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Desktop Robot Soccer

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1. Introduction

Robot soccer pits teams of fast-moving robots in a dynamic environment (Sng et al., 2002). Robot soccer fosters AI and intelligent robotics research by providing a standard problem where a wide range of technologies can be integrated and examined (Asada & Kitano, 1999). Today two international robot soccer federations, *RoboCup* (RoboCup, 2007) and *FIRA* (FIRA, 2007), organize competitions in an eclectic range of categories. Those competitions are accompanied with technical conferences. The first international robot soccer tournament MiroSot'96 was held at Korea Advanced Institute of Science and Technology (KAIST), in November, 1996. At the time of writing, we can count more than ten different robot soccer leagues from RoboCup and FIRA.

Taxonomy of the robot soccer leagues could start with the vision system used. The *global vision* group contains all the leagues that allow a global vision system (camera that gives an eye-bird view of the playing field). The image processing is done on a PC that controls the robots via a radio link. Whereas the *local vision* group contains all the leagues that require the vision processing to be done on the robots themselves. In this second group, the robots achieve a higher level of autonomy. Only wheeled robots are used in the global vision group. Whereas, the local vision group can be subdivided into wheeled robots and legged robots. Finally there are simulation leagues that provide a test bed for multi-agent research for those who do not have access to real robots.

Robot soccer not only stimulates robotic research, but also provides a platform for computational intelligence education that allows the development of engaging undergraduate level assignments. However, there are several limiting factors for the widespread use of robot soccer as a research platform or a teaching tool. Most robot soccer leagues like the popular RoboCup Small Size and FIRA Mirosot leagues require a large playing field and a team of several postgraduate students to build the hardware and develop the complex software. The least resource-demanding robot soccer league is the simulation league. Unfortunately, by its very nature, this league does not provide the invaluable experience of real robots. With the constraint of using real robots, the least resource-demanding robot soccer league is arguably the FIRA KheperaSot league. This league represents *Desktop Robot Soccer*, in the sense that the playing field fits on a desktop or a computer laboratory bench.

The regulations of the KheperaSot league impose size restrictions on the robots. The size limitation lowers the entry barrier for participants in relation to other robot soccer

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tournaments, making it more accessible to individuals and small teams with modest funding and infrastructure support. The size limitation also poses challenge for hardware technology. It pushes the limits of how much processing and sensing can be put into the small package at a reasonable cost. However the size is not as small as to requiring miniaturisation technology beyond the reach of standard electronics and construction techniques. The KheperaSot league was the first fully autonomous robot soccer league of FIRA.
Section 2 provides an overview of KheperaSot league. Section 3 describes the winner of the 2003, 2004 and 2005 KheperaSot World Cups. Section 4 discusses how robot soccer can be used in the undergraduate curriculum. Section 5 concludes the paper.

2. KheperaSot League

The KheperaSot league has its origin in the 1997 Danish Robot Soccer Championship organised by Henrik Hautop Lund (Lund, 1999). The Khepera robot (Fig. 1) is a two-wheeled cylindrical robot with a diameter of 70 mm, equipped with a ring of 8 IR proximity sensors, wheel encoders and a linear camera turret (Fig. 2) that produces a horizontal linear image of 64 pixels with 256 grey levels. These 64 pixels allow the detection of the ball (a yellow tennis ball), the goal (large black zone), and the opponent robot (wearing a black and white stripped shirt).
The main difficulties of the KheperaSot league reside in the limited computational resources (512K of memory) and the low resolution of the linear camera.

Fig. 1. Khepera II robot

The KheperaSot playing field is 105 centimetres long and 68 centimetres wide (see Figure 3) and is surrounded by grey walls. The goals are openings in opposite walls and are painted black inside. Both goals look identical. A match consists of five rounds of at most four minutes each. A round ends when a goal is scored or when the ball does not move for thirty seconds. The team that scores the largest number of goals is declared the winner. At the beginning of a round the ball is placed at the centre of the field. The players are positioned differently at the start of each round.

Fig. 2. Linear camera turret

The referee points out 180-degree rotation symmetric starting positions. Each player starts facing its opponent's goal line. A starting position in the opponent's half is possible. The KheperaSot environment is shown in Figure 4.

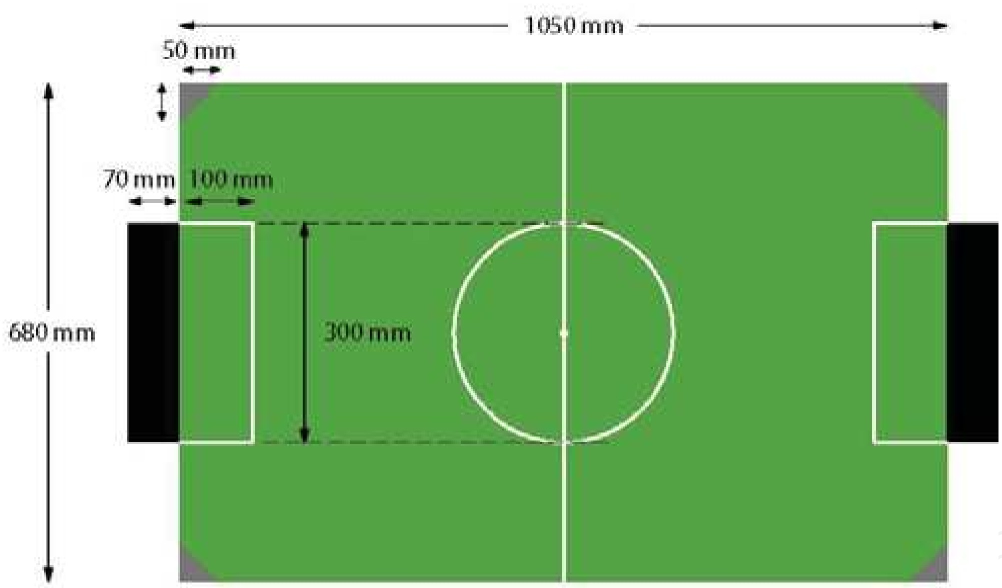

Fig. 3. KheperaSot's floor plan

Unlike leagues allowing a global vision system, the KheperaSot robot has to find it own position in a completely symmetric environment. The only information that the robot can exploit is that it is facing the opponent's goal line at the start of each round. But if the robot get disoriented in the course of a round, it is impossible to determine which goal is the opponent goal from visual clues. Apart from the intrinsic limitations of the odometers, pushing by the opponent can create further odometric errors. It was not uncommon in the first years of the competition to see confused robots score own goals.

The cylinder shape of the robot and the grooves on the tennis ball makes dribbling the ball a challenging task. During a game, the ball might be pushed into a corner. It is not a trivial task to unstuck the ball from the corner.

Fig. 4. KheperaSot's arena

One of the most attractive features of the KheperaSot league is its relatively low cost. Robot soccer leagues which require many robots and a large field such as RoboCup – Small Size League, have budgets of at least 30,000 US$ for the hardware (Peel, 2003). KheperaSot requires a much smaller budget. Moreover the playing field can fit on a desktop. A single person can look after a KheperaSot system, whereas the other leagues have typically teams of half-a-dozen people.

3. Description of Kheperoo

QUT's entry in the KheperaSot league, called *Kheperoo*, has won three KheperaSot World Cups in a row (2003, 2004 and 2005) before retiring. In this section, we give an overview of the system and describe the strategy used.
The software architecture used is a finite state machine with multiple threads running concurrently. Kheperoo's top priority in the game is to get to the ball first and move the ball away from the opponent. If Kheperoo manages to move ball away from the opponent's vision field, the opponent will need some precious time to locate the ball again. During that time, our robot can take advantage of the opponent confusion and push the ball towards the opponent line. Kheperoo deliberately does not try to head for the goal directly, but simply the opponent line. The rationale behind this decision is that the opponent is more likely to be in between its goal and the ball because of the symmetry of the starting condition.

After racing to the ball, Kheperoo dribbles the ball towards the opponent's goal line based on the estimated orientation provided by the wheel-encoders (they play the role of a virtual compass for a short period of time).

If Kheperoo is lucky, the ball may end up directly in the opponent's goal. Most of the time, the ball will get stuck against the opponent's wall. This situation triggers a complex behaviour to push the ball into the opponent goal. An overview of Kheperoo finite state machine is shown in Figure 5.

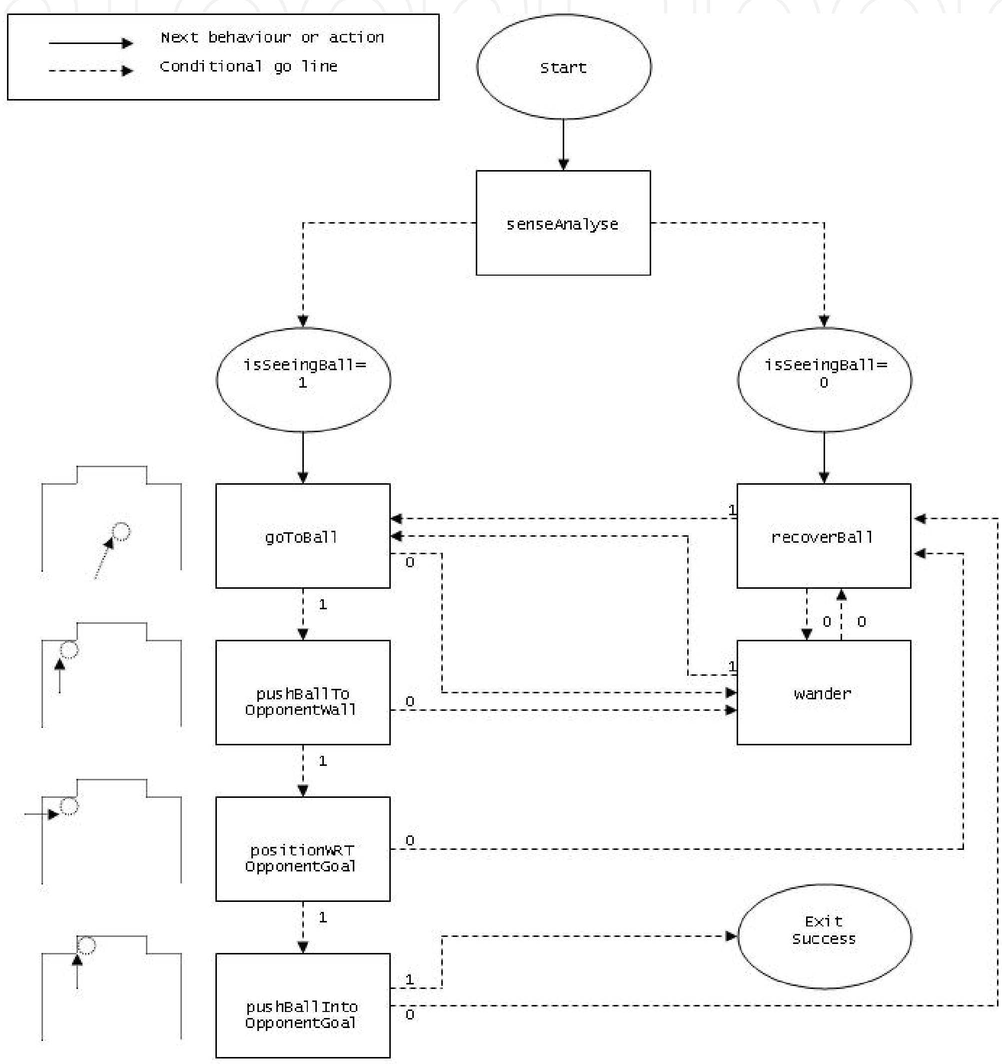

Fig. 5. The finite state machine of Kheperoo

Apart from the main control thread, a watchdog thread is used to monitor the robot's wheels' status. The robot has to be able to detect and stop when it runs against a wall to avoid the wheel slippage problem and prevent any damage to the robot itself. The actual wheel speeds and desired wheel speeds are compared to determine whether a static obstacle is in the way.

To alleviate the problem of accumulative odometry error, Kheperoo will reset its pose when it knows the actual direction base on some specific situations. When the robot moves steadily along the side wall, its direction must be either facing opponent or facing own goal lines, this information and its current pose based on odometry can be used to determine its actual direction. The robot can also calibrate its direction using proximity sensor when it stops in front of the opponent wall.
Complex behaviours such as *unstuck the ball from the corner* also use the watchdog to complete their tasks. To unstuck the ball, first, the robot will position itself carefully with respect to the ball, then push the ball straight to the wall until some resistance is felt. After that, the robot will spin on itself to unstuck the ball. Hopefully, the ball will roll out from the corner.
For dribbling the ball, we use the fact that it is more effective to control the ball direction when the ball is rolling because the ball already has some momentum. One method to make the ball roll straight away before the robot starts dribbling is to give a strong kick to the ball. After the kick, the ball usually rolls in a straight line and the robot can continue to forward dribble the ball. In some case, the ball does not roll in a straight direction and the robot needs to circle around the ball to recover its dribbling direction. But at least after the kick, the ball has moved closer to the opponent side.
We attribute the success of Kheperoo in competition to its speed, robustness to sensor noise and ability to handle deadlock situations.

4. Experiences with desktop robot soccer as a teaching tool

The development of practical sessions and assignments for undergraduate teaching typically requires a compromise between what is achievable by an average student and what engages the interest of a more advanced students in the class. Selecting a suitable compromise is particularly problematic for undergraduate computational intelligence (CI) teaching units which typically attempt to cover a very broad range of AI and machine learning techniques. At our university, the curriculum of the CI unit includes topics like fuzzy logic, neural networks, reinforcement learning and genetic algorithms. We believe that the undergraduate students should experience the non-deterministic characteristics of a real robot environment (as opposed to a simulated one). Students should focus on the interaction of a single robot with its environment before dealing with scenarios that require a multi-agent system. In other words, students should familiarize themselves with sensory noise, motor characteristics and uncertainty before trying to coordinate complex robot behaviours for a team play in a multi-agent framework.
A challenge with teaching abstract concepts is finding illustrative examples for the ideas presented. That is, finding real problems to be solved with the abstract methods provided in the lectures. In the prevailing teaching paradigm, the lecturer instructs the student on how to solve a problem step by step. The lecturer also tells the student what problems are solvable with each problem-solving method. The drawback with this approach is that the lecturer performs the greatest part of the cognitive processing. This is why we have followed a problem based approach. The goal of the assignment is formulated and given to the students who should find suitable solutions to the problem by themselves. It is up to the students to decide which of the CI techniques covered in the lectures are relevant to their problem. In this context of problem based teaching, the lecturer and the tutors become

coaches for groups of students. In problem based learning, it is very important to make goals, assignments and expectations on the students as clear and exhaustive as possible (Ambury, 1992). If the requirements are unclear the students might lose interest in the course or do something totally different than what was expected by the teachers.
Below is the weekly task schedule of the laboratory sessions. The first sessions are relatively structured and served as an introduction to mobile robotics to most of the students (Keeratipranon et al., 2003).

- Session one; get an idea on how we can communicate with the robot
    a. Install KTProject (software to compile and download executables to the Khepera robot)
    b. Get familiar with Tera Term Pro (terminal emulator for serial communication with the Khepera robot)
    c. Communicate with the robot using Matlab
    d. Modify the *obstacle avoidance*, Braitenberg vehicle project such that the robot avoid the black area (robot's IR proximity sensor cannot detect black object as black colour does not reflect well the IR signal back to the robot) using KTProject
    e. Implement a *wall following* behaviour.
- Session two; provide students with a template example
    a. Reverse engineer the template; student will know how to
        1. Read and use proximity sensor values
        2. Control a robot using the keyboard and serial communication
        3. Create a multi threaded program (multi tasking)
        4. Detect that the robot is stuck
        5. Estimate the direction of the robot base on the left and right wheel encoders.
    b. Create a new project using a given template.
    c. Interact with the robot via keyboard control
    d. Modify the *wall following* function so that it can follow a T-shape object.
    e. Brainstorm about what basic behaviours are required in order to create a robot soccer player.
- Session three; implement some basic behaviours
    a. Continue the exploratory work on proximity sensors.
    b. Finish the *obstacle avoidance* and *wall following* behaviours.
    c. Implement a *ball following* behaviour. In this behaviour, the robot will follow the moving ball using only proximity sensors while the ball is in front of the robot at a short distance and moved by a person.
    d. Implement a *circle around the ball* behaviour. In this behaviour, the robot will move around a static ball.
- Session four; implement more complex behaviours
    a. History shows that many teams will not have completed the *wall following*, *ball following*, or *circle around the ball* behaviours. Therefore, this session gives more time for the slower teams to catch-up.
    b. Implement a *dribble the ball* behaviour. In this behaviour, the robot will push the ball forward in a straight direction. The *pushing ball* behaviour is one of the

milestones for the assignment. Teams that cannot demonstrate this behaviour on the real robot by the deadline suffer a penalty in their final marks.

- Session five; milestone week and use of a new sensor: the linear camera
    a. At this stage of the semester, every team should have mastered the proximity sensor well enough to demonstrate a dribbling behaviour.
    b. Get familiar with the linear camera.
    c. Design a *look for the ball* and a *go to ball* behaviours.
- Session six; vision sensor
    a. Implementation of a *look for the ball* behaviour. The aim of this behaviour is to locate the direction of the ball. A tennis ball can be differentiated from other objects as it has a bright colour compared to the wall or the goal.
    b. Implementation of a *go to ball* behaviours. After locating the ball, the robot has to be able to move to the ball. The desired property of this behaviour is speed and reliability.
- Remaining three sessions; free style development
    a. The development of all other behaviours is left to the initiative of the students. They have to decide which of the techniques presented in the lecture they will use (if any). The tutors employ at this stage a problem based learning approach to guide the student groups.
- Final session; friendly competition
    a. Each team has the opportunity to showcase the result of their effort in the end of the semester KheperaSot competition. The assignment marks do not depend directly on the competition results, but observations made during the games are taken into account for some marking criteria.

Outside the laboratory sessions, the students have access to a KiKS, Khepera simulator (Nilsson, 2001).

5. Discussion

As discussed above the KheperaSot in its current form poses challenges in motion control, navigation and self-localisation, as well as in higher level autonomous behaviour design and implementation.

The reason why we support and encourage the KheperaSot league is the complete autonomy of the robot combined with its small size. The autonomy enhances the educational value of the tournament by putting it on par with prospective autonomous mobile robot applications that have to rely entirely on their own sensors to acquire information of the world around them. The autonomous nature of the KheperaSot league also provides a natural evolutionary pathway for the game, allowing it to maintain challenges as the technology and the experience of the players advance.

The size limitation lowers the entry barrier for participants in relation to other robot soccer tournaments, making it more accessible to individuals and small teams with modest funding and infrastructure support. The size limitation also poses challenge for hardware technology. It pushes the limits of how much processing and sensing can be put into a small package at a reasonable cost. However the size is not as small as to require miniaturisation technology beyond the reach of standard electronics and construction techniques.

We have successfully integrated Khepera robot soccer into our computational intelligence course. The laboratory sessions are organized in a standard computer laboratory equipped with rows of computer benches. At the beginning of a session, we bring in the soccer fields. Students have demonstrated that they gain understanding of the many issues with embedded systems programming such as the real time aspects; interrupt driven programming, and completely different program debugging resources.
Student's programming skills have been expanded from the experience with real robots. Students can have a visual feedback through the displayed behaviour of the robot. Unexpected situations have happened such as a failure to track the ball while the robot is moving fast to the ball. This failure is not necessarily due to the low frame rate of the camera but can be due to the backward tilt of the robot with the acceleration (the ball goes below the horizon). These types of real-world problems are not experienced with a simulator.
The most obvious extension of the current KheperaSot is the replacement of the current 1D vision by a 2D colour camera. Digital image sensors of the type used in mobile phones are cheap and widely available, some of them include a microprocessor for low level image processing. Two solutions are already available for the Khepera: the adaptation of the CMUcam by K-team (K-team, 2007) and the 2D camera developed by the Paderborn team (Chinapirom et al., 2004). Both allow vision image processing on the robot. Upgrading the vision system will provide the enriched realism of the game without a large increase in cost. With a 2D vision system the KheperaSot league will have all the features of the humanoid and AIBO leagues, which are all autonomous, with the added complication of legged locomotion. For some time to come, wheeled locomotion will allow much faster games than the legged leagues resulting in more interesting games. Most importantly, 2D vision will facilitate multi-player teams and thereby largely expanding the opportunities for collaborative strategies. An expansion to 3 player teams seems feasible with a moderate enlargement of the playing field and without fully loosing the desktop characteristic of the KheperaSot league. One may argue that increasing the number of players per team also rises the cost. However, because of the autonomy of the robot, teams could be formed by students of different institutions each providing their own robots. Our ultimate vision would be to bring the cost to a level where individual enthusiast could buy their own pocket sized soccer robot for participating in a school or neighbourhood team.
Up to now the league uses Khepera robots, hence its name; however the rules do not exclude other manufacturers. As more powerful small size and low power single board computer (SBC) come on the market at low prices, such as the Gumstix (Gumstix, 2007) boards. We expect alternative robots to be built for the game.

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Many papers in the book concern advanced research on (multi-)robot subsystems, naturally motivated by the challenges posed by robot soccer, but certainly applicable to other domains: reasoning, multi-criteria decision-making, behavior and team coordination, cooperative perception, localization, mobility systems (namely omni-directional wheeled motion, as well as quadruped and biped locomotion, all strongly developed within RoboCup), and even a couple of papers on a topic apparently solved before Soccer Robotics - color segmentation - but for which several new algorithms were introduced since the mid-nineties by researchers on the field, to solve dynamic illumination and fast color segmentation problems, among others. This book is certainly a small sample of the research activity on Soccer Robotics going on around the globe as you read it, but it surely covers a good deal of what has been done in the field recently, and as such it works as a valuable source for researchers interested in the involved subjects, whether they are currently "soccer roboticists" or not.

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