Mechanics and Electronics of the Footballer Autonomous Mobile Robot

Carlos Machado, Fernando Campos, Manuel Martins, Sérgio Sampaio, Fernando Ribeiro
University of Minho, Dep. of Industrial Electronics
Campus de Azurém, 4800 Guimarães, PORTUGAL

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, playing algorithms, etc. This robot uses one major sensor which is a vision system with the use of a colour camera. This robot uses also a convex mirror placed on its top looking downwards with the video camera pointing to it. This way, the robot can see both goals, the ball and other robots, all the time. This paper describes the mechanics involved and the electronics. The encoders to detect position and orientation of the robot, the motor and its control, as well as the ball holder mechanics system are described.

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.

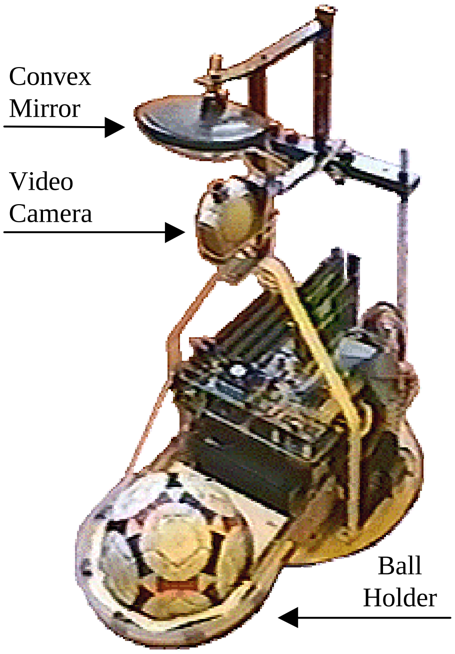
In this paper, it is described the robot itself, the image processing and the control algorithm.

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.



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 Motors

3.1 Power Electronics

A decision was taken to use a bridge in order to invert and control the motor's power. The bridge used was an unusual solution because it consists of a mixed bridge. This uses, in the upper part, two PNP transistors and, in the lower part, two MOSFET (Metal Oxide Silicon Field Effect Transistor). The MOSFET in the upper part was not used because it needed to be isolated (complicating the solution), resulting then in a solution between the simple and effective.

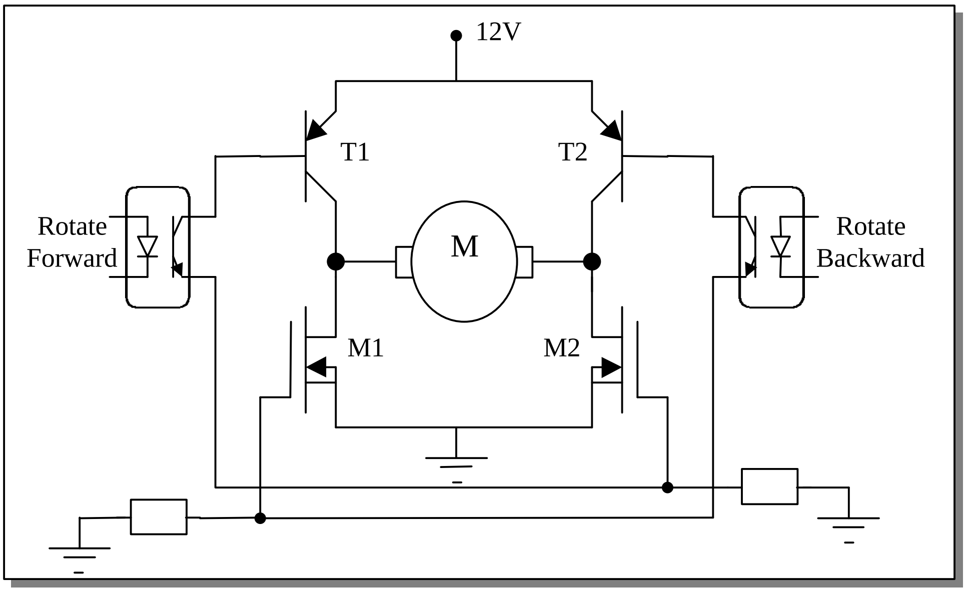


Figure 1: Mixed bridge

For the motor to spin forward, opto-coupler enables the current to flow turning T1 and M2 on. The same way, to spin backwards, the opto-coupler enables the current turning T2 and M1 on. It is necessary to prevent that the two opto-couplers get enabled at the same time, which would result in a short circuit.

- Hardware (Signal Circuit)

The signal circuit makes the interface between the computer and the power circuit. The PC parallel port controls the bridge. This has an undefined state at the PC start and can destroy the power circuit by turning all the semi-conductors on. To prevent this problem and possible software bugs, the signal circuit warrants that only one of the opto-coupler is turned on at any time.

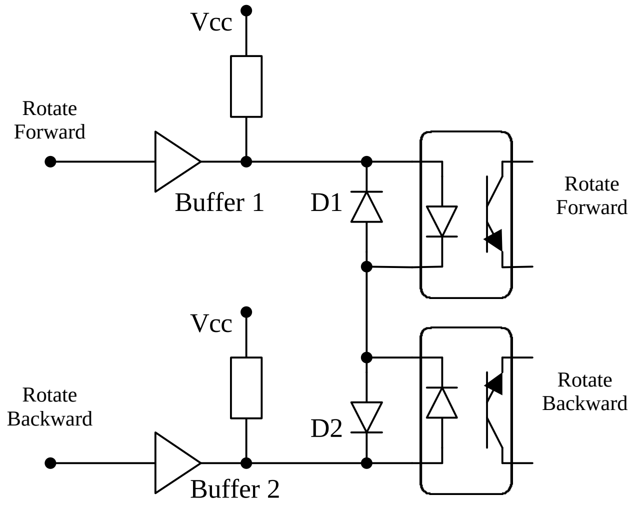


Figure 2: Signal Circuit

The buffers are in open collector to be able to drive enough current to enable the opto-couplers. To turn the motor forward, buffer 1 closes and current passes through the resistance, through the opto-coupler, through the D2 and through buffer2. In the opposite way, to turn the motor backwards, the current passes through the buffer 2, through the resistance, through the opto-coupler, through D1 ending in buffer 1. In case the two buffers are simultaneously close, the current will not flow, avoiding a short-circuit.

3.2 Pulse Width Modulation (PWM) Driver

The motor's control is made in the main processor, resulting in a cheap solution and in simple hardware. The signals are sent trough the PC parallel port.
Routines have been developed to control the motors, as transparent as possible, in order to make it easy for the higher level software. That way, all the control is made in background, using the PC timer's interruption. These routines are able to choose in how many levels can Duty-cycle and signal frequency change. The duty-cycle can change ranging from 10 to 100 levels and the frequency can change between 20Hz and 200Hz. Depending on the choice, the CPU's load changes. The default value used was 100 duty-cycle levels, with 100Hz signal frequency. These options resulted in a 10Khz CPU's interruption, which is a reasonable value to an Intel Pentium MMX 200Mhz processor.

The 8254 timer, which is incorporated in most motherboards, was programmed to generate an interruption with the minimum time unit used. In this case it was:

$$\frac{\text{PWM levels}}{\text{Signal frequency}} = \text{Base time unit}$$

or

$$\text{Signal frequency} \times \text{PWM levels} = \text{Interruption frequency}$$

Using base time unit, all the control is based in counters. That way, a counter was used to the signal ON and another counter to the signal period. The resulting algorithms are very much simpler.

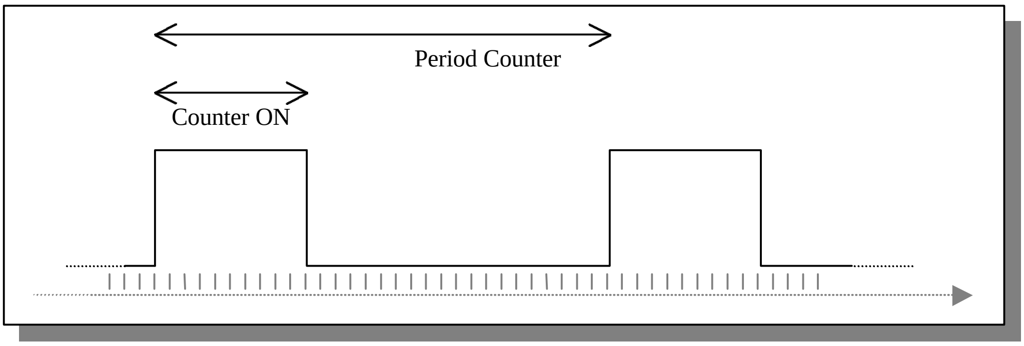
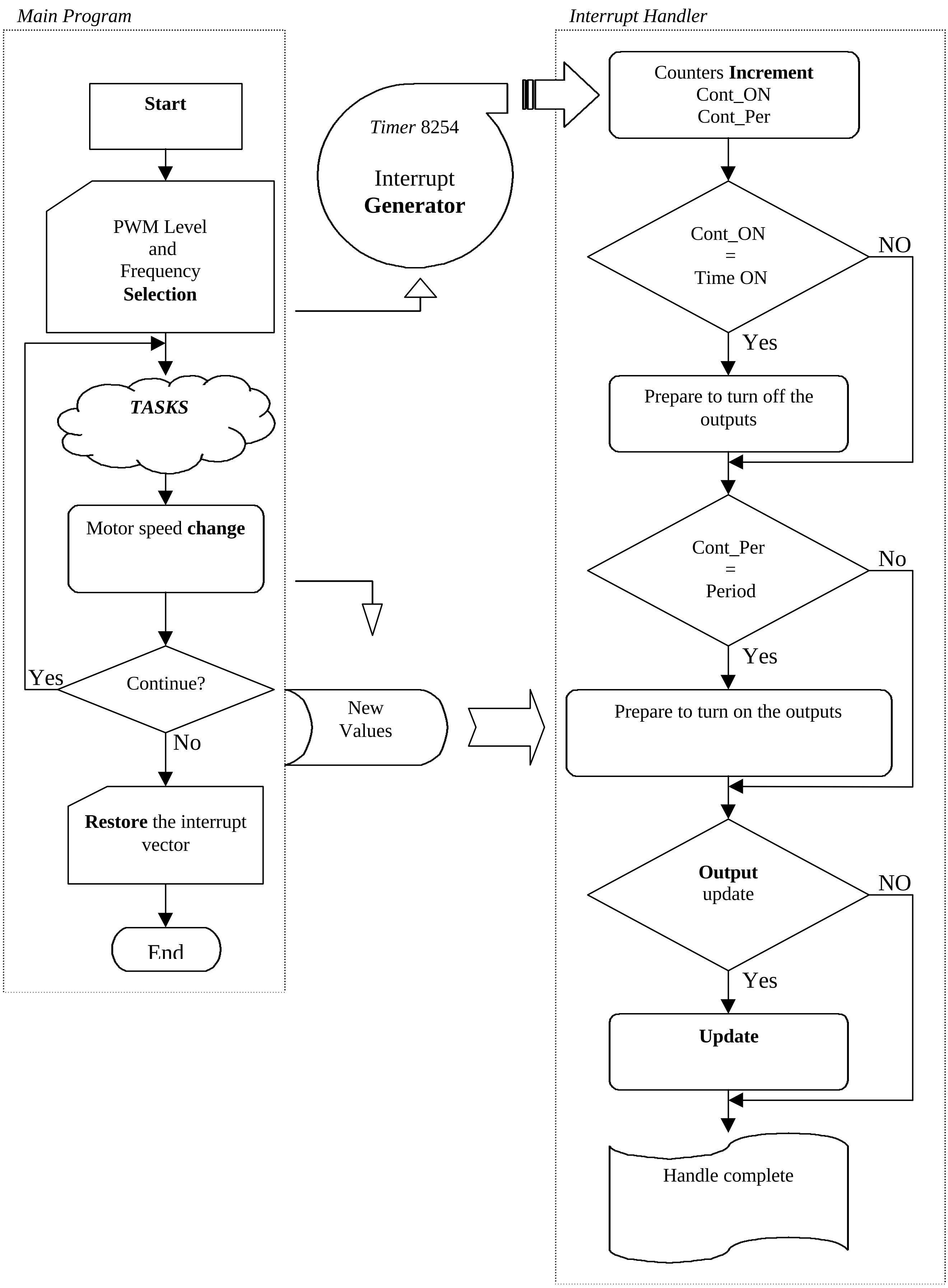


Figure 3: Interruption Routine Counters



Main Program
Interrupt Handler
Start
PWM Level
and
Frequency
Selection
TASKS
Motor speed change
Continue?
Yes
No
Restore the interrupt vector
End
Timer 8254
Interrupt
Generator
New
Values
Counters Increment
Cont_ON
Cont_Per
Cont_ON
=
Time ON
NO
Yes
Prepare to turn off the outputs
Cont_Per
=
Period
No
Yes
Prepare to turn on the outputs
Output
update
NO
Yes
Update
Handle complete

Communication between the two tasks is made through memory global variables. The output update is done at the end of the cycle, preventing shape changes when the values change.

Once that all the outputs use the PC parallel pins, the control is done through only one register (data register of LPT), being necessary to consider the other pin values that control the other motor. Used PC parallel pins are:

- pin 2 => (data 0) Left Motor PWM (spin forward)
- pin 3 => (data 1) Left Motor PWM (spin backwards)
- pin 4 => (data 2) Right Motor PWM (spin forward)
- pin 5 => (data 3) Right Motor PWM (spin backwards)

4 Encoders

The robot structure includes supports for the encoder's sensors and each wheel has holes to be used by the encoders. The speed and direction information of each wheel can be extracted from the encoders. With that information it is possible to determine the position of the robot in relation to its starting position. It is also possible to go back to a position where the robot has been before.

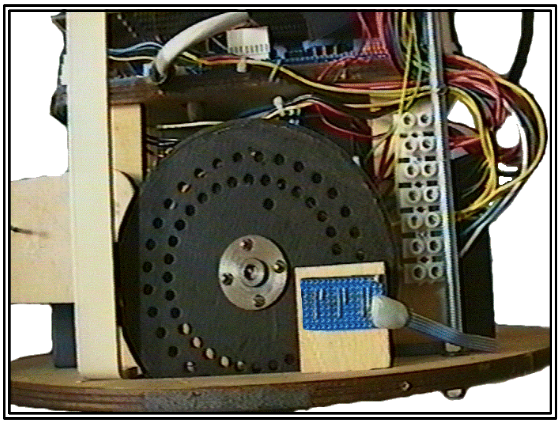


Figure 4: Robot football player wheel (with holes) and respective Encoders

4.1 Electronic circuit

The encoders electric circuit is divided in two parts. The first part consists of an infrared emitter and the second part of an infrared receptor.
The emission of light does not have any modulation. Although it may suffer some noise by the sun light, the short distance between the emitter and the receptor and the use of the receptor circuit will eliminate completely this problem.

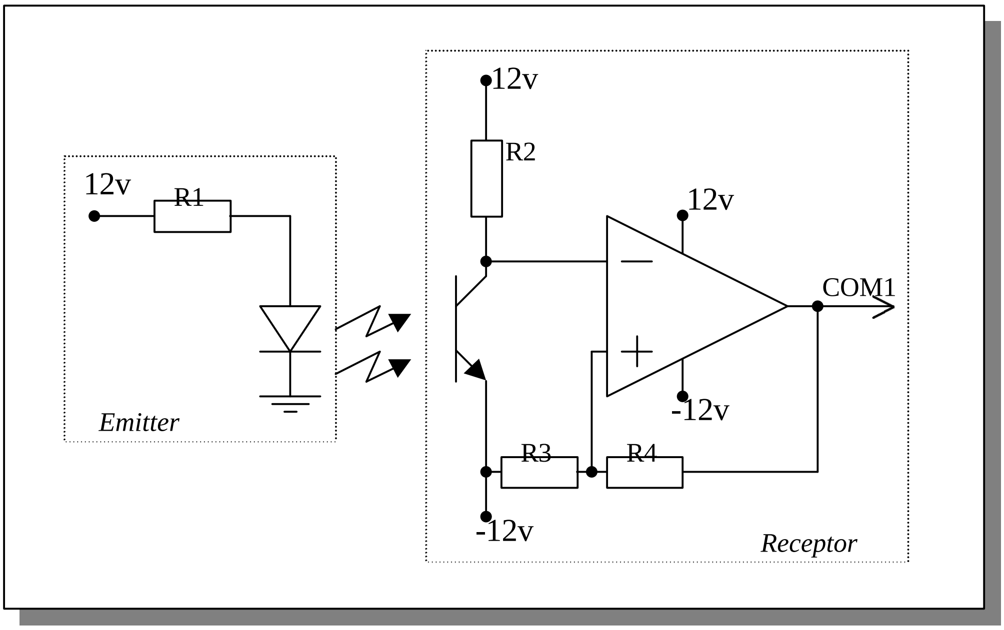


Figure 5: Encoder Circuit

The emitter consists only of a resistance and an infrared LED emitter. The resistance is calculated in such a way that the receptor will saturate.

The receptor consists of a phototransistor linked to a comparator with bias. The R2 controls the sensibility, R3 and R4 have the same value resulting in a window of more than 10V (this way the noise problem is solved).

At the amplifier's output, a voltage varying from 10V and -10V is achieved and this can be directly connected to the PC serial port.

4.2 Calculating the robot Position and Orientation

The encoder's routines count the ticks and store them in memory, to allow the software to use the values. The routines calculate also the robot position and orientation in relation to the reset position. To calculate the position and orientation angle, two holes rows are used:

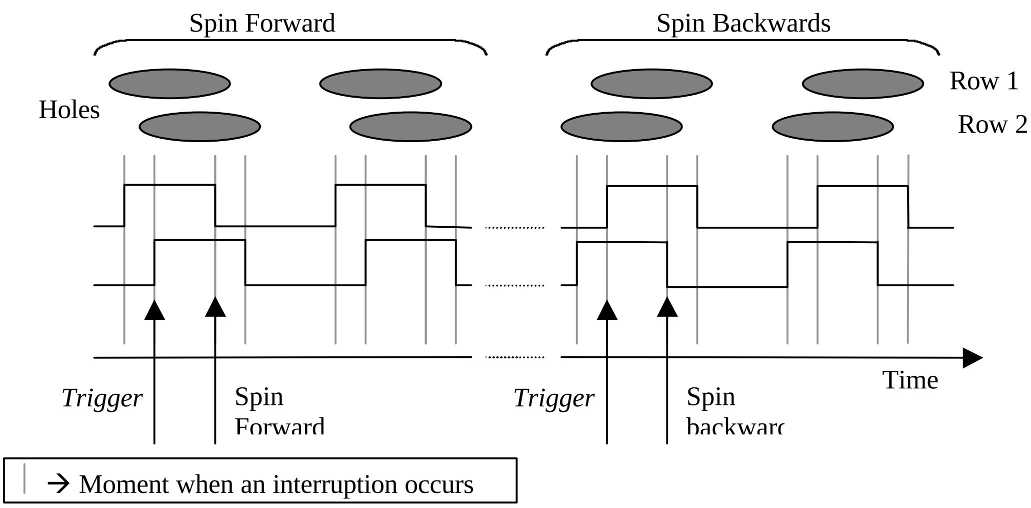


Figure 6: *Encoders* Graphic for direction calculation

To calculate the spin direction, the system has to wait for the trigger. The system triggers when both signal are high. Then, the first to become low represents the spin direction.

When the direction is known, the new position and angle can be calculated. Considering that when one wheel moves one tick, the other is in the last position, the new position can calculated with the following equations:

$$pos\_x = pos\_x + xi \times \cos(p\_ang) + yi \times \cos(p\_ang + \frac{p}{2})$$

$$pos\_y = pos\_y + xi \times sen(p\_ang) + yi \times \sin(p\_ang + \frac{p}{2})$$

$$p\_ang = p\_ang + ai$$

where pos_x, pos_y e p_ang are position and angle global variables
xi, yi e ai are the increment of X, Y and angle respectively.

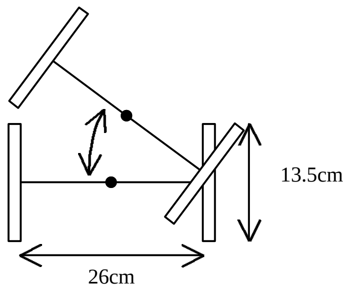


Figure 7: calculating the robot's position and orientation

The wheel perimeter is given by:

$$P_{roda} = 2 \times \pi \times r = \pi \times 13.5 = 42.4 \text{ cm}$$

Considering that in each turn it generate 48 ticks, in each tick the wheel will move:

$$Dpt = P_{roda} / 48 = 0.88 \text{cm}$$

Considering that if the robot only moves one wheel at the same time, then it would draw a circle with 26 cm of ray, with the perimeter as:

$$P_{robô} = 2 \times \pi \times r = 2 \times \pi \times 26 = 163.36 \text{ cm}$$

The increment of the angle can be calculated as:

$$ai = (Dpt \times 2\pi) / P_{robô} = 0.88 \times 2\pi / 163.36 = 0{,}033984 \text{ radians}$$

The position increments are:

$$xi = (26 - (26 \times \cos(ai))) / 2 = 0{,}00750 \text{ cm}$$

$$yi = (26 \times \sin(ai)) / 2 = 0{,}4417 \text{ cm}$$

The increments depend on the wheel direction, changing its signal according to the following table:

		Incremental signals		
Wheel	**Direction**	P_ANG	POS_X	POS_Y
Right	Forward	+1	-1	+1
Right	Backward	-1	-1	-1
Left	Forward	-1	+1	+1
Left	Backward	+1	+1	-1

The use of this method is only possible because access to the encoders interruption is possible.

5 Ball Holder

5.1 Actuator Circuit

The ball holder is a mechanical structure to enable the robot to control the ball. It consists of a wood-ring that descends over the ball. It uses two levers action by a servomotor. Only the servo mechanics are used, a relay was placed inside to invert the power.

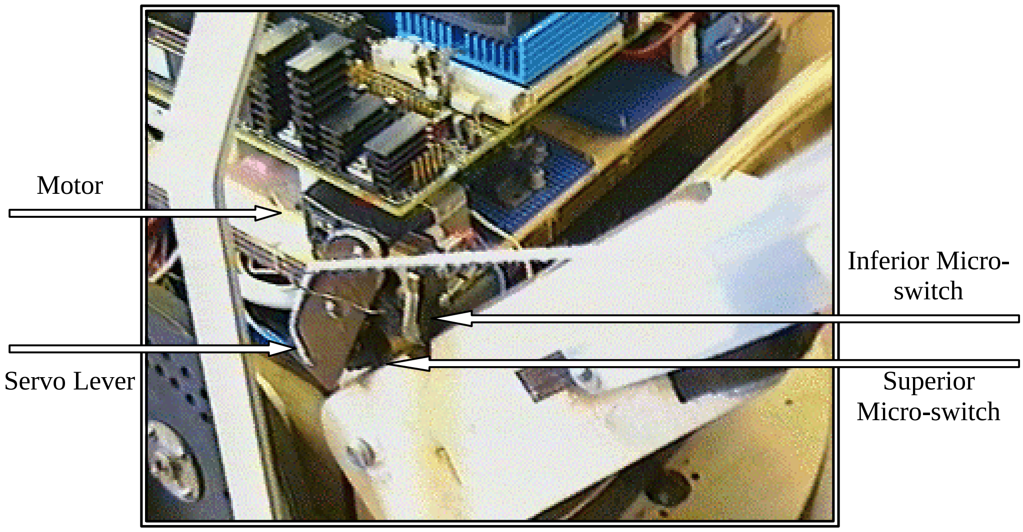


Figure 8: Ball Holder (up position)

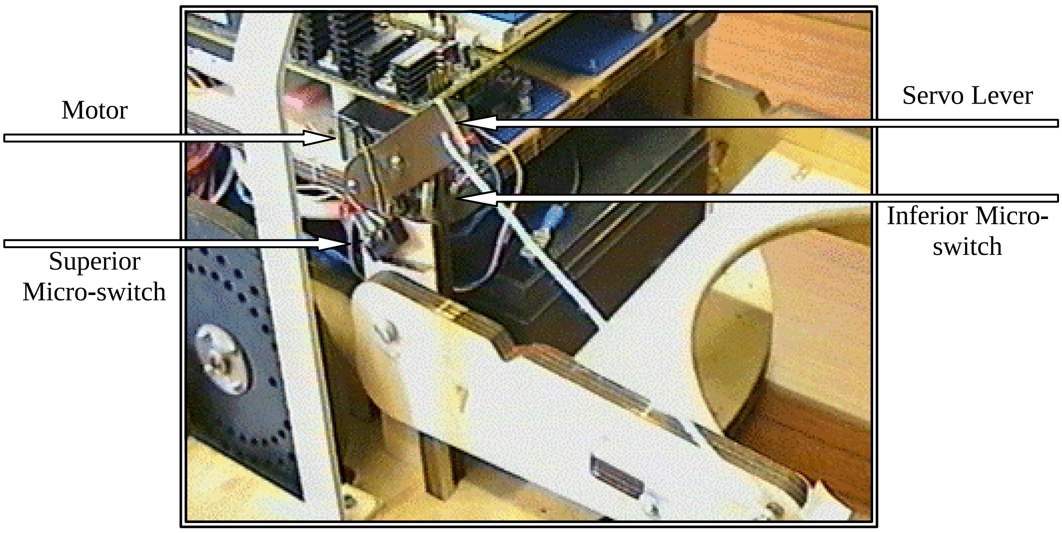


Figure 9: Ball Holder (down position)

The upper and lower positions are controlled through two micro-switches connected to a simple circuit. The motor is normally off, no matter the ball holder is up or down. The ball holder stays in the upper position because no torque is made in the servo lever.
The ball holder circuit works in an open loop. The Vision System is used to make sure the ball is caught. The game rules clearly state that should the ball holder be touched by other robot, the ball holder should be lifted. To sense the touch, five micro-switches are used around the ring.

- Hardware (Ball Holder Circuit)

The ball holder circuit uses only one digital output. When this is zero, the ball holder is in the upper position and when it is one, it is in lower position. The servomotor rotates until a micro-switch is reached.

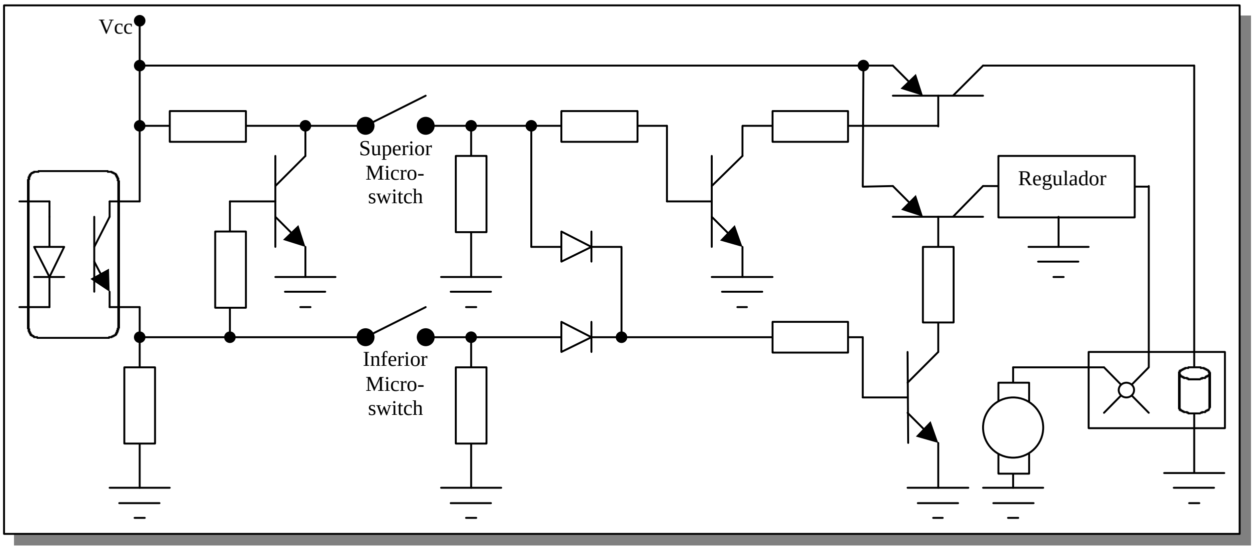


Figure 10: Ball holder Control Circuit

The two micro-switches (upper and lower) are connected in the normally close position.

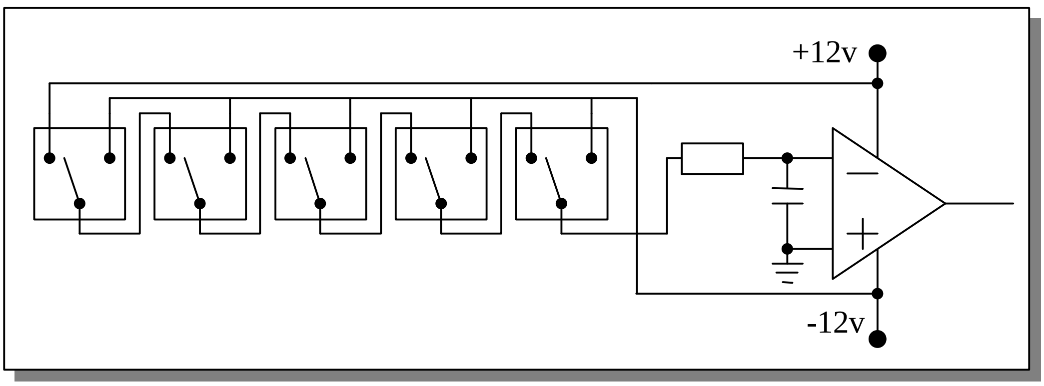


Figure 11: Frontal bumper Circuit

6 Auxiliary Systems

6.1 Processor (memory, video board)

The robot uses an high performance low price typical motherboard. Although the operating system used was MS-DOS, 16Mbytes of RAM were used in order to increase the image processing performance.
In order to avoid damaging the robot hard disk, while the robot moves (it is important to remember that sometimes the robot collides with opponent robots) Power Management was used in order to turn off the hard disk drive.

6.2 Frame Grabber board

The frame grabber board has two inputs, one in S-video and the other in composite video.
The board uses a PCI bus and uses only the chip **Bt848** (*Single-Chip Video Capture for PCI*) from Brooktree.
The most advantageous features of this frame grabber are:

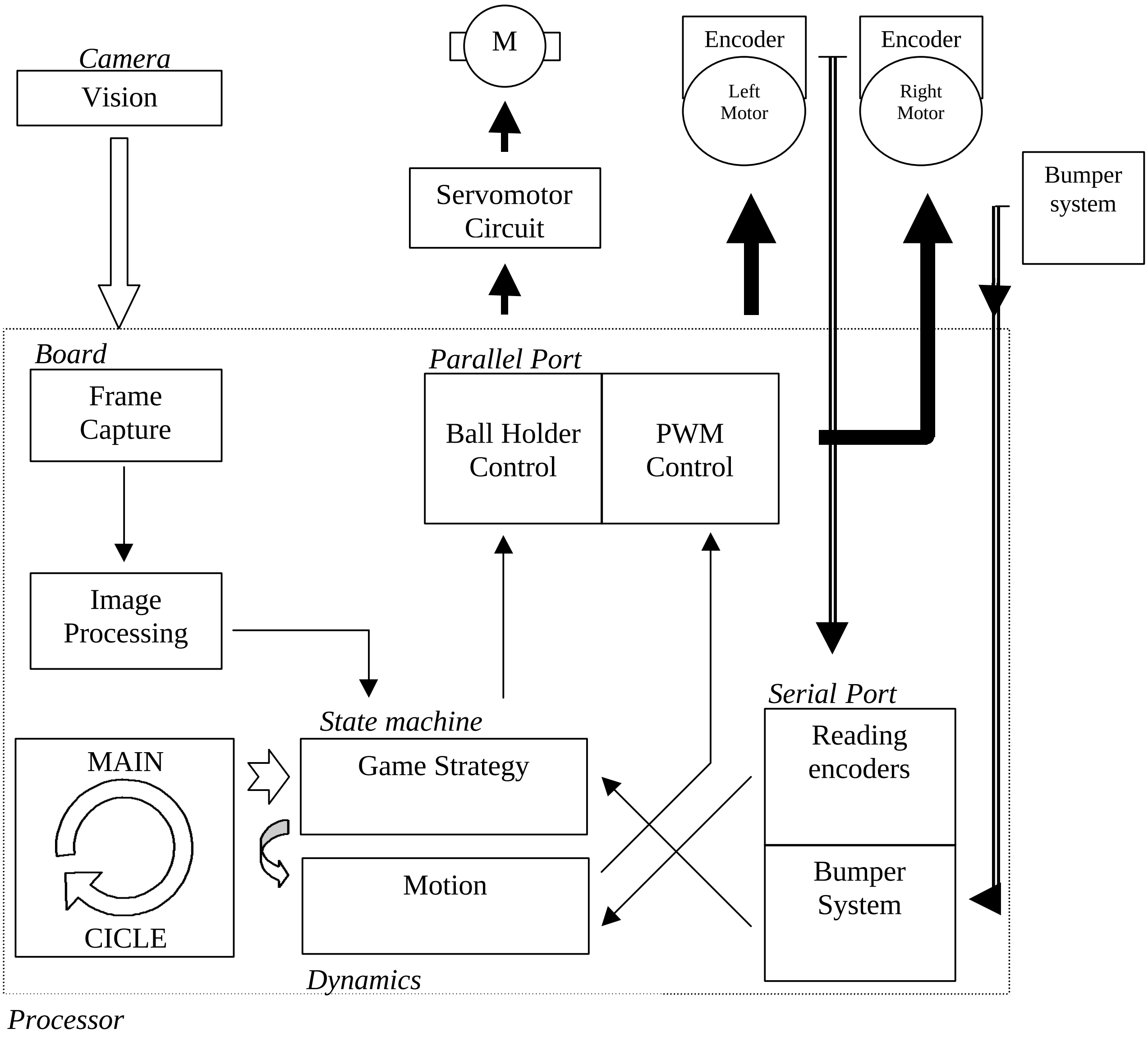
- Supports the resolution of up to 768×576 (all PAL resolution)
- Supports complex clipping of video source
- Multiple YCrCb and RGB pixel
- Supports NTSC/PAL/SECAM analogue input
- Image size scalable down to icon using vertical & horizontal interpolation filtering

6.3 DC/DC Converter

The motherboard is powered by a DC/DC converter with an input ranging from 30V to 10V.

7 Global Diagram

Following, is a diagram that describes the whole mechanical, electronics and software system.



8 Conclusion

The participation in the autonomous mobile robot football contest was very successful. The image processing technique used (specially the convex mirror) was very useful, and with lots of advantages. 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.

Two lead acid batteries were used in each robot weighing each one approximately 2,5 kg. This made the robots heavy and though wasting more energy in the accelerations and breaks. If lighter batteries could be used that would make them more agile and fast, increasing though their autonomy.

The use of a PC board and his peripheries (parallel and serial ports) simplifies the electronics, increasing the reliability. It is also possible to add more controller boards to add more function to the robot.

All the control (direction, image processing, PI, PWM) was made in the main processor. That way, changes in the control method can be made with new software only instead of changing the hardware.

The MS-DOS operation system was used in order to be able to control directly all the hardware and to develop routines to run in real time.

Since two driving wheels are used, the robot movement is made using differential control.