular into the predicted trajectory resulting in a very short distance. Experiments carried out in our laboratory showed that this behavior drastically reduces the number of goals received by shots to the farther goal post.

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