IMAGE PROCESSING APPLIED TO A ROBOTIC FOOTBALL TEAM

Carlos Machado, Sérgio Sampaio, Fernando Ribeiro

Grupo de **A**utomação e **R**obótica, Industrial Electronics Department,
University of Minho, Campus de Azurém,
4800 Guimarães, PORTUGAL
fernando@dei.uminho.pt
http://www.robotica.dei.uminho.pt/

Abstract

Autonomous mobile robots are ever increasing their number of different applications, even in ludic applications or in sports. In the last few years, several robotic football competitions have been organised with participating teams from all over the world. This paper describes a team of Autonomous Mobile Robots which play football, developed by the Group of Automation and Robotics at the Industrial Electronics department (School of Engineering) of the University of Minho, in Guimarães (Portugal). In these competitions each team is free to use and/or build all the different electronics, sensory systems, playing algorithms, etc. as far as they cope with the rules imposed by the organisation. From every team new ideas emerge, sometimes the most incredible ones, but proving in the end that they work. These competitions proved to be very fruitful scientifically as well as very mediatic.

INTRODUCTION

Following a participation in other football competition, this team decided to increase reliability of these robots as well as implementing new improvements. The mechanics needed rebuilding and the software needed to cope with communication between the robots. Also some rules demanded some changes in the software and game tactics. Basically, the robots are typical ones with two motors/wheels with a differential type steering control. Each robot has a standard personal computer inside and some electronics to read the wheels movement (through encoders).

Instead of using several different sensors increasing electronics complexity, this team decided to use only one major sensor and invest some time on it: a vision system with a small colour camera. The main feature of this team consists of an innovative image processing system developed on purpose for this robots. In order to see the whole field, this vision system uses a convex mirror placed at the top of the robot looking downwards with the video camera looking upwards, towards the mirror. With this technique, the robots can see all around themselves with a top view, which means continuous vision of the ball, goals and other robots. All the image processing algorithms were developed from scratch. With this vision system, all the information necessary for the game is read avoiding though other sensors. Collision detection was an important aspect taken into consideration and is achieved also with image processing.

ROBOTS DESCRIPTION

The team is made up of four equal robots (with a small difference only to the goal keeper later described). Even the software running on each robot is the same. This way standardisation was achieved which means that they should behave the same.

The robot base used is made up of very light wood. It consists of a two levels platform with the two wheel voids. On the bottom level was placed the DC/DC converter (between the two wheels) and the two 12V 7Ah batteries (one at the front side and the other at the rear side). At the top level, it was placed the computer mother board and respective boards (video and graphics boards). The hardware consisted of a personal computer mother board with a Pentium processor running at 200 MHz (MMX), with 32 Mbytes of memory (although the DOS operating system was used and therefore only 1Mbyte was accessed). The hard disk had 2 Gbytes. A colour video camera was used with a frame grabber type Bt848. The communication hardware and software was not ready in time for the RoboCup99 competition and therefore each robot played on his own. Figure 1 shows one robot.

Figure 1 – One footballer robot with the ball

PERCEPTION

The game is played through the use of certain known colours. The ball is red, the goals are blue and yellow, the field is green with white lines, the surrounding walls are white and the robots are black. This sort of approach forces the call for a video camera. Therefore these robots use one only sensor to perceive all these items needed to play a game, which is a simple colour camera with its frame grabber plugged on a computer slot. But, most important of all is the way the camera sees. The camera is pointing upwards onto a convex mirror (as described in Figure 2), allowing therefore vision all around the robot from the top. This top view allows the robots to see far even when an opponent robot is covering the field of view. The mirror is pointing slightly to the front since it is more important to see to the front rather than to the back.

The image distortion provoked by the convex shaped mirror is not very relevant as can be seen in the example in Figure 3, since what matters is the direction of the entities and not their actual position.

Figure 2 – One footballer robot with the ball

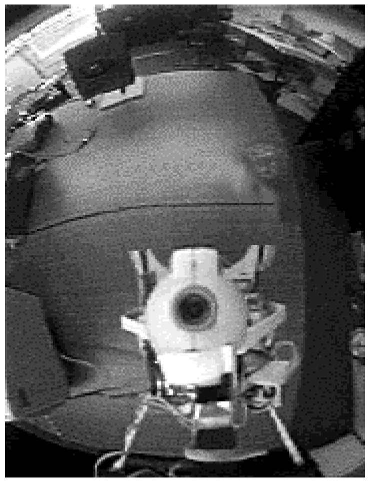

Figure 3 – Image seen by the robot

To perceive all the necessary entities of the game (ball, goals, etc.), these robots grab one image every 20 ms, and the software finds the peak of a certain colour (after removing noise). For example, to track the ball, the software searches a peak of red. Since colours depend very much on the light conditions, a calibration is made prior to a game, in order to inform the software what is the minimum value for a red to be a ball. The software tracks down the following items:

- the ball (by its red colour)
- the two goals (also by their yellow and blue colours)
- all other robots (mainly black coloured)
- the field surrounding walls (mainly white coloured)

These robots avoid collisions, by perceiving as uncollidable items all the black and/or white items. This is the way they avoid walls (mainly white) and other robots (mainly black). The white lines on the green field are ignored because what the robot sees is not "mainly white" due to the slim thickness of the lines.

WORLD MODEL

At any given time, these robots are aware of the ball (knowing its direction) and both goals direction. Robots on the field are also seen but not distinguished whether they belong to own or opponent team. This information is kept in the form of a direction variable, and when required they move towards it, updating that direction variable at every frame captured. These robots do not memorise anything else.

It is important to point out that these robots do not know precisely where they are on the field at each moment, but that is irrelevant according to the way they play football. They only need to know the other entities direction (ball, goals, etc.) from their actual position. This way, complex systems of triangulation or similar techniques are avoided (both hardware and software) simplifying the whole solution.

COMMUNICATION

Until now, this team did not use any communication between the robots. However, wireless network boards are now being implemented in order to achieve better results during a game. The network boards will allow faster programming, debugging and also

knowledge on the field (variables of the game) which can be shared with the other robots of the team.
Not a lot of information needs to be sent, just the state of a few variables, like instructions about actual state (a position, or a decision) or what to do next, and these messages have different levels of importance. Each robot can communicate with one other particular robot or with all of them at the same time. Being so, a complete confusion could be generated and therefore different levels of importance are used. This level depends on the owner position, or distance to the ball, goals, opponent robots, etc. The robots communicate only when it is needed (not all the time) in order to keep the radio environment free for urgent messages to pass through.
Since the goal keeper is most of the time still on the field, he can be used to send to all other robots important information the like the position of the opponent robot players or the direction of the ball, or even if he is alone at the goal and need help (just call all the other robots). Once again, the information have different degrees of importance.

SKILLS
In order to drive the ball, these robots use an arc shape controller with a re-entrance of 7cm (maximum allowed by the rules). This way, ball control is achieved just by pushing it, although a sudden change of direction might mean loosing the ball. These sudden changes of direction are avoided by the robots software by following longer and wider trajectories.
These robots intercept the ball very easy. When they see the ball, they just go towards it, avoiding collision with the opponent robot, but insisting and never giving up, until the opponent robot looses the ball. Once they have the ball, they move towards the opponent goal dribbling the opponents (and avoiding collisions). In case they loose the ball, instantaneously start the procedure "following ball" again.
When owning the ball near the opponent goal, these robots do not kick the ball. They run into the goal pushing the ball with their body. This means a disadvantage since most goalies are very good and attack the ball sufficiently fast to avoid scoring.
This team's goalie is different from the other players only what concerns the direction of the wheels. These are rotated 90 degrees in order to be fast defending the goal rather than moving towards the front. The goalie software is very simple and consists of looking and observing the ball all the time. That is possible with the convex mirror. It then moves sideways in order to keep its body always in the ball's direction no matter how distant this is. When the ball approaches, the goalie kicks the ball with its arc rotating its body, doing a movement like a tennis player with its racket. This movement is very beautiful and improves the quality of the game and the emotion when watching. This technique not only avoids a goal but also kicks the ball far away from its goal.

STRATEGY OF THE GAME
Since these robots always have an eye on the ball, their reaction is very simple and efficient. When they don't have the ball, they go towards it and don't give up until they get the ball. Once they have the ball they go towards the opponent goal in order to score, and avoiding obstacles. If, for some rare reason they don't see the ball, they start moving in a spiral until they see the ball again (avoiding the walls, of course).

As the only sensor available for the game, the vision is of extreme importance. The game strategy consists of a set of rules and contains the robot's "personality and behaviour". The game strategy needs some variables, which are given by the image processing. From each image the following variables are extracted.

BD - indicates if the ball is seen by the robot
BP - indicates if the ball is near the robot
BH - indicates if the ball is in the ball holder
BAD - indicates if the opposite goal is seen
BAP - indicates if the robot is in front of the opposite goal
BND - indicates if the own goal is seen
BNP - indicates if the robot is in front of the own goal

Some others variables are also extract but not as relevant as these ones. If the maximum of a pre-determined colour is inside one of the defined squares, that means that variable is on. Five (or more, depending on the configuration used) white rectangles around the camera are used to detect collision. Should one of the "sensors" be mostly filled with the white or black colours or pixels (normally these should be green) then it means that an obstacle is in that location. In that case, the obstacle avoidance routines automatically starts off, making it high priority moving the robot away from that place and therefore avoiding the obstacle no matter it is another robot or a wall. The white lines drawn on the green filed will not be considered an obstacle since they will never fill in one of the rectangles (they are too narrow). Figure 4 shows an example of an image seen by the robot with all the squares (or rectangles) superimposed. Arrows point to coloured rectangles or maximum of some colours.

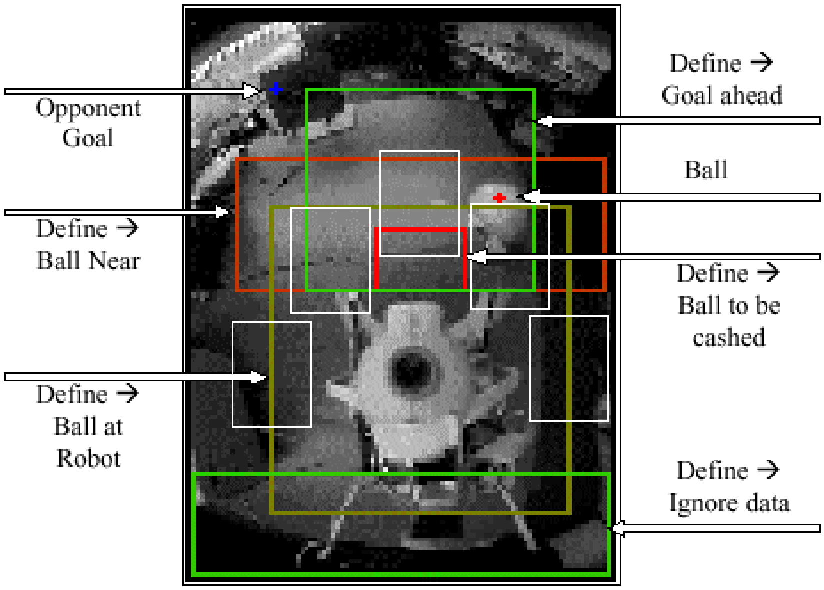

Figure 4 – Variables captures from the image seen by the robot

With all these variables, the robot strategy simply consists of a *Grafcet* , which sets up the robot's aim as well as the dynamics moves towards a specific target, such as the ball or the goal.
In all, the control used by this robot has three levels:

- Level 3 (Grafcet) ⇒ This is responsible for the robot's global behaviour. This level sets up the targets and sequences to reach the final aim.
- Level 2 (dynamics) ⇒ This level is responsible for the immediate behaviour, i.e., the control of movements, based on the aims established by level 3.
- Level 1 (Controller PI) ⇒ This level serves directly the motors and is responsible to perform the plan established by level 2. At this level it is possible to extend the performance of the superior levels.

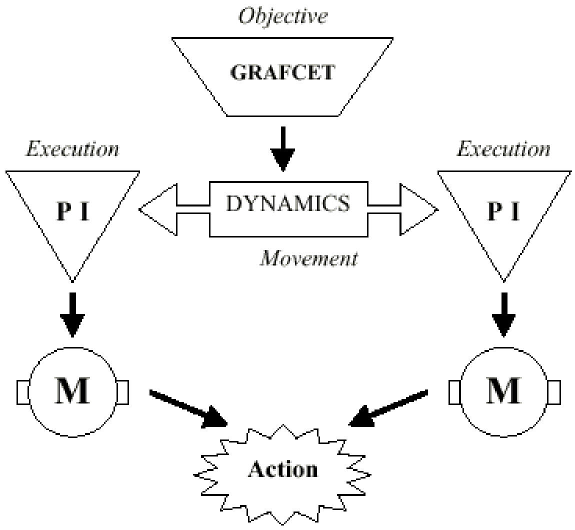

Figure 5 – Levels of Control

SPECIAL TEAM FEATURES

The image processing was the most important aspect of this team. It proved to be very consistent, very fast and original. All the video drivers were re-written by the team in assembly language in order to take the most out of the video board. This way, 50 frames were achieved making the rest of the control program an easy task. All the image processing routines were written in assembly language in order to increase speed and it proved to be very necessary. The general control program and strategy was written in C language since it did not need to be extremely fast. Sometimes, in two consecutive cycles the same image was analysed (giving the same result as the previous cycle), proving that it was not necessary to have a so fast machine.

The mirror technique also proved to be very efficient since everything can be seen at all time. With everything on sight, it is much easier to make the flux control program.

CONCLUSIONS

As main conclusions it can be said that the image processing developed and used by this team is the most important characteristic. It is very reliable, consistent, fast and original. The robot movements are very smooth and acceptably unpredictable unlike a typical algorithm with known steps used by many teams.

All the hardware in the robots was designed, developed and built by undergraduate students at the University of Minho. Only four robots were built due to lack of budget (no spare robots). These 4 robots were designed, built, programmed and tested by three industrial electronics students only. By participating on RoboCup'1999 the team learned a lot and gained experience in competing. The main improvements needed by these robots consist mainly in improving the mechanics reliability.

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