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and Physical Sciences

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Football Goal Scoring Detection System

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I declare that all material contained in this report, including ideas described in the text, computer programs and drawings, is my own work except where explicitly and individually acknowledged.

Signed ……………………..

Date ………………………..

Abstract

The purpose of this project has been to develop an electronic system capable of detecting goals in a football goal scale made.

This system intends to clarify goals which the referee is not sure if they are or not, commonly called: ghost goals. In this sense, this project focuses on an electronic system for detection goals in a short time and notify to the referee's watch by wireless; in this project it is not going to be a wireless notification but a simulated notification will be done by a red led.

The system is composed of IR-Leds and IR-Photodiodes, emitters and receivers. Starting for the bottom led until the top led, leds will be switched on and off until the ball is detected. It is like a scan going from the bottom to the top and starting again from the bottom; making an infinite loop until something is between the IR-Led and the IR-Photodiode. This scan will be carried out by a microcontroller which also makes a sequence for detecting when the ball is crossing the goal line.

If something interposes between the emitter and the receiver, scanning will be stopped, then, the size of the object will be checked, if is the ball, it is goal; if not, no notification will be transmitted.

The aim of this report is to demonstrate another solution about the ghost goals problem, apart from the real solution of magnetic fields which it has been approved by FIFA.

Acknowledgements

First of all, I would like to thank my supervisor, David Heys. Who gave me the idea of this project and who supported me in every problem or question that I had.

I am thankful to the people who work in the store. They provided me with everything, every component I needed and they helped me in my questions as well.

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List of Abbreviations

GLT	Goal Line Technology
IR-Led	Infrared Light-Emitting Diode
IR-Photodiode	Infrared Photodiode
FIFA	Fédération Internationale de Football Association
IFAB	International Football Association Board
RF	Radio Frequency
ITF	International Tennis Federation
ATP	Association of Tennis Professional
WTA	Women's Tennis Association
2D-3D-4D	2-3-4 Dimensions
GAA	Gaelic Athletic Association
USA	United States of America
RGB light	Red Green and Blue light
DVD	Digital Versatile Disc
E-R pair	Emitter-Receiver pair
µC	Microcontroller
I/O	Input/Output

CHAPTER 1

INTRODUCTION

1. Introduction.

The project objective is to simulate Goal Line Technology (GLT) in a football goal. For this, an electronic system is designed and built which is able to detect when the ball has crossed the goal line. This system also can differentiate if the object which has crossed the goal line is the ball or the goalkeeper or whatever it may be. Infrared technology is used in order to develop the GLT, specifically a kind of infrared light curtain.

To carry out this technology is necessary to define the basic operation of this. IR-Leds and IR-Photodiodes are used as emitters and receivers, respectively. They make a kind of infrared light curtain because unlike a proper curtain, in this case, all of the emitters are not switched on at the same time, only a pair of emitter-receiver are switched on, then they are switched off and then the following pair of emitter-receiver are switched on, doing a scan along of the emitters-receivers pairs columns. Another requirement of GLT is using an alarm device; a red-led is switched on in the case of detecting that the ball has crossed the goal line. On the other hand, if another thing crosses the goal line, no notification is showed.

This system is designed and built for a goal, a ball and a player in scale; it can be applicable in real life and also shows another way of how the "ghost goals" can be solved. This system can help the referee to clarify controversial situations in football which means an improvement of this sport and a forward step in order to make this game fairer.

CHAPTER 2

BACKGROUND

2. Background.

Since television has showed replays of controversial plays in a match, refereeing errors have been observed. One of the most controversial is the "ghost goal". FIFA, who initially opposed any technological improvement, gave the approval on Thursday July 5, 2012 to two systems that let the referee know if the ball completely crosses the goal line or not.

On October 22, 2012 license agreements were signed with providers of goal-line technology (GLT), Sony Europe and Fraunhofer-Gesellschaft. This means that both companies that develop the technology, Hawk-Eye and GoalRef, have official authorization to install their systems in all pitches worldwide.

Up to this point, both companies had to pass tests in the laboratory, in field and in match simulations, as well as tests in real matches.

Figure 2.1: The Goal.

Tests in the laboratory are compliant with basic standards of FIFA. The ball and the referee's watch must comply with international standards. The field tests are used to determine the reliability and performance of the systems. Different tests are made, such as shots on goal, shots on an impact wall, test the cart across the goal line and test in various weather conditions. Finally the tests in real situations of the game consist of the installation in two stadiums in official training sessions.

Both systems send a signal to the referee's watch, in less than a second, he can indicates the goal. The referee has the power to allow the goal or not, he has the last word.

Figure 2.2: The Referee.

When the systems put into operation, the role of the referee will be modified. The IFAB, the International Football Association Board (international association made up of the four football associations of the United Kingdom and FIFA), is responsible for defining the rules of football worldwide and any amendments thereto; it was founded on 2 June 1886 in London.

IFAB has decided that the referee has the authority to choose to use GLT or not. The referee, after a series of tests 60 minutes before kickoff, is free to ignore this technology. If he decides to use the GLT and the ball completely crosses the line, the GLT will automatically notify the referees, goal. The message will show in the of the referee's watch.

After the successful test in the FIFA Club World Cup 2012 in Japan last December, it can be said that GLT is a part of reality. Its utilisation was so enormous that GLT will be utilised in the FIFA Confederation Cup this year in Brazil and FIFA World Cup Championship next year 2014 in the same country. Also in the strongest European football leagues in the coming years we will see these technologies. The Premier League in England and the Fußball-Bundersliga in Germany, will utilise these techs next season 2013-2014. In Spain "La Liga", in Italy "Il Calcio" and then in France "Ligue 1" will wait until their organisations are agreed with the condition of the use of both technologies.

2.1. GLT: GoalRef.

The company responsible of developing this technology note:

"GoalRef is a radio-based sensing system that uses low-frequency magnetic fields to detect if a goal has been scored. The system uses low-frequency magnetic fields.

One field is created in the goal area, the other is created in and around the ball whenever it approaches the goal. This is achieved through magnetic induction, which in turn is made possible by a passive electronic circuit embedded in the ball.

The interaction between the main field around the goal and the field induced around the ball is picked up by coils attached to the goal.

By measuring and analysing changes in the magnetic field around the goal, it is possible to determine whether the ball has completely crossed the line. The data is processed using software developed by Fraunhofer IIS, yielding a clear, accurate result that removes any doubt about whether a goal has been scored.

The result is wirelessly transmitted to the referee's wristwatch, and a message is displayed in real time, coupled with a vibrating alert. The information is encrypted to prevent eavesdropping or tampering."

Picture 2.3: The Ball.

GoalRef technology was not developed to solve the problem of "ghost goals" in football, but rather that was conceived as a solution in handball. Fraunhofer IIS is the German company responsible for the technology, is an institute for integrated circuits. In 2011, GoalRef began to work with the German organisation the Fraunhofer IIS, entering the first set of GLT tests in February 2011.

Rene Dunkler, manager of communications and public relations for GoalRef, said June 7, 2012, after some tests on Numremberg, how the system works:

“Our system works in each goal, with ten antennas mounted on the goalposts and crossbar, encased in plastic. There is an antenna ‘exciter’ that is partially below the ground, and this is connected to a processor. Inside the ball, there are three electronic coils, sitting between the bladder of the ball and the ball panels. When the ball enters the goal, the antenna system is activated, and ‘excites’ the processor. Once the magnetic field has been crossed, signalling a goal, the wireless RF signal is transmitted to the referee’s watch. We believe we can achieve all this in less than 0.5 seconds.”

Figure 2.4: Simulation of GoalRef

After these statements, Mr Dunkler continued with an explanation that would be more understandable: “Imagine a still lake with no wind; the water is completely flat.

Then if it begins to rain, the first raindrop disturbs the surface of the water. When our balls crosses the magnetic field, this ‘disturbs’ our system, and we can pinpoint that the ball has crossed the goal-line.”

2.2. Systems Available in Others Sports.

The most commonly used system to clarify controversial plays in other sports is Hawk-Eye. This is due to the high percentage of reliability. In sports like tennis, rugby, cricket or American football this technology is implemented in the routine of the game for a long time.

First developed in 1999, Hawk-Eye Innovations Ltd. has used the expertise gleaned from years of broadcasting to remain at the cutting edge of sports technology and broadcasting.

Hawk-Eye has become one of the leading vision processing companies within the sports sector. Since first used in cricket, the company has revolutionised sports broadcasting, officiating and coaching across a number of sports.

The company is proud to be an integral part of many of the world's premier sporting events. With an annual involvement in over one hundred events, these include The Wimbledon Championships, the Cricket World Cup, Davis and Federation Cups, World Championships snooker, the Indian Premier League cricket, and The Olympic Games.

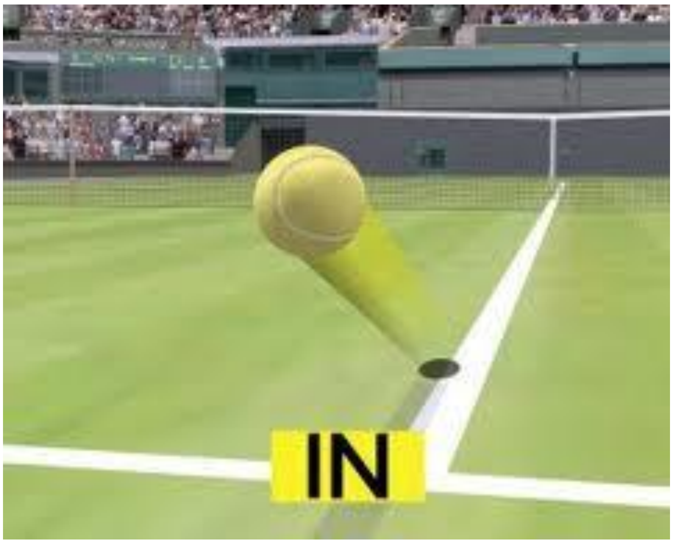


Figure 2.5: Hawk-Eye in Tennis.

- ***Tennis:***

The Hawk-Eye tennis officiating system is the first and only ball-tracking technology to have passed stringent ITF testing measures. With 6 years of officiating history behind it, the technology is now an integral part of the ATP, WTA and ITF tennis tours, featuring at over 60 events across the tennis calendar.

Using 10 high-speed cameras situated around the main tennis arenas, the Hawk-Eye Official Review System has now become an expected element of elite tennis match play. Travelling teams of trained Hawk-Eye technicians temporarily install and operate systems throughout the tennis year, with up to 10 different events worldwide able to capitalise on the technology for any given week.

The system is able to display the outcome of any given bounce within 5 seconds of the ball landing, with the result displayed to the players, umpire, fans and via television simultaneously.

The company responsible of developing this technology note:

“2D (x,y): Vision processing is used to identify the centre of the ball within each frame of each camera. Camera movement is compensated for by also tracking the lines of the court. 3D (x,y,z): The system triangulates the information from each calibrated camera to provide the 3D position of the ball. 4D (x,y,z,t): This process is repeated for each frame so that the 3D positions of the ball can be combined to produce a single trajectory of the flight of the ball.

Bounce Mark: The trajectory is then used to calculate the exact contact area that the ball made with the court during the bounce phase, being quickly and clearly shown via our virtual reality software.”

Figure 2.6: The Company Logo.

- ***Cricket:***

As the pioneering sport, Hawk-Eye's cricket systems have been used by host broadcasters around the world since 2001. In a similar fashion to tennis, the accuracy and reliability of the system soon reached a level that meant that it was added as part of the Decision Review System, first used in the New Zealand series late in 2008. As applications of Hawk-Eye in cricket relates are in: Beehives, RailCam, Ball speeds and Reaction Time.

- ***Snooker:***

In this sport, the Hawk-Eye system is focused to the viewer. It offers a vision of the board in 3D and 4D to make it more attractive to see the player's decision. Among the displays are: Player's view, Blue Dot, Animated Shots, Shadow, Distance Potting, Potting Angle.

- ***Other Sports:***

In other sports like GAA (Gaelic Athletic Association) or baseball (in USA) the Hawk-Eye system is being tested, to be implemented in the future and used in the routine of the game.

CHAPTER 3

ANALYSIS

3. Analysis.

The requirement of the project is switching on and off every single pair of emitter-receiver of the column placed behind the vertical goal posts. This scan from the bottom to the top of the column will be carried out until something interferes with the IR-beam. If something blocks that beam a second scan will be done in order to clarify what kind of object is.

The situation of the IR-beam is the key because as FIFA says, until the ball has not completely crossed the goal line, the goal will not be counted. For this reason the emitter-receiver pairs will be placed exactly the radius of the ball far from the goal line, this is so that when the ball has just crossed the goal line, the IR-beam will be blocked by the diameter of the ball in order to make the determination of the object easy, if it is the ball or not.

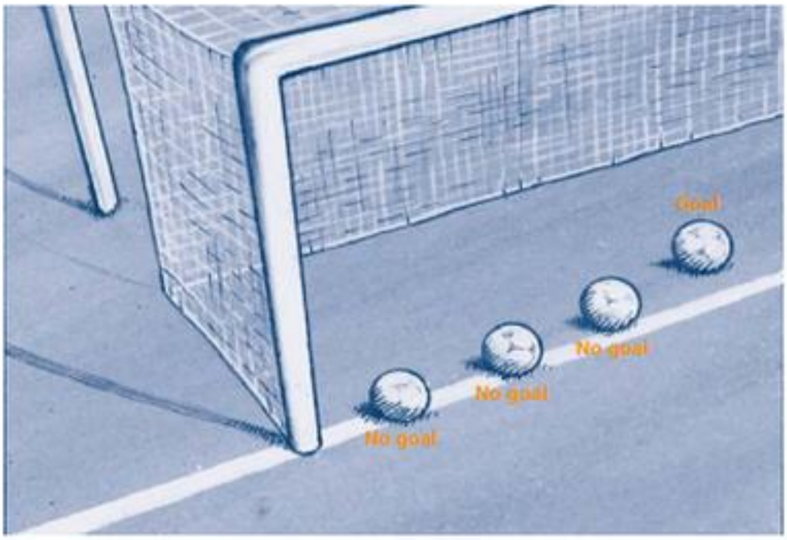


Figure 3.1: When a goal is correct.

3.1. Requirements.

It has not been easy to choose one technology with the aim of solving the main problem of the project, the detection and identification of the ball after having crossed the goal line. A kind of infrared curtain has been chosen for several reasons.

One major reason was its price due to the fact that each student is allocated a budget of £50, which cannot be exceeded. So keeping that in mind, using a number of IR-Leds and IR-Photodiodes and a microcontroller which managed the scans of them, it would be a good option to develop the project.

Another reason is the physical space. A model has been built with the aim of demonstrating that the system works and the choice of infrared curtains would be plausible.

Finally, the sentence: “make it easy” said by the supervisor, moderator and every single person who has explained how to produce a good final project in the seminars, has been taken into consideration when thinking about and producing the final report and model.

3.2. Problems and solutions adopted.

3.2.1. What kind of technology to use? Infrared curtains.

When the project was chosen, it thought about something related to laser emitters and receivers. This thought was removed because it was too expensive and difficult to implement in a model. Instead of that, and after having done a deep research and background, I thought of infrared curtains.

Figure 3.2.1.1: Infrared Light Curtains.

Light curtains fall into a category of equipment known as presence detection devices. Light curtains are supplied as a pair with a transmitter and receiver. The transmitter projects an array of parallel infrared light beams to the receiver which consists of a number of photoelectric cells.

The light beams emitted from the transmitter are sequenced, one after the other, and pulsed at a specific frequency. The receiver is designed to only accept the specific pulse and frequency from its dedicated transmitter. This enables the rejection of spurious infrared light and thus enhances their suitability as components within a safety system.

The Transmitter unit sends modulated infrared light from Led array to a corresponding array of photo-transistors in the receiver unit. When an opaque object interrupts one or more of the beams, the light curtain sends a stop signal to the guarded machine.

3.2.2. What kind of emitters and receivers to use? IR-Leds and IR-Photodiodes.

According to what has been said in the previous section, infrared curtains are made of pairs of emitters and receivers. This point was easy to solve because the solution was clear, IR-Leds and IR-Photodiodes. They are cheap, easy to implement and successful if they are used accurately.

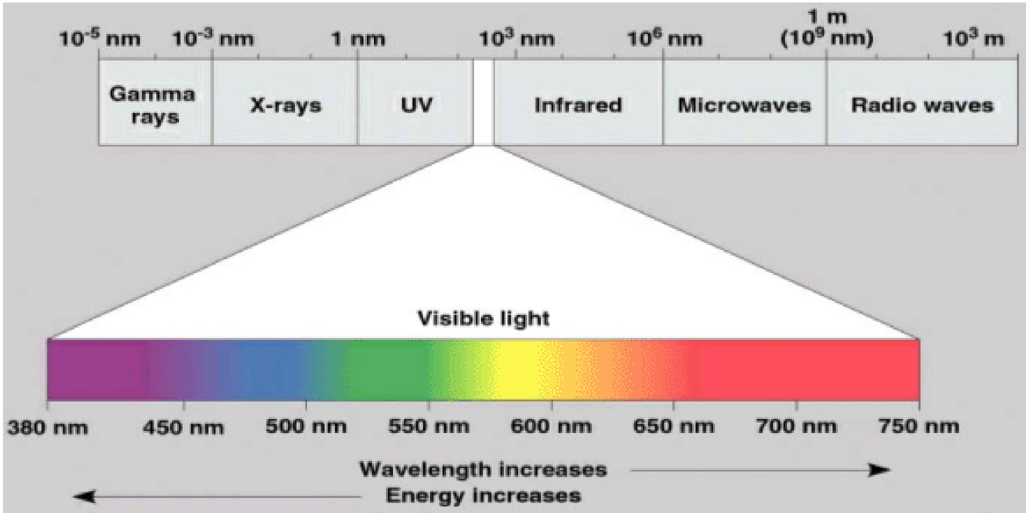


Figure 3.2.2.1: Visible Spectrum.

The visible spectrum is the portion of the electromagnetic spectrum that is visible to (can be detected by) the human eye. Electromagnetic radiation in this range of wavelengths is called visible light or simply light. A typical human eye will respond to wavelengths from about 380 to 750 nm. In terms of frequency, this corresponds to a band in the vicinity of 400–790 THz.

Infrared (IR) light is an electromagnetic radiation with longer wavelengths than those of visible light, extending from the nominal red edge of the visible spectrum at 0.75 micrometres (µm) to 380 µm. This range of wavelengths corresponds to a frequency range of approximately 790 to 400 THz and includes most of the thermal radiation emitted by objects near room temperature. Infrared light is emitted or absorbed by molecules when they change their rotational-vibration movements. The existence of infrared radiation was first discovered in 1800 by astronomer William Herschel.

A stand for "Light-Emitting Diode" a Led is an electronic device that emits light when an electrical current is passed through it. Early Leds produced only red light, but modern Leds can produce several different colours, including red, green, and blue (RGB) light. Recent advances in Led technology have made it possible for Leds to produce white light as well.

When a Led is switched on, electrons are able to recombine with electron holes within the device, dismissing energy in the form of photons. This effect is called electroluminescence and the colour of the light (corresponding to the energy of the photon) is determined by the energy gap of the semiconductor.

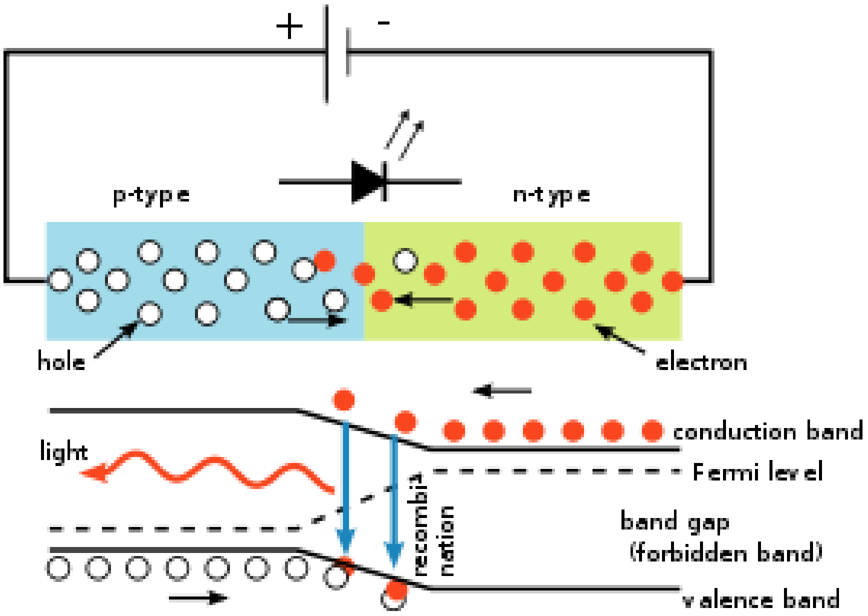


Figure 3.2.2.2: LED Equivalent Schematic.

Light-emitting diodes are used in a multiplicity of applications as diverse as aviation lighting, automotive lighting, advertising, general lighting, and traffic signals. Leds have allowed new text, video displays, and sensors to be developed, while their short time required to switch mades them ideal for advanced communication technology. Infrared Leds used in the remote control units of many commercial products including television sets, DVD players, and other domestic appliances.

An infrared light-emitting diode is a type of electronic device that emits infrared light not visible to the naked eye. An infrared Led operates like a regular Led, but may use different materials to produce infrared light.

This infrared light may be used for a remote control, to transfer data between devices, to provide illumination for night vision equipment, or for a variety of other purposes.

An infrared Led is, like all Leds, a type of diode, or simple semiconductor. Diodes are designed so that electric current can only flow in one direction. As the current flows, electrons fall from one part of the diode into holes on another part. In order to fall into these holes, the electrons must shed energy in the form of photons, which produce light.

The wavelength and colour of the light produced depend on the material used in the diode. Infrared LEDs use material that produces light in the infrared part of the spectrum, that is, just below what the human eye can see. Different infrared LEDs may produce infrared light of differing wavelengths, just like different LEDs produce light of different colours.

A very common place to find an infrared Led is in a remote control for a television or other device. One or more Leds inside the remote transmit rapid pulses of infrared light to a receiver on the television. The receiver then decodes and interprets these pulses as a command and carries out the desired operation.

Figure 3.2.2.3: IR-Led chosen.

Photodiodes are PN junction diodes designed specifically to harness the photoelectric effect. This means the device exposes the junction region of the PN diode to incoming photons which results in conducting the transfer of electrons across the junction. This process can also be reversed to produce photons.

As can be speculated, there are many useful applications of this phenomenon, such as solar cells, light detection/emission, and thus signal receiving/sending.

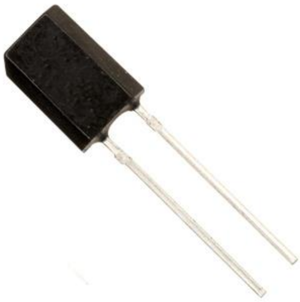


Figure 3.2.2.4: IR-Photodiode chosen.

3.2.3. What kind of IR-Leds and IR-Photodiodes to use? L-7113F3BT and BPW41N.

These electronic devices have been chosen because it was easy to get them in the store and for the project propose have been useful. Their datasheets have been included in the appendices.

3.2.4. What kind of goal notification to use? Red Led.

It was thought of using a common red Led which will be switched on when the whole ball has crossed the goal line. Like IR-Leds and IR-Photodiodes, datasheets of this led has been included in the appendices.

Figure 3.2.4.1: Common red Led.

3.2.5. Non-electronic components used for the model.

A ball done to scale has been used, the ball of old computer mousse with a measurement of 22.29 mm. From there, it has been calculated the scale (1:10).

SCALE → 1:10	REALITY	MODEL
GOAL	7320 mm (width) 2440 mm (heigh)	732 mm (width) 244 mm (heigh)
BALL	222.9 mm (diameter)	22.29 mm (diameter)
PLAYER	1800 mm (heigh)	180 mm (heigh)

Table 3.2.5.1: Model size.

The material to represent the goal has been wood and net. For the player, a dummy has been used which was according with the scale measures. To support the model wooden plank 1250 mm (width) x 500 mm (length) have been used, that is the basis of the project and a couple of bars of rectangular 100 mm (width) x 50 mm (height) x 500 mm (length) of wood that also serve as support.

The goal has been built with dimensions of 732 mm (width) x 244 mm (height) x 150 mm (length) and placed on the base. The wooden posts are vertical, square base and with dimensions of 12 mm (width) x 12 mm (length) x 244 mm (height). The horizontal post or cross post is also of wood and a square base and with dimensions of 756 mm (w) x 12 mm (length) x 12 mm (height).

The auxiliary posts have been placed in the back of the goal to make the model more realistic. These sticks are made of wood and a square base, like other pots. The dimensions are 12 mm (width) x 12 mm (W) x 50 mm (height). All pots, including auxiliary, have been painted white with appropriate paint for wood, then varnished. The posts are secured to the floor with an appropriate adhesive and resistant glue, in the same way the auxiliary posts are stuck to the rear cross post of the goal.

For net, fishing net has been bought which simulates the net used in the football fields. The net has been anchored to the posts by staples, ensuring that it will not open anywhere. To simulate a player, in this case has been simulated a goalkeeper, has been used a miniature mannequin whose height, scale, looks like a keeper, 200 mm.

Figure 3.2.5.1: Goal, Ball and Goalkeeper.

3.2.6. How to place the emitters and the receivers in the goal?

Thirty E-R pairs have been used and placed behind the vertical goal posts with a 1 mm gap between them. IR-Led's and IR-Photodiode's columns have been separated from the goal line the distance of the ball radium, 11.15 mm.

This point has been very difficult to solve because the position of the IR-beam is crucial for this project and has been the most important thing to think about it. First of all, placing the IR-beam exactly the diameter of the ball far from the goal line was thought of. Doing this, it got that if the ball blocked the beam, it would be goal. The problem of this is that anything could block the beam and there was not any way to recognise if it was the ball of not, so this idea was removed.

Afterwards, placing the IR-beam exactly the radium of the ball far from the goal line, was thought of; which meant that when the ball had completely crossed the goal line, the beam would have been blocked by the diameter of the ball. In addition, choosing this option meant that the size of the blocking object could be measured and make the difference between the ball and the rest of the things doing a double scan, when the ball had blocked the IR-beam without having crossed completely the goal line firstly and then when the ball had already crossed the goal line. The situation of the beam was located but the number of E-R pairs has to be chosen.

Taking into account the height of the in the model (244 mm), the size of the ball in the model (22.29 mm), the size of the IR-Leds and the IR-Photodiodes, 30 was chosen as the number of E-R pairs with a gap between them of 1 mm. Thereby, when the ball is blocking the IR-beam, only 3 E-R pairs will be blocked at most. At this point, the problem of the placement of emitters and receivers had been solved.

3.2.7. How fast will the switching of the E-R pairs have to be done?

After doing research and looking for the most powerful shot in football, it can be said that David Hirst in the 96/97 season in the match Sheffield Wednesday- Arsenal. The strike was 114 mph which means 51 mm/ms. With these calculations the switching of the whole model, the 30 pairs, would have to be done in less than 1ms.

To summarise, no delays between the E-R pair switching has been chosen just for one reason, to do the scan as fast as the microcontroller can. After the first scan 5 seconds of delay has been decided to do in order to simulate the advancement of the ball.

Figure 3.2.7.1: David's shot.

3.2.8. What kind of microcontroller to use? And how to connect the emitter-receiver pairs with the microcontroller.

The MC9S08QG8 microcontroller was chosen. It was chosen because I was acquainted with its operation and it is thought that it could be useful for this project.

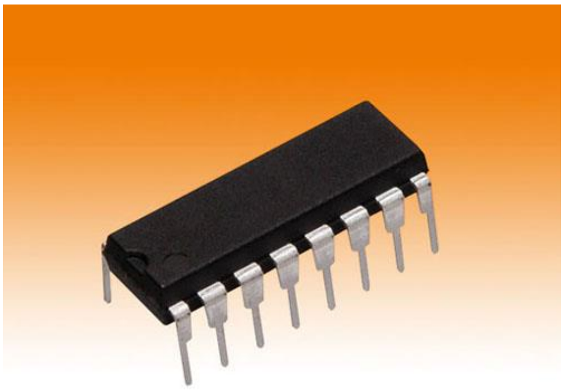


Figure 3.2.7.1: Microcontroller.

A microcontroller (µC) is a programmable integrated circuit capable of executing the orders recorded in its memory. It includes within the three main functional units of a computer: central processing unit, memory and peripheral input / output (I/O).

When manufactured, the microcontroller does not contain data in ROM. So, to manage some processes, it is necessary to generate or create and then record in the EEPROM, or equivalent, of the microcontroller a program, which can be written in assembly language or other language for microcontrollers.

The first µC was the Intel 4004 microprocessor of 4 bits, launched in 1971. However, its processor required additional circuitry to implement a working system, raising total system cost.

The Smithsonian Institution says that Texas Instruments engineers Gary Boone and Michael Cochran succeeded in creating the first microcontroller, TMS 1000, in 1971, was marketed in 1974. It combined ROM, RAM, microprocessor and clock on a chip and it was intended for embedded systems.

Microcontrollers are designed to reduce economic costs and energy consumptions of a particular system. So, the size of the central processing unit, the amount of memory and peripherals included depend on the application.

People think a microcontroller is equal to a microprocessor, but it is not. They differ from each another in many ways. The first and most important difference is its functionality.

In order to use the microprocessor in a real application, it must be connected with components such as memory components or data transmission buses. Although the microprocessor is considered a powerful computing machine, it is not ready for a communication with peripheral devices connected to it. To communicate microprocessors with peripherals, special circuits must be used. That was in the beginning and this practice is still in force today.

On the other hand, the microcontroller is designed so it has all the components integrated in the same chip. It does not need other specialized components for its application because all necessary circuits, which otherwise correspond to peripherals are already incorporated. In this sense, time and space are saved to build the device.

After choosing the microcontroller, it had to think about how to connect it with 30 E-R pairs. The solution was simple, multiplexers and de-multiplexers. Having 2 multiplexers which would be connected their outputs with the E-R pair. In this sense it would choose what E-R pair that one would like. In addition 2 de-multiplexers would be used and connected with the IR-Photodiodes with the purpose of detecting which one is not receiving the IR-beam.

Also, to connect the 30 E-R pairs with the multiplexers and de-multiplexers 2 of 40-pin connector have been used for this purpose.

Figure 3.2.7.2: 40pin connector.

3.2.9. How to detect a goal? Double scan.

This point has been also difficult to solve, it was about how to identify and detect a ball that has crossed the line. Having the IR-beam 11.5 mm far from the goal line, the detection of a goal was not too difficult to do. Moreover, the way to make out between the ball and the rest of the thing that could cross the IR-beam had to be found.

First of all, it was thought of, having all E-R pairs on, focusing the IR-beam with a lens but this idea was removed because of the price and the size of it, doing a recalculation of the number of E-R pairs and their positions. At that point a double scan was thought of.

After that idea, doing a double scan switching on and off every single E-R pair was thought of. Starting from the bottom to the top every E-R pair would be switching on and off and when whatever intercepts with the IR-beam, it would have an interruption and the first scan would be done. The first scan would consist in detecting what receiver does not receive the IR-beam and wait for a delay.

Afterwards, the second scan would be done. It would consist in having the same receiver that does not receive the IR-beam, switching on the receivers next to that receiver said in order to create an IR-beam which covers the diameter of the ball and if they do not receive IR-beam it would mean that it is a goal.

This point will be explained in depth in the point that explains how the system works.

CHAPTER 4

SYSTEM DESIGN

4. System design.

The system is built to be able to detect goals in a goal made to a scale. It is also designed to be able to make the difference between a ball and other things. One microcontroller is used to manage what E-R pair has to be on and detect which pair does not receive the IR-beam. The microcontroller is programmed in C language. Also several multiplexers and de-multiplexers are used to select the E-R pairs. A red led is used to simulate the goal notification in the referee's watch.

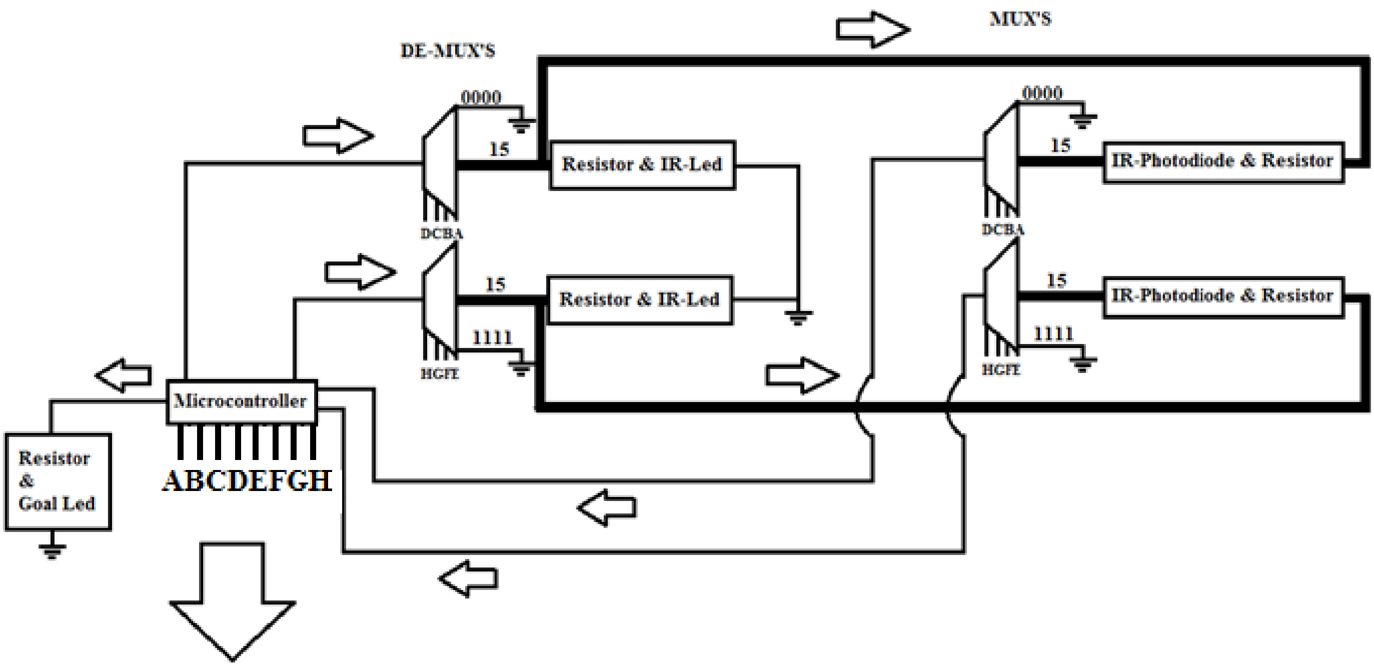


Figure 4.1: System diagram.

4.1. Hardware.

4.1.1. System parameters.

In this part some calculations are made to justify the selection of the electronic devices used to implement the system.

4.1.2. Board and tracks.

The tracks of the circuit have been designed with a standard width of 0.5 mm; this value is between the recommended values in the *Student Handbook*. Furthermore, pads on the via and µC have been 1.75 mm. The tracks have been printed in both sides of the board, top and bottom.

4.1.3. Goal notification.

Goal notification has been carried out by a red led. In this led the forward voltage is 2.25 V and the forward current maximum is 20 mA. Therefore, the value the resistor is calculated according to this data.

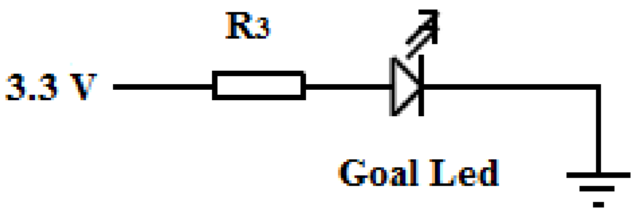


Figure 4.1.3: Goal Led.

$$I = \frac{V}{R};\ I_{max} > \frac{V}{R}; R > \frac{V_{CC} - V_F}{I_{max}};\ R > \frac{3.3 - 2.25}{20 \cdot 10^{-3}} > 52.5\ \Omega; R = 91\ \Omega$$

4.1.4. IR-Leds and IR-Photodiodes.

IR-Leds have been connected between the outputs of the multiplexers and ground. The inputs of the multiplexers are connected to the microcontroller. So, for IR-Leds the forward voltage is 1.7 V and the forward current maximum is 20 mA. Therefore, the value of every resistor is calculated according to this data.

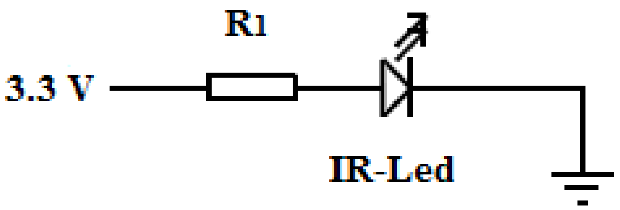


Figure 4.1.4: IR-Leds.

$$I = \frac{V}{R};\ I_{max} > \frac{V}{R}; R > \frac{V_{CC} - V_F}{I_{max}};\ R > \frac{3.3 - 1.7}{20 \cdot 10^{-3}} > 80\ \Omega; R = 91\ \Omega$$

IR-Photodiodes have been connected between the outputs of the multiplexers and the inputs of the de-multiplexers. .The inputs of the multiplexers are connected to the microcontroller. .The outputs of the de-multiplexers are connected to the microcontroller. So, for IR-Photodiodes the reverse voltage is 32 V and the reverse current maximum is 100 µA. Therefore, the value of every resistor is calculated according to this data.

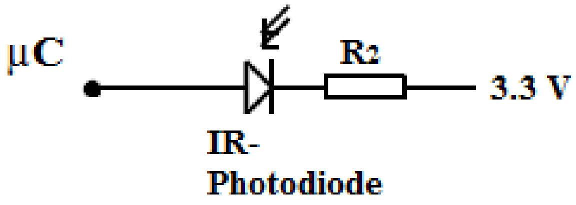


Figure 4.1.4: IR-Photodiodes.

$$I = \frac{V}{R};\ I_{max} > \frac{V}{R}; R > \frac{V_{CC} - V_F}{I_{max}};\ R > \frac{32 - 3.3}{100 \cdot 10^{-6}} > 287\ k\Omega; R = 3\ k\Omega$$

4.1.5. Voltage reference.

There are 2 input voltages, one is from the power supply and its value is 3 V, this is only for the µC which, as the datasheet says, it has to be fed by a 3 V power supply. There is another power supply of 5 V to feed the other electronic components: multiplexers and de-multiplexers.

As the datasheet says in the 2.2 chapter called Recommended System Connections: "VDD and VSS are the primary power supply pins for the MCU. This voltage source supplies power to all I/O buffer circuitry, ACMP and ADC modules, and to an internal voltage regulator. The internal voltage regulator provides a regulated lower-voltage source to the CPU and other internal circuitry of the MCU.

Typically, application systems have two separate capacitors across the power pins: a bulk electrolytic capacitor, such as a 10- μ F tantalum capacitor, to provide bulk charge storage for the overall system, and a bypass capacitor, such as a 0.1- μ F ceramic capacitor, located as near to the MCU power pins as practical to suppress high-frequency noise.”

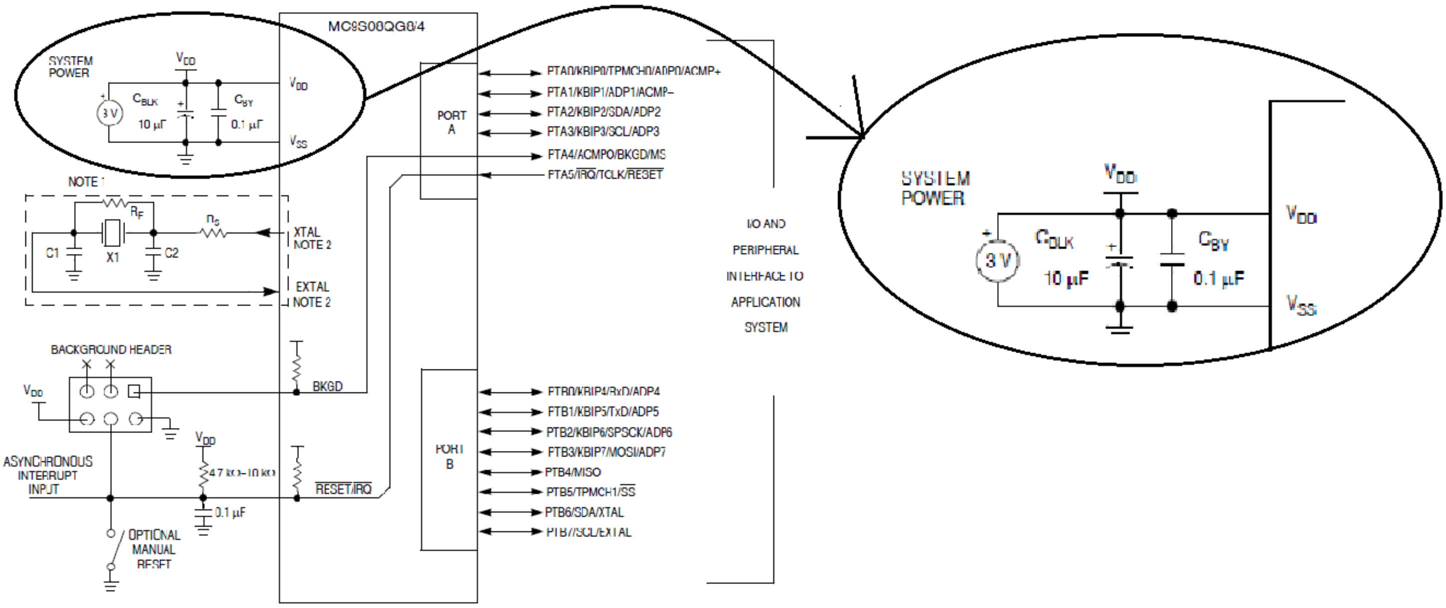
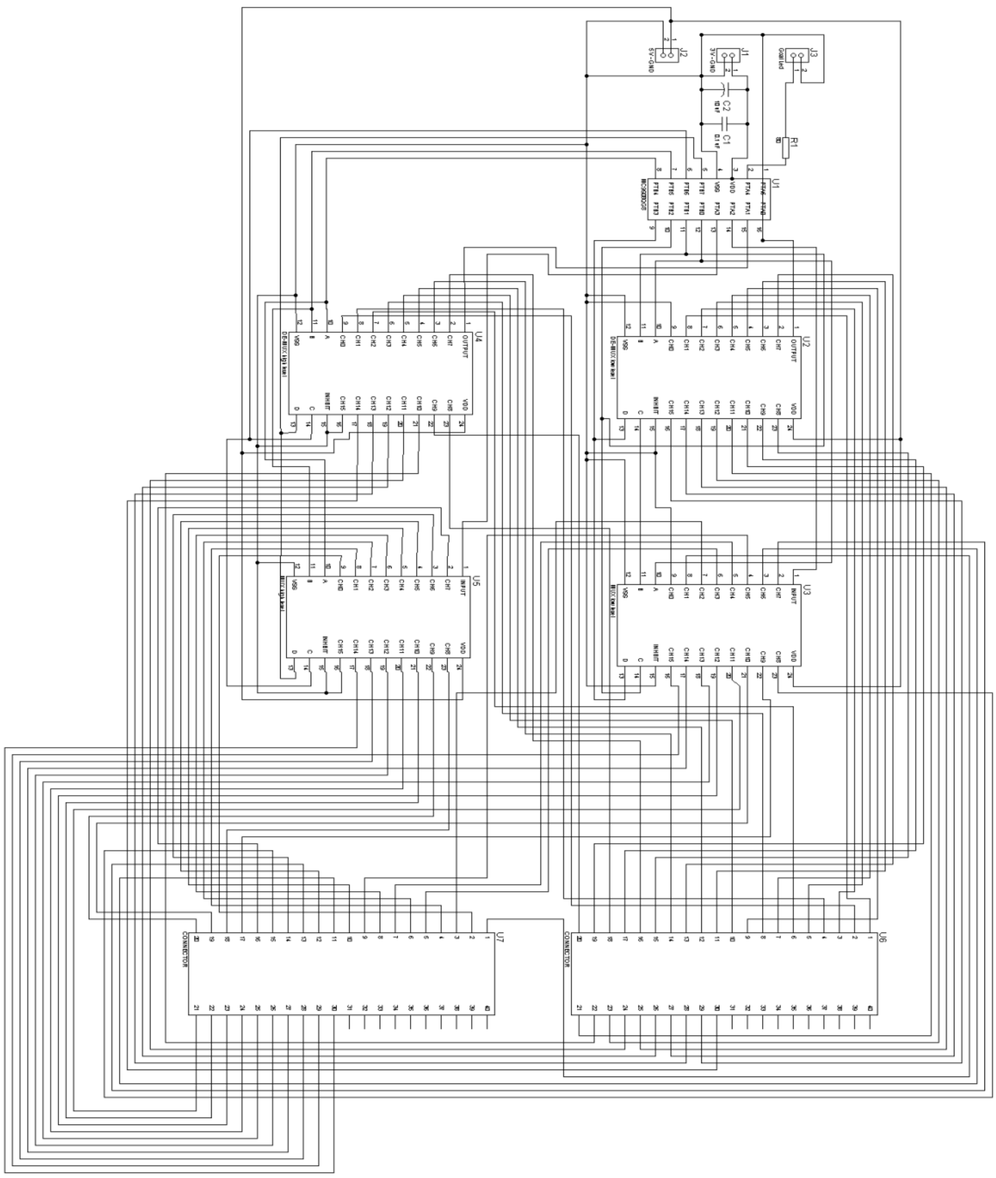


Figure 4.1.5: Capacitors.

4.1.6. Board development.

The program used to develop and implement the boards is *Proteus 7 Professional*.



4.1.7. List of components.

Description	Details	Manufacturer	Quantity
Microcontroller	MC9S08QG8	Freescale	1
Mux/De-Mux	CD4067BE	Texas Instruments	4
Resistor 91 Ω	0.5W carbon film resistor	TruOhm	31
Resistor 3 kΩ	0.5W carbon film resistor	TruOhm	30
IR-Led	L-7113F3BT	Kingbright	30
IR-Photodiode	BPW41N	Kingbright	30
Red Led	L-7113HD	Kingbright	1
Capacitor 10 μF	Radial electrolytic capacitor	Panasonic	1
Capacitor 0.1 μF	Radial electrolytic capacitor	Panasonic	1
Connector	40pin connrector	Rapid	2
μC Board	16.5 mm x 9 mm	-	1

Table 4.1.7.1: List of components.

4.2. Software.

The software part has been written using the C language; and the program used to compile and program the microcontroller is CodeWarrior. This program is available when bought the microcontroller and the demo kit. Two main programs were written, one for the main loop and the other for the interruption. To explain the operation of the programs, some flow charts are represented below.

There are two programs, the main program that is an infinite loop and the KBI interruption that occurs only when the microcontroller detects that interruption. After the interruption the program comes back to the main loop.

4.2.1. Flow chart of the main loop.

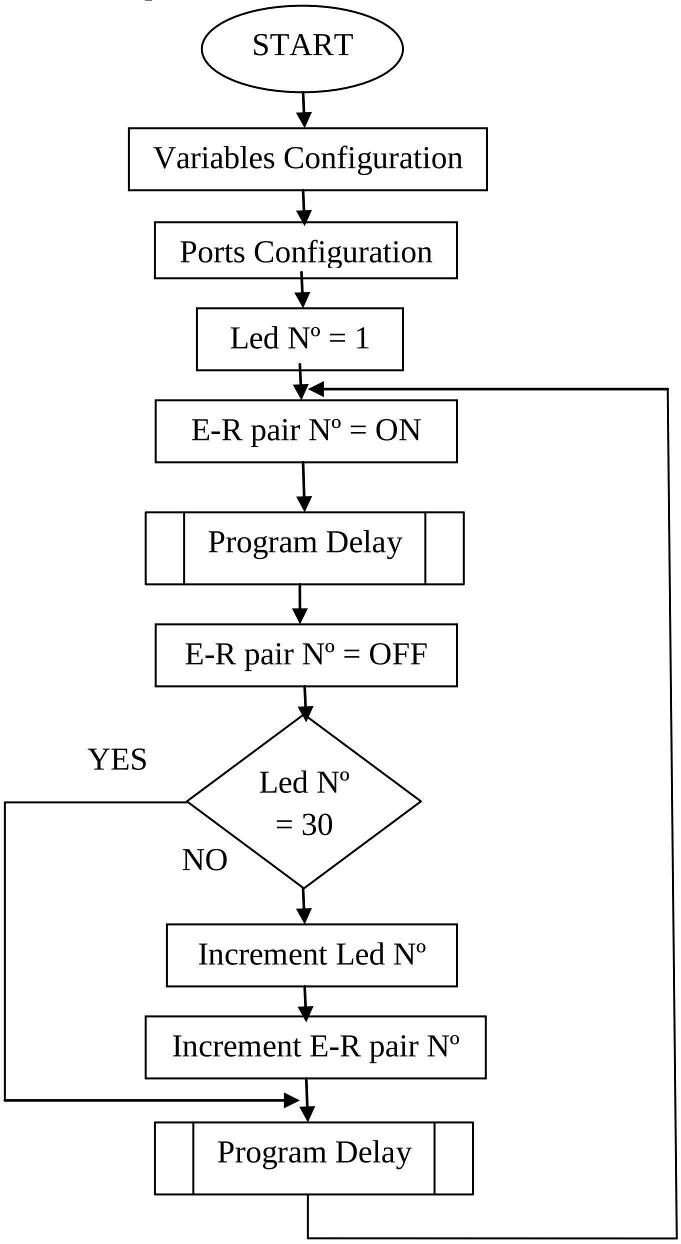


Figure 4.2.1.1: Main loop.

4.2.2. Flow chart of the KBI interruption, first scan.

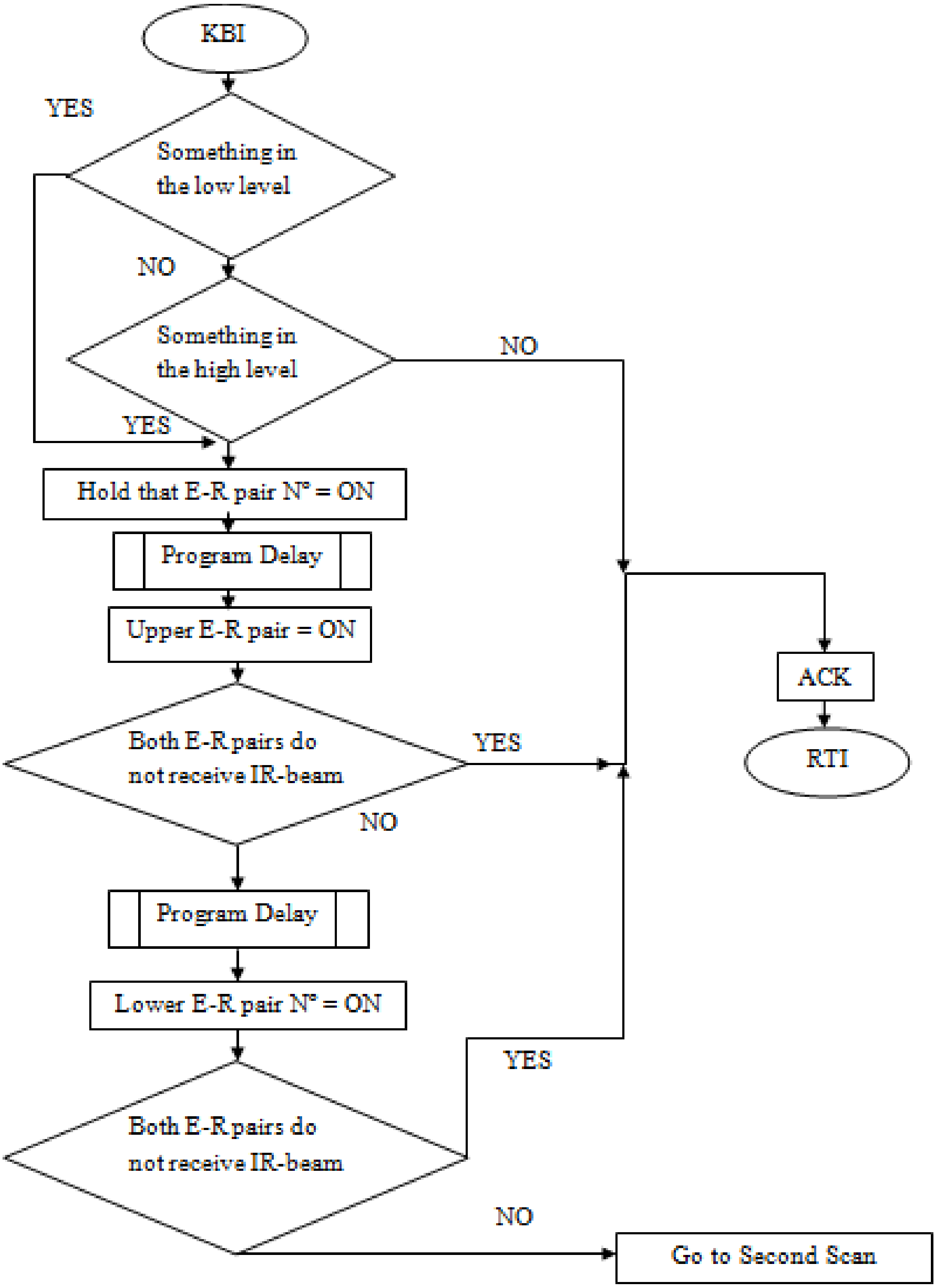


Figure 4.2.2.1: 1st scan flow chart.

4.2.3. Flow chart of the KBI interruption, second scan.

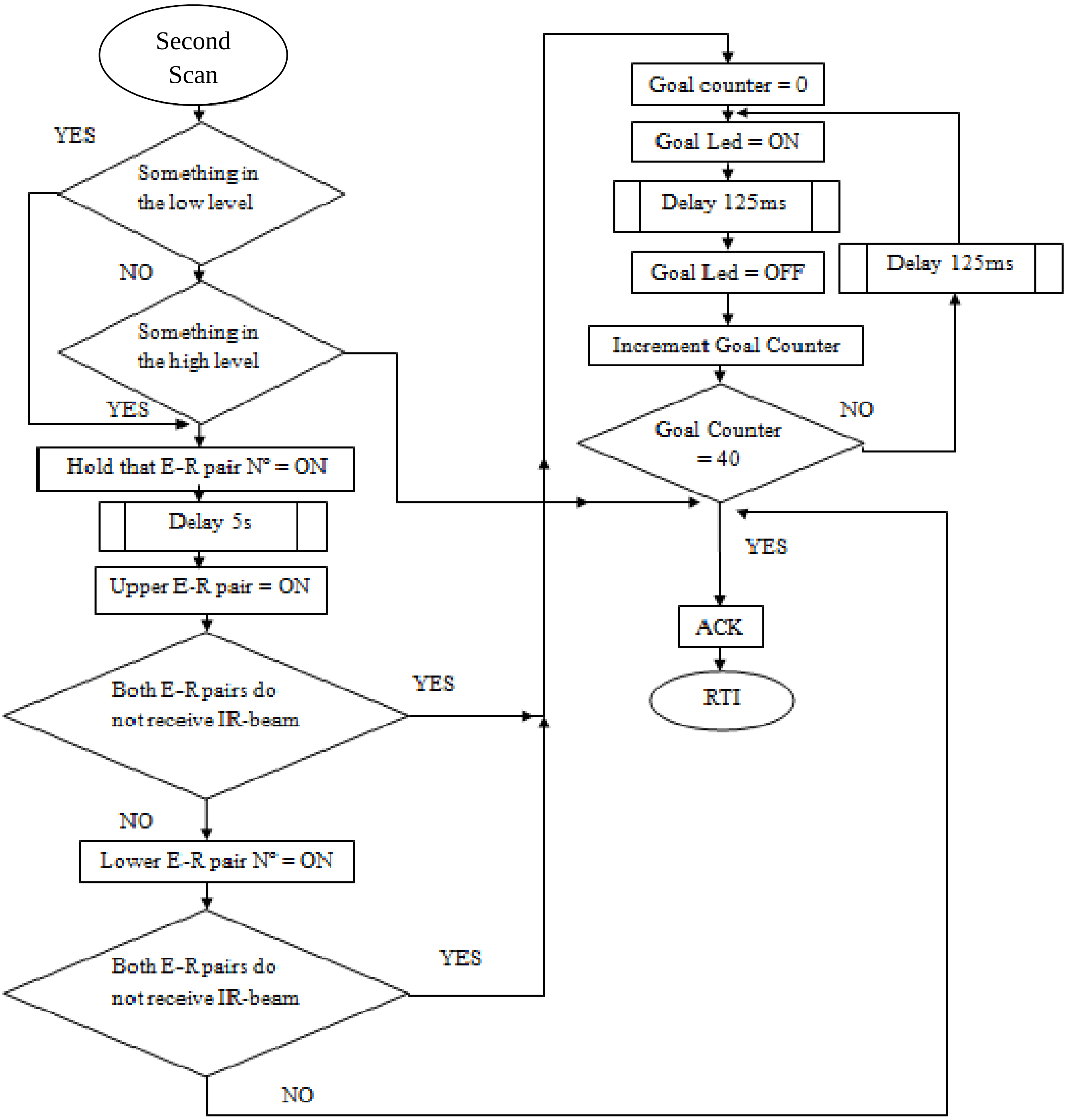


Figure 4.2.3.1: 2nd scan flow chart.

4.3. How this system works.

This chapter will explain how the system works more in depth. As it has already been mentioned, the system is based on the action of a double scan to determine a goal and in turn identify whether is the ball or other object which has completely crossed the goal line.

The microcontroller has two ports, PTAD and PTBD. PTBD is dedicated entirely to the selector pin of the multiplexers and the de-multiplexers. 16 bits, the lower level corresponds to the outputs from the 0 to the 3 and the other 4 remained outputs correspond to 8 bits of the higher level.

PTAD is projected to enable the de-multiplexers, to receive if an interruption of the two multiplexers and to notify a goal by the Goal Led. This port has 6 outputs but only the 5 firsts have been used.

Once the ports have been configured as inputs and outputs, depending on further use, the main loop is planned to switch on and off each E-R pair, starting from the bottom to the top. This is realized by increasing PTBD as it will be changing the channel selection in both de-multiplexers that they will select the emitters and the multiplexers that they will select the receiver.

Once the scan reaches to the top then it will start again from the bottom making an infinite loop that it will be only interrupted if at the same time that the E-R pair is switched on, the emitter emits light and the receiver does not receive it which means that something blocks the light . Thus when this takes place, reading PTBD, it will be known what pair is switched on and which one is not receiving light.

Before turning to the second scan, it is determined if the object that interrupts the light beam is the ball or not. To do so said pair will be activated simultaneously with the upper pair. If both do not receive light this means that object is larger than the ball and the interruption ended back to the main loop. If it receives light this last pair is switched off and the first pair are activated and also the lower pair for the same purpose. If both do not receive light means that object is larger than the ball and the interruption ended back to the main loop. If it receives, this last pair is switched off and it is moved on to the second scan.

It should be noted that if the penultimate pair, starting from the bottom or from the top, only the pair immediately below and immediately above the pair have to be switched on, respectively, to determine the size of the object.

The second scan aims to determine that the ball has crossed the goal line completely and notify a goal only when the object is the ball. To do this, after having obtained pair of E-R from the first scan, it has to wait 5 seconds to simulate the movement of the ball. The choice of this time is described above in the chapter of switching time.

After these five seconds the second scan will start and will be performed in the same modus operandi that the first scan did, with the difference that instead of going to another scan, it will be thrown on to the goal notification by the goal led.

The determination of the object's size is explained in that, if when one of the upper or lower pair does not receive light it will be determined a goal. In case of it receives light; the object will be somewhat less than the ball and the interruption will end getting back to the main loop.

CHAPTER 5

BUILDING & TEST

5. Building and test.

The board has been built in the laboratory of the C&T building and the model has been built at home and then it was brought to the lab and checked with the electronic devices.

To study the reliability of the built system, some tests have been done. With the aim of testing if the infrared works, a simple test has been done.

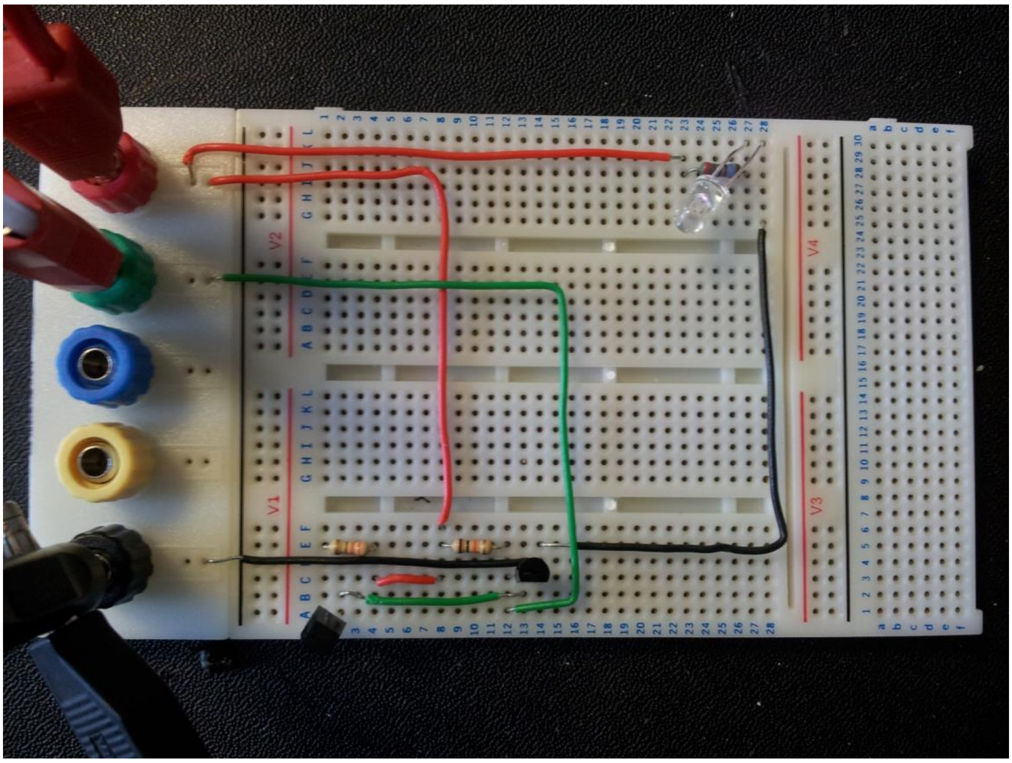


Figure 5.1: IR testing board.

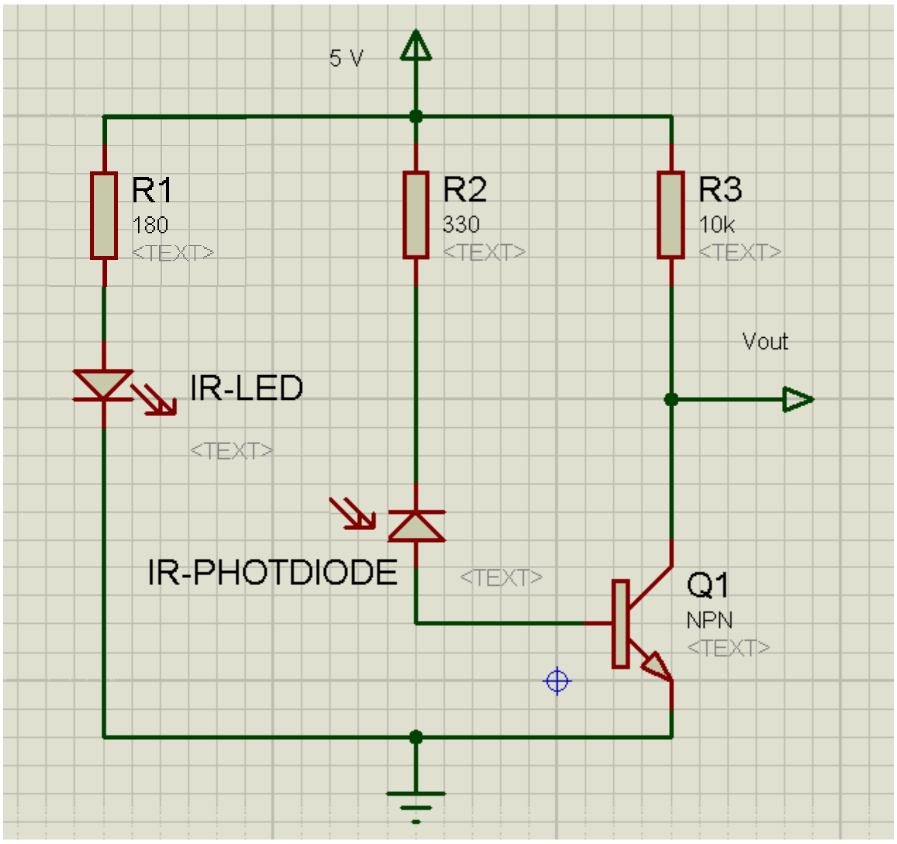


Figure 5.2: Design of IR testing circuit using ISIS.

The calculations have been done according to the characteristics of the components.

$$I = \frac{V}{R};\ I_{max} > \frac{V}{R}; R > \frac{V_{CC} - V_F}{I_{max}};\ R > \frac{5 - 1.7}{20 \cdot 10^{-3}} > 165\ \Omega; R = 180\ \Omega$$

After having implemented this circuit, with a camera phone, a picture has been taken with the purpose of demonstrating that the circuit works properly.

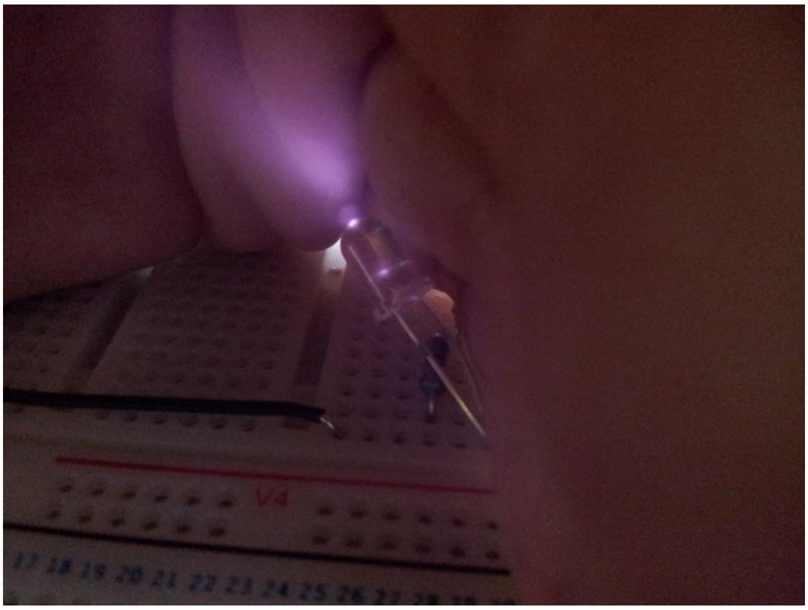


Figure 5.3: IR-Led at working.

Relating with the programming of the microcontroller, a specific demo board has been utilised. It is called DEMO9S08QG8 and it has been served to program the microcontroller.

First of all, CodeWarrior, the ide to program the microcontroller had to be installed, then the code was written and finally the code was exported to the microcontroller thanks to the demo.

Figure 5.4: DEMO9S08QG8.

At the end the final board has been built.

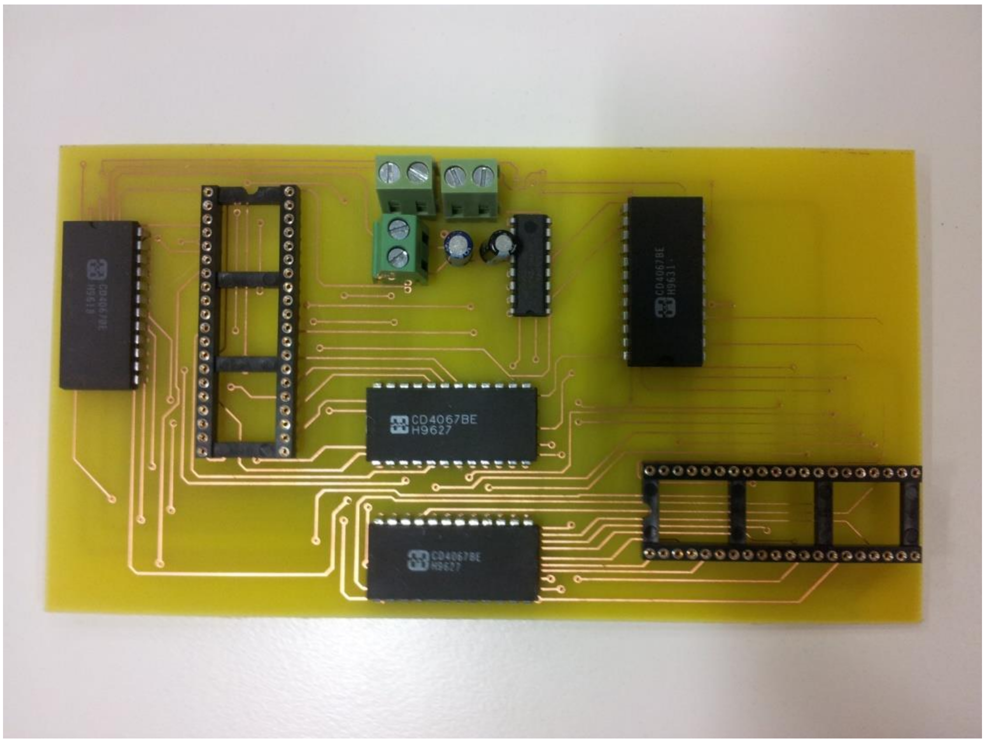


Figure 5.5: PCB board.

CHAPTER 6

FUTURE WORK

6. Future work.

The project is able to detect when a in scale ball has completely crossed the goal line by using IR-Leds and IR-Photodiodes, emitters and receivers, respectively. However, this project, like every project, can be improved. In the aspect of E-R pairs laser sensors could be used. Focusing the IR-beam could be other way. These studies would be interesting.

The way to identify could be different. If lenses are used in order to focus the IR-beam, the size of the object which is interposed with the IR-beam could be measured easier. Another thing that could be improved is reducing the number of components used. Instead of building a whole goal in scale, a model could be designed which only need a few E-R pairs.

With respect to the code, it could be written in a different way with the aim of an easier reading and understanding. The code could be changed in some actions to facilitate the execution of the program. Relating to the microcontroller, it could be utilised other more powerful and faster with the purpose of switching the E-R pairs faster. Also having a more powerful microcontroller, all the E-R pairs could be switched on, if the numbers of them are not too large.

If the project wants to be expanded, different ways to Goal Line Detection Systems could be implemented. A list of possible task is given below:

- GLT by the use of IR curtains focusing the beam.
- GLT by the use of laser sensors.
- GLT by the use of IR curtains with all E-R pairs switched ON at the same time.
- GLT by the use of 2 E-R pairs (one pair behind the two posts and the other pair behind the cross bar and on the ground).
- Building a small model with a different technology.

CHAPTER 7

CONCLUSIONS

7. Conclusions.

The design and development of the project has been done successfully. A Football Goal Scoring Detection System has been made with specific requirements. The characteristics of the system allow an easy and intuitive use of the system by the users. The model is also quite big because it has been done to a scale of an actual goal. The design and development of the microcontroller is needed to manage the E-R pairs, it is the main item which has to be looked after.

After having some difficulties writing the code and programming the microcontroller, finally it was done successfully. The last order of components was delayed but in the end the project could be built. Also some problems have been had with the manufacture of the PCB board due to the magnitude of it. In addition, in some tests, a small percentage of them, this system does not work as it has to.

Once the model was built with the E-R pairs and the microcontroller was programmed, the main conclusion obtained was that implementing this technology into a scale, has been quite elaborate. The principal reason is that all non-electronics components were in a scale except the electronic devices, for example, the ball has been reduced to a scale from its actual size but, on the other hand the IR-Leds has not.

This means that if this technology could be used in a real goal, it would probably work.

APPENDICES

Appendix A: References.

1. Books:

A.Bergh, *Light Emitting Diodes*, Edition Oxford 2000.

H.Schneider, *Quantum Well Infrared Photo-Detectors: Physics and Applications*, Edition Berlin 2007.

K.Schneider, *Highly Sensitive Optical Receivers*, Edition Berlin 2006.

J. Wilson, J. Hawkes, *Optoelectronics an Introduction*, Edition London, 1998.

X. Maldague, *Infrared Methodology and Technology*, Edition Canada 1994.

2. WebPages:

FIFA (no date) "*Goal Line Technology*" Available at:

http://www.fifa.com/search/index.html?q=goal+line+technology

FRAUNHOFER (Jul 05, 2012) "*GoalRef: FIFA approves intelligent goal from Fraunhofer*" Available at:

http://www.iis.fraunhofer.de/en/pr/pm_archiv/press-releases-2012/goalref.html

HAWKEYE INNOVATIONS (no date) "*Hawk-Eye in Sports*" Available at:

http://www.hawkeyeinnovations.co.uk/

Appendix B: Statement of work.

1. Aim

The project objective is to simulate Goal Line Technology in a football goal. For that, it will be used Infra-Red technology, IR-Curtain. This IR-Curtain will be done using IR-LEDs and Photodiodes, such as emitters and receivers.

2. Background

Since television has allowed to see replays of controversial plays in a match, have been observed refereeing errors. One of the most controversial is the ghost goal. FIFA, initially opposed any technological improvement, gave the approval on Thursday July 5, 2012 to two systems that let you know if the ball completely crosses the goal line or not.

These systems are: Hawk-eye, used in tennis, cricket or rugby, and GoalRef technology that has a chip inside the ball and creating a magnetic field on the goal line, can be known if it is goal or not. Both systems send a signal to the referee's watch, in less than a second, he is that indicates the goal. The referee has the power to allow the goal or not, he has the last word.

FIFA has given its approval, but the organ that dictates the laws of football is the International Football Association Board (IFAB), the organization responsible for the regulation of football, and after refereeing errors in the last European Championship, despite having auxiliary referees, decided to investigate possible solutions to this problem.

3. Activities

3.1 Work breakdown structure

1. Background Study

1.1. GoalRef (GLT-Goal Line Technology)

1.2. Other Systems

1.3. Approach Model

1.4. Technology to Use

2. Construction

2.1. Match Data and Statistics

2.2. Preliminary Design

2.3. Advantages and Disadvantages

2.4. Model Estimates

2.5. Final Model

2.6. Testing and Repairing possible errors

3. Reporting

3.1. Progress Report Revision

3.2. Draft Report Compilation

3.3. Final Report Preparation

3.2 Task descriptions

After doing the Background Study about technologies currently in different sports (WBS1.1-1.2), it will be available to explain the technology chosen. That technology is the Infra-Red technology, IR-Curtain (WBS1.4). Once the technology has been defined and specified for the aim of the project it will begin with the analysis of data collected from different matches (WBS2.1). Those data may include, average goals per match, the number of times a player crosses the goal line, how many times a part of the body of goalkeeper crosses the line...

During this time it will proceed to the construction of the structure of the model (WBS2.2). Then, it will be listed advantages and disadvantages to use this technology in the model and in reality, doing a comparison between the two. At this point it will start with the calculations of the electronic circuits, uC, PCB... (WBS2.3-2.4)

Just then, it will build the rest of the model, incorporating electronic items recently calculated, and then the whole model will be tested. In the case there will be any failure, it must be repaired to its correct operation (WBS2.5-2.6).

Finally there will be a report that will include everything done up to that time (WBS3).

3.3 Programme

A Gantt chart is attached.

4. **Dependencies**

Tasks 2.2, 2.4, 2.5, 2.6 will require use of lab and electronic devices and components and access to the labs in C&T Building.

5. **Risk management**

1. Non-availability of labs, causing delay to the project. To manage this risk, the labs will be booked a week in advance of its being required.
2. Lost or stolen computer, causing delays in the project and data loss. To avoid this will proceed to save files in different digital platforms.

3. Delays in the project due to many tasks in other subjects, extracurricular activities or due to illness. This can be solved, being strict in the planning defined in the Gantt Chart.

4. Delays components, both electronic and none, in charge, causing delays in the project. The way to avoid this is to order what is needed in advance.

6. Deliverables

Item		**Due date**
1.	Interim report	9 Nov 2012
2.	Draft Final Report	9 Apr 2013
3.	Final report (2 copies)	26 Apr 2013

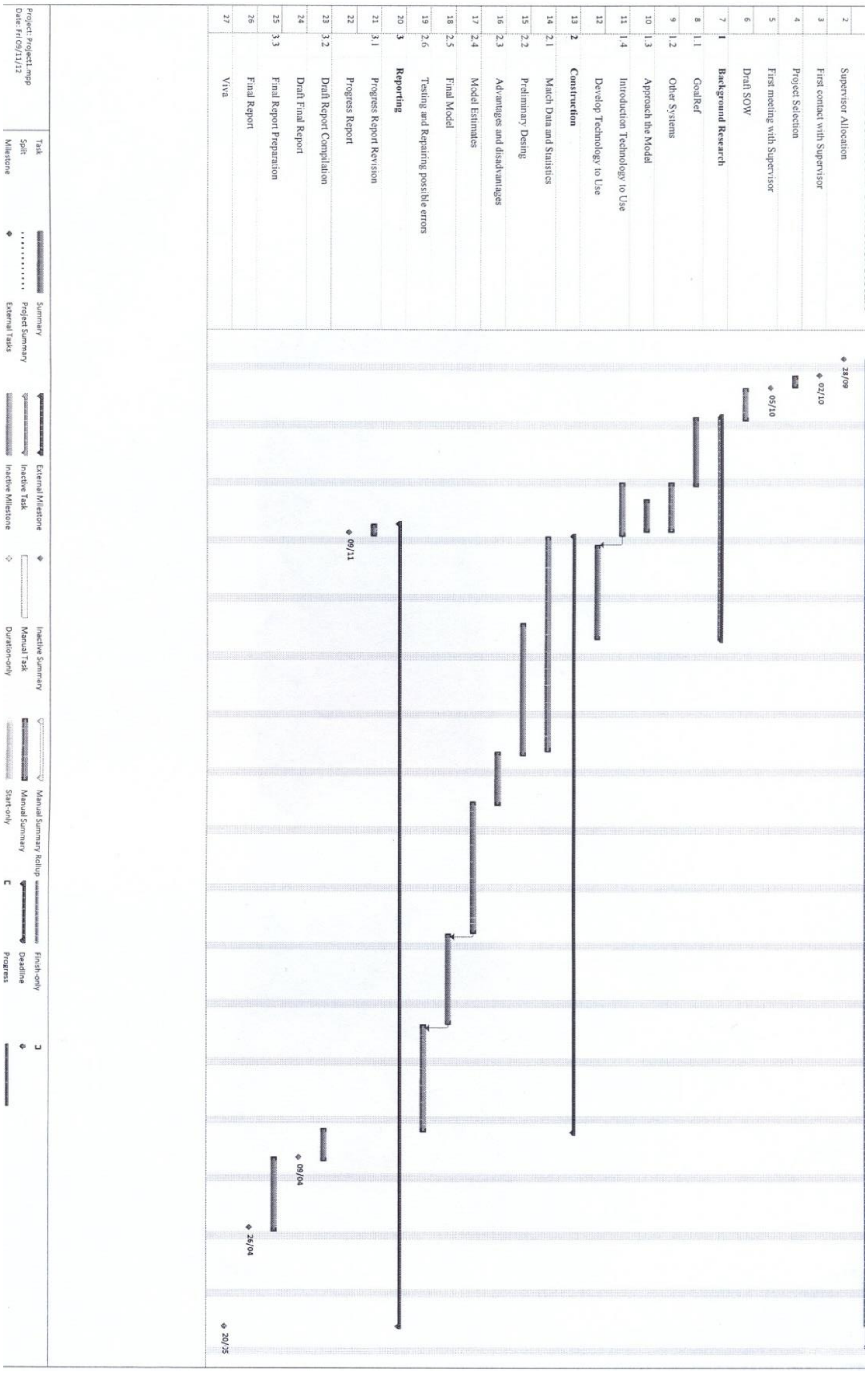
7. References

http://www.fifa.com

http://www.iis.fraunhofer.de/en.html

http://www.hawkeyeinnovations.co.uk/

J. Wilson, J. Hawkes, *Optoelectronics an Introduction*, Edition London, 1998.



2 Supervisor Allocation
3 First contact with Supervisor
4 Project Selection
5 First meeting with Supervisor
6 Draft SOW
7 1 Background Research
8 1.1 GoalRef
9 1.2 Other Systems
10 1.3 Approach the Model
11 1.4 Introduction Technology to Use
12 Develop Technology to Use
13 2 Construction
14 2.1 Match Data and Statistics
15 2.2 Preliminary Desing
16 2.3 Advantages and disadvantages
17 2.4 Model Estimates
18 2.5 Final Model
19 2.6 Testing and Repairing possible errors
20 3 Reporting
21 3.1 Progress Report Revision
22 Progress Report
23 3.2 Draft Report Compilation
24 Draft Final Report
25 3.3 Final Report Preparation
26 Final Report
27 Viva
28/09
02/10
05/10
09/11
09/04
26/04
20/05
Project: Project1.mpp
Date: Fri 09/11/12
Task
Split
Milestone
Summary
Project Summary
External Tasks
External Milestone
Inactive Task
Inactive Milestone
Inactive Summary
Manual Task
Duration-only
Manual Summary Rollup
Manual Summary
Start-only
Finish-only
Deadline
Progress

Appendix C: Code in C Language.

```
#include <hidef.h>      /* common defines and macros */

#include "derivative.h"      /* derivative-specific definitions */


//Global variable declarations


unsigned char Counter;

unsigned char LedCounterLowLevel;

unsigned char LedCounterHighLevel;


//Function declarations


void PortStart (void);

void EmitterReceiver (void);

void Delay (unsigned int time);

void Delay2 (unsigned int time);

void KBIStart (void);

void LedScanLowLevel (void);

void LedScanHighLevel (void);
```

```
void main(void) {

  /* put your own code here */



PortStart ();

EmitterReceiver ();

LedScanLowLevel ();

LedScanHighLevel ();

KBIStart ();


            EnableInterrupts;

  for(;;) {

    _FEED_COP(); /* feeds the dog */

  } /* loop forever */

  /* please make sure that you never leave main */

}


void PortStart (void){                        // Ports Configuration



  PTADD = 0b11110011;                    // Port A, Inputs-Outputs

  PTBDD = 0xFF;                          // Port B, Outputs

  PTAD = 0b00000011;                     // Enable DMux's

  PTBD = 0b00000000;                     // Emitter-Receiver (E-R) Pairs Off-Off
```

```
}
  void EmitterReceiver (void){              // Goal Scanning
 LedCounterLowLevel = 1;                    // Low Level Scan Counter
 do {
   PTBD += 0b00000001;               // Increment Low Level PTBD, Nº(_) E-R On-Read
   LedCounterLowLevel ++;                  // Increment Low Level Scan Counter
 }while (LedCounterLowLevel<16);          // Until PTBD: 0b00001111
   PTBD = 0;                          // Finish Low Level Scan, Restart PTBD
 LedCounterHighLevel = 1;                  // High Level Scan Counter

 do {
   PTBD += 0b00010000;              // Increment High Level PTBD, Nº(_) E-R On-Read
   LedCounterHighLevel ++;                // Increment High Level Scan Counter
 }while (LedCounterHighLevel<15);         // Until PTBD: 0b11100000
 }

void Delay (unsigned int time){                              // 125ms Delay
        unsigned char i;
        for (i = 0; i < time; i++){
        asm{
                        PSHH
                        PSHX
```

```
                LDHX #$0000
    loop:   AIX #1
                CPHX #62500
                bne loop
                PULX
                PULH
            }
    }
}

void Delay2 (unsigned int time){                    // 5s Delay
    unsigned char y;
    for (y = 0; y < time; y++){
    asm{
                PSHH
                PSHX
                LDHX #$0000
    loop:   AIX #1
                CPHX #2500000000
                bne loop
                PULX
                PULH
```

```
            }
      }
}
void InterruptKBI (void) {
 if (PTAD_PTAD2 == 1){                  // Low Level PTBD
  PTBD += 0b00000001;                   // Increment Low Level PTBD, Check Upper E-R
   if (PTBD > 0b00001111){              // Check Low or High Level PTBD
    if (PTAD_PTAD3 == 0){               // Check High Level PTBD
    PTBD -= 0b00000010;                 // Decrement x2 PTBD, Check Lower E-R
     if (PTAD_PTAD2 == 0)               // Check Low Level PTBD
     PTBD += 0b00000001;                // Increment PTBD, Initial E-R
     else goto FINAL;                   // NO-GOAL, It is something bigger than ball
    }
    else goto FINAL;                    // NO-GOAL, It is something bigger than ball
   }
   else if (PTAD_PTAD2 == 0){           // Check Low Level PTBD
    if (PTBD == 0b00000010){            // Check 2nd Lowest E-R
    PTBD -= 0b00000001;                 // Decrement PTBD, Check Lowest E-R
    goto FirstStep;                     // Jump to
    }
    else PTBD -= 0b00000010;            // Decrement x2 PTBD, Check Lower E-R
     if (PTAD_PTAD2 == 0)               // Check Low Level PTBD
```

```
        FirstStep: PTBD += 0b00000001;     // Increment Low Level PTBD, Initial E-R
        else goto FINAL;                   // NO-GOAL, It is something bigger than ball
      }
      else goto FINAL;                     // NO-GOAL, It is something bigger than ball
        goto SecondScan;
    }


    else if (PTAD_PTAD3 == 1){             // High Level PTBD
      PTBD -= 0b00010000;                  // Decrement High Level PTBD, Check Lower E-R
      if (PTBD < 0b00010000){              // Check Low or High Level PTBD
       if (PTAD_PTAD2 == 0){               // Check Low Level PTBD
       PTBD += 0b00000010;                 // Increment x2 PTBD, Check Upper E-R
        if (PTAD_PTAD3 == 0)               // Check High Level PTBD
        PTBD -= 0b000100000;               // Decrement High Level PTBD, Initial E-R
        else goto FINAL;                   // NO-GOAL, It is something bigger than ball
       }
       else goto FINAL;                    // NO-GOAL, It is something bigger than ball
      }
      else if (PTAD_PTAD3 == 0){           // Check High Level PTBD
       if (PTBD == 0b11010000){            // Check 2nd Highest E-R
       PTBD += 0b00010000;                 // Increment PTBD, Check Upper E-R
       goto SecondStep;                    // Jump to
```

```
        }
        else PTBD += 0b00100000;          // Decrement x2 PTBD, Check Upper E-R
          if (PTAD_PTAD3 == 0)            // Check High Level PTBD
          SecondStep: PTBD += 0b00010000;   // Increment High Level PTBD, Initial E-R
          else goto FINAL;                // NO-GOAL, It is something bigger than ball
      }
      else goto FINAL;                    // NO-GOAL, It is something bigger than ball
  goto SecondScan;
  }

SecondScan: {
  Delay2 (5000);                              // 5s Delay in order to start the SecondScan
  if (PTAD_PTAD2 == 1){                   // Low Level PTBD
    PTBD += 0b00000001;                   // Increment Low Level PTBD, Check Upper E-R
      if (PTBD > 0b00001111){             // Check Low or High Level PTBD
        if (PTAD_PTAD3 == 1)              // Check High Level PTBD
        goto GOAL;                        // GOAL
        else PTBD -= 0b00000010;          // Decrement x2 PTBD, Check lower E-R
          if (PTAD_PTAD2 == 1)            // Check Low Level PTBD
          goto GOAL;
          else goto FINAL;                // NO-GOAL, It is something bigger than ball
          }
```

```
    else if (PTAD_PTAD2 == 1){          // Check Low Level PTBD
     goto GOAL;                         // GOAL
     if (PTBD == 0b00000010);           // Check 2nd Lowest E-R
     PTBD -= 0b00000001;                // Decrement PTBD, Check Lowest E-R
     goto ThirdStep;                    // Jump to
    }
     else PTBD -= 0b00000010;           // Decrement x2 PTBD, Check Lower E-R
      if (PTAD_PTAD2 == 1)              // Check Low Level PTBD
      ThirdStep: goto GOAL;             // GOAL
      else goto FINAL;                  // NO-GOAL, It is something bigger than ball


  }


  else if (PTAD_PTAD3 == 1){            // High Level PTBD
    PTBD -= 0b00010000;                 // Decrement High Level PTBD, Check Lower E-R
    if (PTBD < 0b00010000){             // Check Low or High Level PTBD
     if (PTAD_PTAD2 == 1)               // Check Low Level PTBD
     goto GOAL;                         // GOAL
     else PTBD += 0b00000010;           // Increment x2 PTBD, Check Upper E-R
      if (PTAD_PTAD3 == 1)              // Check High Level PTBD
      goto GOAL;                        // GOAL
      else goto FINAL;                  // NO-GOAL, It is something bigger than ball
```

```
      }
      else if (PTAD_PTAD3 == 1){          // Check High Level PTBD
      goto GOAL;                          // GOAL
        if (PTBD == 0b11010000);          // Check 2nd Highest E-R
        PTBD += 0b00010000;               // Increment PTBD, Check Upper E-R
        goto FourthStep;                  // Jump to
        }
        else PTBD += 0b00100000;          // Decrement x2 PTBD, Check Upper E-R
          if (PTAD_PTAD3 == 1)            // Check High Level PTBD
          FourthStep: goto GOAL;          // Increment High Level PTBD, Initial E-R
          else goto FINAL;                // NO-GOAL, It is something bigger than ball
    }


  }


GOAL: {
  PTBD = 0b00000000;                      // E-R Off
  Counter = 1;
  do {                                    // GOAL-Led Loop
   PTAD = 0b00010011;                     // GOAL-Led On
   Delay (125);                           // 125ms
   PTAD = 0b00000011;                     // GOAL-Led Off
```

```
   Counter ++;
  } while (Counter<40);                    // 5s Loop
}

FINAL: KBISC_KBACK = 1;                    // ACK_Interrupt

}

     void KBIStart (void){
  KBISC = 0b00000110;
  KBIPE = 0b00000110;
  KBIES = 0b00000000;
}
```

Appendix D: Datasheets

The datasheets have been printed and submitted with this project.

The datasheets describe the following components:

- Microcontroller: MC9S08QG8.
- IR-Led: L-7113F3BT IR LED 5MM BLUE LENS (RC).
- IR-Photodiode: BPW41N INFRA RED SENSOR (RC).
- Mux and De-Mux: CD4067BE.
- Red Led: L-7113HD LED 5MM RED DIFF 5MCD (RC).