Footballer Autonomous Mobile Robot – Control and Vision System

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Abstract

This paper describes an Autonomous Mobile Robot which plays football. This project was developed by three senior students from the Industrial Electronics Engineering course during their probation period. The rules dictated the same structure for every team but then each team would solve, develop and use different electronics, sensory systems, play algorithms, etc. This robot uses one major sensor which is a vision system with the use of a colour camera. All the image processing algorithms used by the robot were developed and are hereby described. This robot uses also an innovative approach to see the whole football field (or most of it) at any time. A convex mirror was placed on the top of the robot looking downwards and the video camera looks at it. This way, the robot can see both goals, the ball and other robots, all the time. This idea proved to be very usefull for this type of application. This paper describes all the image processing and control software made specially for it

Keywords: Mobile Robotics, Autonomous Robotics, Image Processing, Football Robot Contest.

1 Introduction

The work hereby described consisted in the construction of an autonomous mobile robot that plays football to participate in an international football competition of mobile robots, namely the "Festival International des Sciences et Technologies" held in France.

These type of competitions are getting more and more frequent as well as more competitive as more universities are getting involved. Different and innovative approaches are being thought of and some of them can then be used in other applications whether industrial or not.

The construction of robots or teams of robots to participate in this sort of competitions involves many areas like electronics, mechanics, computer science, systems design, therefore involves also a team of people with different backgrounds working together, generating though sometimes good solutions.

For this particular contest, several teams competed with the most different ideas. The main rule was that the wood platform should be equal for every team as well as the motors, in order to have a fair game between all the teams.

The sensory system and the algorithm to actually play football was up to each team. The project described in this paper, used as sensory system a unique video camera which "sees" everything needed for the game. Since one camera can see only in the direction which it points to, a convex mirror was placed over the robot and attached to it, and the video camera points to that mirror. With this technique, the robot can see all around it (360 degree around it and not only to the front), the field of view is increased, and a top view is achieved which simplifies the playing algorithm. This technique proved to be very successful and worked better than expected.

In this paper, it is described the robot itself, the image processing and the control algorithm.

2 Robot Description

In this section the mobile robot platform as a whole is described. This system has several different and independent parts which implies an independent description.

2.1 Platform

The football player platform is made of wood and consists of a round base with 35 cm of diameter; a 22 cm side squared platform placed over the round base; four 15 cm height supports to hold this superior platform; encoders sensor supports; and motors supports. The superior platform is where the computer mother board is placed and the batteries are placed under it.

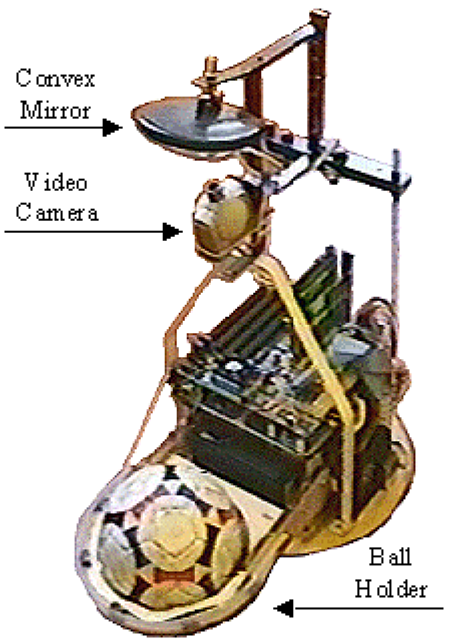

Figure 1: Footballer

2.2 Wheels

Two 9V DC motors with speed reduction are used. Each robot has two drive wheels and two support wheels. The two support wheels are spherical and made of metal and are able to rotate in any direction. These wheels are positioned at the front and back of the robot. The drive wheels are made of wood and measure approximately 13 cm diameter, they are positioned one of each side of the robot's base, and they are directly connected to the motors. These have three rows of holes. Two rows can be used to determine the speed and direction of the rotation. The other row can be used to calibrate the encoders.

2.3 Ball Holder

The Ball Holder is a structure that enables the robot to control de ball. It consists of a wood ring that descends over the ball helped by two levers. A servomotor activates these levers. The Ball Holder has also a bumper to detect touch.

This device enables the robot to manoeuvre and control the ball and to simulate the opponent players, without losing the ball. When the ball passes under the ball holder, it is moved down and catches the ball.

2.4 Mirror and Camera Support

The mirror and camera support is made of iron and aluminium. This structure allows changing de mirror and camera positioning and can also be used to grab the robot like a handle.

3 Vision System

3.1 Vision strategy

In order to play football, the robot has to be able to locate the ball, to grab the ball, to push it up to the opponent goal and to score a goal, taking the ball into the opponent team goal.

For locating entities, colours were used. Therefore, the colour red was used for the ball, the colours blue and green were used to locate the goals of each team.

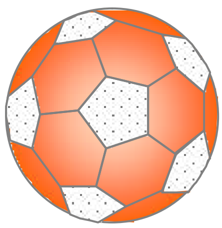

Figure 2: The ball

- Ball recognition

As the ball is red, with some light reflectors, it can be detected by infra-red means (reflected in the ball). It was decided to use the colour of the ball as means to detect the ball. This technique implies a fast and known image processing procedure. This way, the robot has faster reflexes and controls the ball in a better way.

- Goal recognition

To locate the goal it was used the same technique as to locate the ball. The colours blue and green were used to detect the goals (one each). The blue colour was used in the opponent goal by no special reason. A coloured board with a light bulb on it (with the same colour) was placed behind each goal.

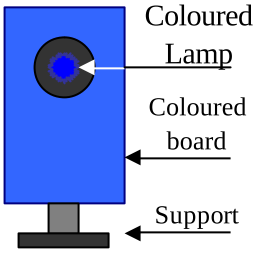

Figure 3: Goal board description

The coloured board consists of:

- a colour board, as larger as possible to enlarge the area, to facilitate detection
- a colour lamp, which helps detection from long distances
- a support that allows height control of the board (for longer distances)

3.2 Convex mirror

- Field vision

The convex mirror used enables the robot to have a wider and better vision in every direction and from the top. The convex mirror conveys the surrounding scenery to the camera. This increased vision field enables the robot to locate the ball, as further as 8 metres away, although this value is dependent on the distance between the mirror and the camera. The 360 degrees vision helps to control the ball without losing it from sight or to detect the presence of opponent robot even at the back side. The vision from the top helps to locate the ball, even if this is behind other robots. This way, time is not wasted to search the ball. This technique enables the robot to see the ball and the goals on the same image.

Figure 4: Mirror and Camera Support

Since the image processing detects the ball and goals by its colour, distortion caused by the mirror can be ignored. Advantage can be taken from this distortion because when an object is closer, its size is increased by the mirror, being represented on the image with more *pixels* and therefore the detection becomes more reliable with higher precision.

With the use of the convex mirror, the robot does not need to run all over the field, looking for the ball or the goal. Therefore, the robot moves towards its targets, saving energy and time.

Figure 5: Robot Vision

Typically, image processing systems demand heavy computations and this one was no exception. A powerful processor was used, an Intel Pentium MMX with 200 MHz with a small and low cost motherboard.

3.3 Board programming

The camera was placed underneath the mirror, in the vertical position looking up, in order to face the mirror as much as possible. In this case, the mirror was oriented in order to get a better view towards the front and less towards its back. This way it is able to see the goals from a wider distance.

- Video camera

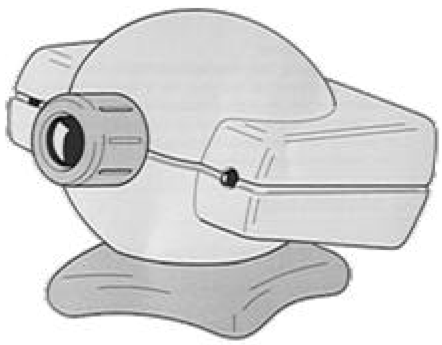

Figure 6: Video Camera

Due to weight and energy restrictions, the colour camera used was a small dimensions camera (77 x 62 x 84mm), low consumption (less than 2.5 W) with a single wire that links it to the board (the same wire carries the video link and power).

- Frame Grabber

The frame grabber board is a PCI bus type and has two video entries: an S-video entry and a compound video one. It has an integrated circuit unit called BT848 (Single – chip video capture for PCI) from Brooktree, where every function is done, since the decoding of addresses to the management of video digitalisation. It holds up the image resolution until 768 x 576 (the total PAL's resolution), it enables the image handling, through its RISC processor and digitalisation at RGB or YCrCb´s format.

- Software (Vision system)

Two different parts set up the vision system software: the routines that configure and control the board and the image processing itself. For this project, it was decided to use the MS-DOS operating system since it is less processor consumer, and would run faster. But this frame grabber board did not have drivers for this operating system, and therefore these had to be written. This means that everything was made from scratch.

The registers were configured to obtain a resolution of 768 x 288 with 24 RGB bits by pixel. As each field was considered a frame, 50 frames a second could be obtained. A RISC program was written in order to transfer the samples.

When the board is working on the digitised image, it becomes available in memory and therefore routines to copy the required information were developed. In order to speed up the program and to have more frames per second all the image processing routines were written in Assembler.

3.4 The Filters used

The video digitising board captures the images and moves them into memory. Each image is 768 x 288 pixels and each pixel has 24 bits in the RGB format with 8 bits each component. The pixels are aligned at 32 bits, all over the board, in order to speed the processing. The extra 8 bits are not used.

Pixel 0				Pixel 1				Pixel 2				----------	Pixel n			
	R	G	B		R	G	B		R	G	B	----------		R	G	B

Figure 7: Frame Grabber memory organisation

- Image Processing

Perception is the main objective of the image processing in an image. In this application, the main task is to identify and localise the elements ball and the goals. The usage of colour was intended to facilitate the recognition of such elements. A filter was developed such that, when set up for a specific colour, only that colour was seen making everything else dark. This facilitates very much the search.

Every pixel has the three components RGB (red, Green, Blue), whose combination can define any colour (ex: a reddish pixel will have an higher value in the red component, than in the other two).

To each pixel, a filter was applied which consisted of the following rules:

RED	GREEN	BLUE
val = C[R] - C[G] IF val < 0 → val = 0	val = C[G] - C[R] IF val < 0 → val = 0	val = C[B] - C[G] IF val < 0 → val = 0

Each filter only uses the information given by two pixels components therefore they do not filtrate some colours, such as violet in the red and blue filter or cyan in the green filter. In this application, there was no problem at all because those colours were not used. Although less robust, these filters were chosen due to their speed.

The value of the filters range from 0 to 255, being 255 the maximum limit in which the predominant colour is stressed. In order to detect, e.g. the ball, this filter is applied to the whole image. To reduce sensibility to the noise, the filters are calculated in a crossways around the pixel. The detection sensitivity can be calibrated being only necessary to add a threshold value.

As these filters have to be applied to an image of 768 x 288 with 24 bits (221184 pixels or 648 Kb of memory), the filters were developed in Assembler language in order to keep an acceptable image rate, taking advantage of the 50 frames available.

The filter routine takes as parameters a position (X , Y) relative to the image as well as a level of probability, which corresponds to the detected object. The detected object represents the greatest colour intensity in the filtered image.

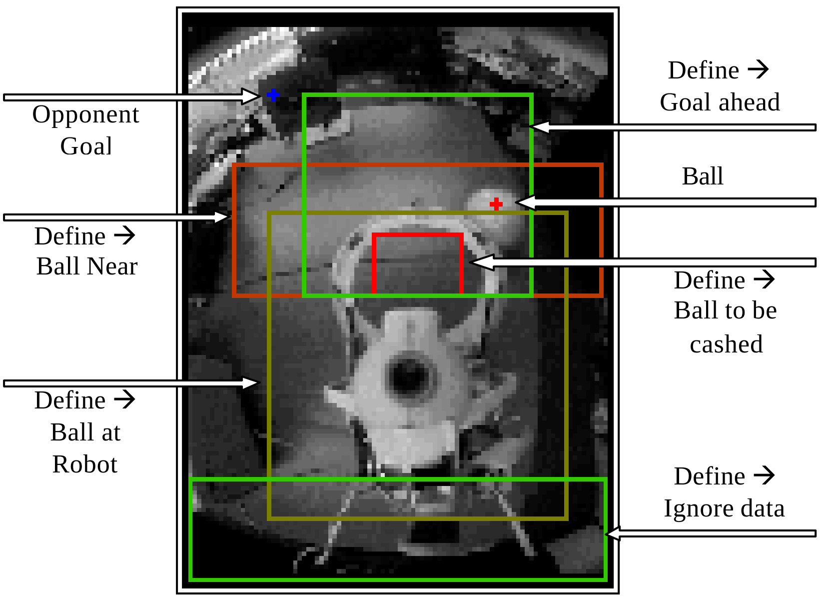

Figure 8: Example of a captured and analysed Image

Figure 8 was taken from a small supervision window of the software. Through this window, the image with all the objects and the context areas can be seen. In this picture, a small cross (red to the ball, blue to the opposite goal and green to the own goal) indicates the respective objects. The context areas are marked by coloured rectangles. The shape of the areas could be circular, three-cornered or any other.

When the elements location is known, this is checked against the colour rectangles in order to give logical values to the variables which will be later on used in the main program. For example, should the ball (that comes up in the picture marked with a red cross) be inside the red rectangle (near the robot), it indicates the ball is in good position to be caught. The process states that: if the ball is in the spindle, then the spindle has to lower, otherwise the spindle should rather be lifted. This action is simple and highly efficient. Besides this actions, there are still other ones (e.g. if the ball gets closer, then the spindle has to move slower).

The result of the image processing will come up as a way of logic variables, which show the context of a specific element. These logic variables can be used to control the program in a higher level, where the game strategy is set up.

3.5 Logical Variables

The game strategy consists of a set of rules and contains the robot's (football-player) personality and behaviour. The game strategy uses the following variables, given by the image processing and the ball holder bumper:

- defence - indicates if the robot is a defender or an attacker
- 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 under 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
- LB - indicates if the robot should let the ball go (by time limit rules)

The robot strategy 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.

4 Game strategy

4.1 Description of the control used

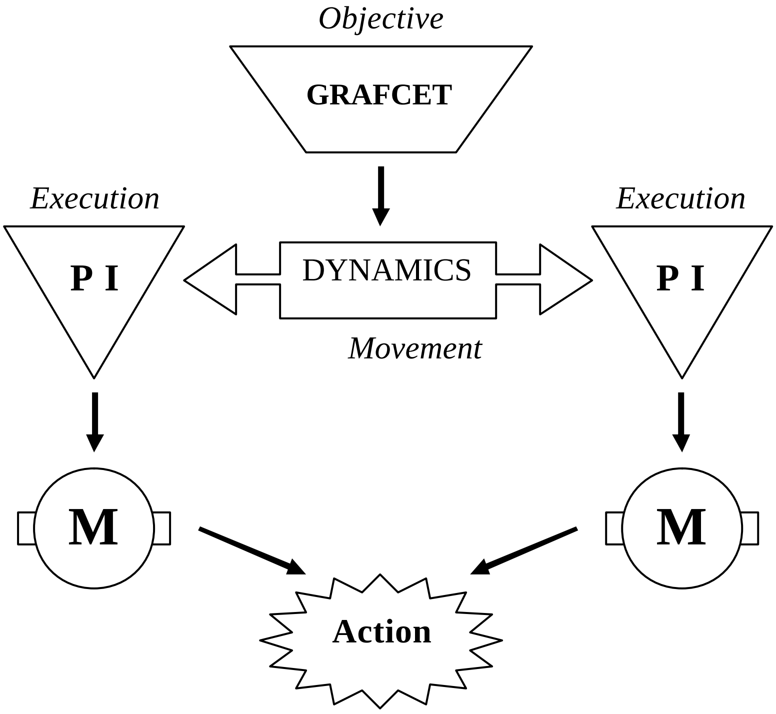

Figure 9: Global Control Diagram

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.

4.2 Controller PI

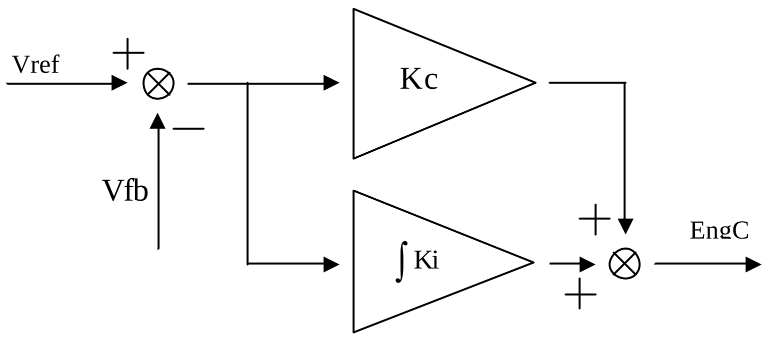

Figure 10: PI controller

A PI controller was used for each motor, to control the speed. The formula used was:

Error = Vref - Vfb

EngC = Kc $\times$ Error + Ki $\int$ Error dt

Where:

Vref → Reference speed
Vfb → Speed read by the decoders
EngC → Motor command
Kc → Proportional Constant
Ki → Integral Constant

4.3 Dynamics

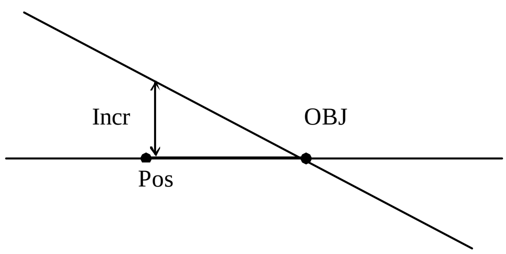

Figure 11: Dynamic function

The dynamics were simply used to help the robot to reach the desired target. This way, the dynamics' equation has a single attractor. In a near future, repulsors might be used to perform obstacle avoidance.

Further reading about dynamics can be done in:

- "A dynamic behaviour based robot", E. Bicho, 3 october 1995, seminario CNRS, Marselha, France.

- "The dynamic approach to autonomous robotics demonstrated on a low-level vehicle platform", E. Bicho, G. Schoner, International Symposium on Intelligent Robotics Systems, July 1996, Lisbon, Portugal.

- "The dynamic approach to autonomous robotics", E. Bicho, G. Schoner, P. Mallet, Journe Robotique, CNRS, Marseille, France, June 1997.

- "The dynamic approach to autonomous robotics demonstrated on a low-level vehicle platform", E. Bicho, G. Schoner, Robotics and Automation systems 21(1997) 23-25.

- "Target position estimation, target aquisition and obstacle avoidance", ISIE'97, 97TH8280, SS13-SS20, 3-7 July 1997, Guimaraes, Portugal.

- "Target representation for phototaxis", E. Bicho, September 1997, Institut fur Neuroinformatik, ruhr-universitat-Bochum, Germany.

- "The dynamic approach to design and implement behaviours on autonomous robotics low-level robots", Machine Intelligence Laboratory, Dep. of Electrical Computer Engineering, University of Florida, Gainsville, USA, October 1997.

4.4 Grafcet

Although a grafcet solution might appear very simple to a complex football robot, this was implemented with success. Each robot player can have two different behaviours within the same software: defender or attacker. The combination of these two behaviours with the logical variables previously described make it possible a simple solution like this. In this game two robots are used. One is said to be defender and the other attacker.

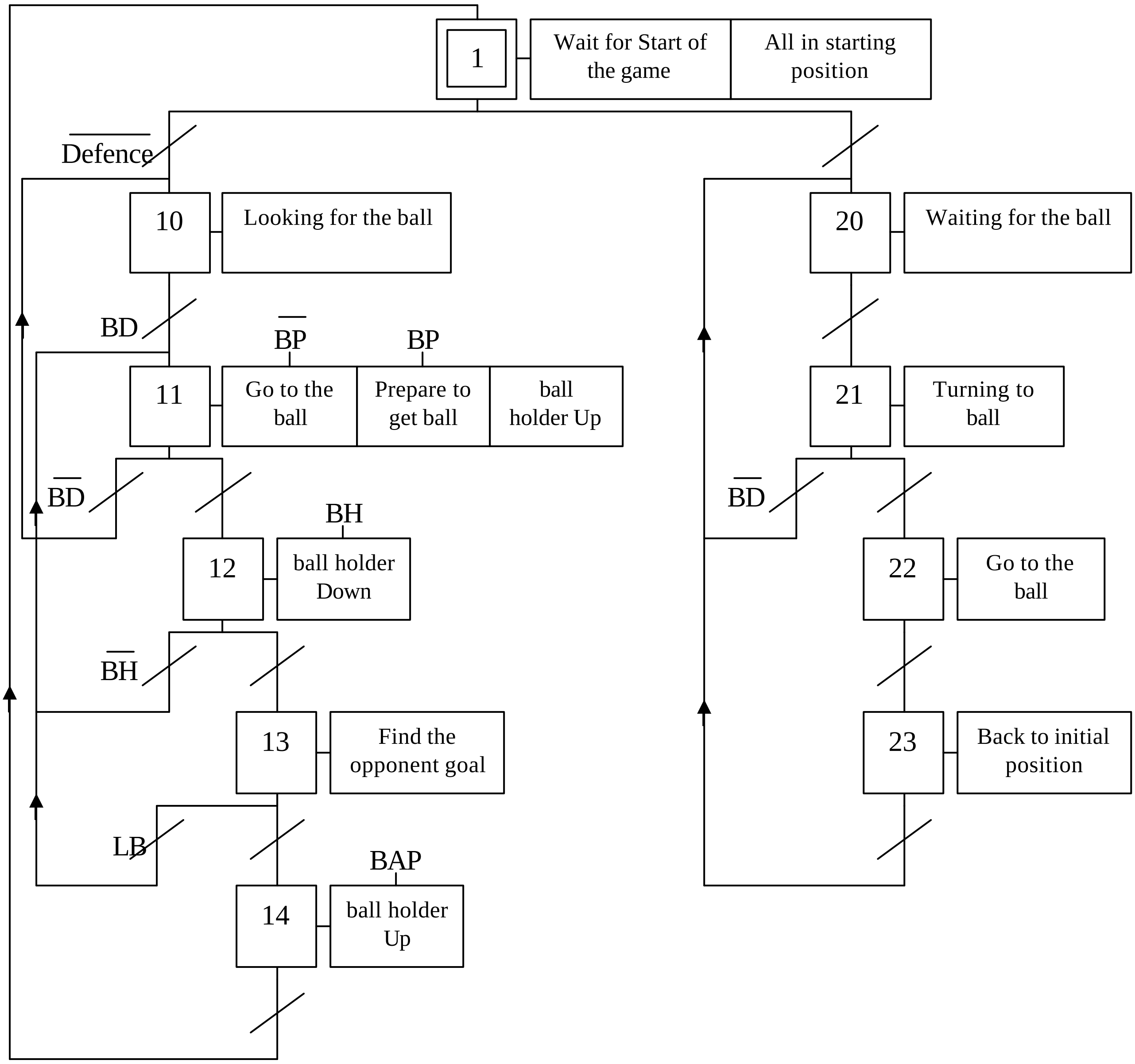

Figure 12: Game strategy *grafcet*

- Attacker

The attacker is placed in the middle of the field and when it sees the ball, it tries to catch it. Once it has the ball, it moves towards the opposite goal (after finding it) or starts moving around itself (in a spiral) until it finds the goal. When it gets by the goal, the robot lifts the ball holder even before stopping, turning back, and then returns to the centre field. If the ball touches the ball holder from the outside, the robot lifts it, but keeps on playing for 10 seconds.

- Defender

The defender is placed between the goal-posts and it stands still before seeing the ball. When the defender sees the ball, it turns to it without moving towards the ball, and if the ball gets closer enough, the motors are set on to the maximum of their speed, throwing the ball away from the goal and returning to the former position.

5 Global Diagram

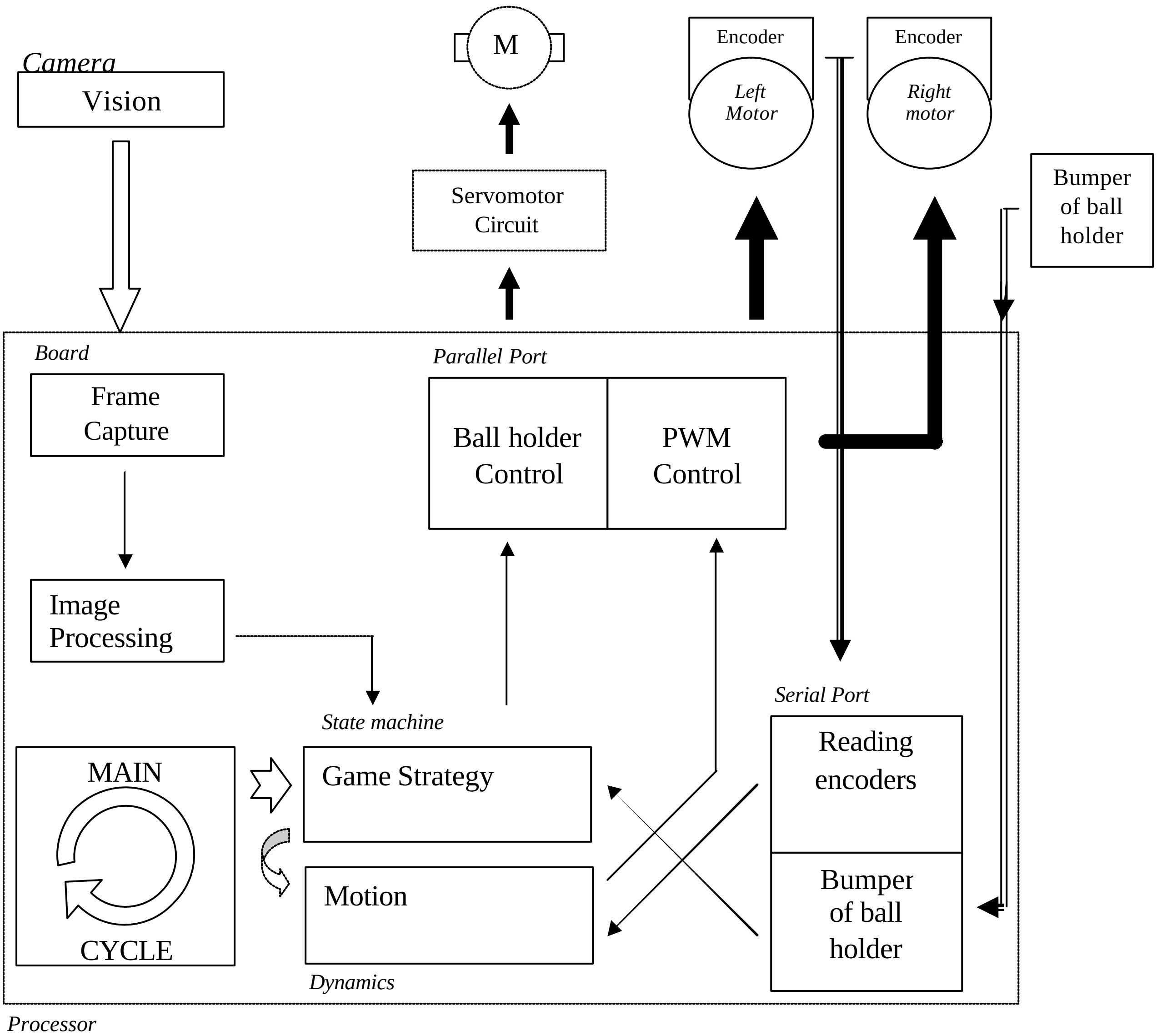

Figure 13: General diagram about the robot (football-player)

6 Conclusions

The participation in the autonomous mobile robot football contest was very successful. No other teams used 360 degrees vision with a single camera and therefore they could not see all the object at all the time. While they were moving around to capture all the information they needed, this robot team was moving towards the goal.

The convex mirror gave several advantages like 360 degrees vision, vision from the top, increased field of view area, more concentration of pixels in the objects near (allowing higher precision in the calculations), and all this was achieved with only one camera, reducing though weight and saving energy for other tasks.

The image processing software written was in Assembly language in order to increase processing speed, and the rest of the program was in C language. This proved to be another big advantage since around about 50 frames per second were obtained. Other teams that used other languages for the image processing software were able to capture only 6 to 8 frames a second.

However, some other aspects of these robots need to be improved. The detection of opponent players would be great in order to avoid collisions, make simulations and preventing it from losing the ball. In order to detect the attackers, image processing or ultra-sound sensors could be used.

Another improvement would be communication between the robots of each team such that they could, for example, switch positions, give orders to each other, etc. The communication amongst robots would make the strategy more efficient, each robot would behave not only accordingly to its program but also according to the information given by its team mate.