COLOR DETECTION USING ARTIFICIAL RETINA

By

ISRAEL YOHANNES BAYOU

FINAL PROJECT REPORT

Submitted to the Electrical & Electronics Engineering Programme
in Partial Fulfillment of the Requirements
for the Degree
Bachelor of Engineering (Hons)
(Electrical & Electronics Engineering)

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
Electrical & Electronics Engineering Programme
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Approved:

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Dr. Mohd Zuki Yusoff
Project Supervisor

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
December 2010

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein has not been undertaken or done by unspecified sources or persons.

Israel Yohannes Bayou

ABSTRACT

Color detection using artificial retina project is meant to simulate color detection and differentiation ability of human retina. The purpose of this project is to develop artificial retina that can be applied in robotics and other color detection needs. Project implementation is using simple electronic components such as LEDs, LDRs, a microcontroller and an LCD display. The motivation for this project is ongoing research in many parts of the world to alleviate color blindness. Although this project might not be directly applicable to human retina it can be integrated with robots and can be used as a reference for future students interested in the area. The project is completed and the constructed color sensor is able to detect 16 different colors achieving the intermediate scope of the project. In this report literature review along with different relevant case studies, the progresses made, the problems faced during the work progress and the results found are discussed.

ACKNOWLEDGEMENTS

The greatest of all my appreciation goes to the almighty GOD, the creator of the universe and everything that is in it. As I would not be here, complete my project and attend education without his gracious will.

Next, I want to thank my supervisor Dr. Mohd Zuki Yusoff, for his constant help, guidance and encouragement throughout the project. Apart from supervising the project work, he was willing to provide extra lessons on programming and troubleshooting of my prototype. Moreover, I would like to thank him for lending his own materials for the project.

Secondly many appreciations to Mrs. Siti Hawa for her advice on various matters and to UTP EE store personnel for their help in providing and locating useful components for the project. And also many thanks for UTP FYP committee for effecting the whole FYP process smoothly.

Furthermore my gratitude goes to PETRONAS for giving me this scholarship to study in UTP and UTP Electrical and Electronics Engineering department staff for helping me gain invaluable knowledge.

Finally I would like to thank all my family and friends, whose unconditional love and moral supports helped me to face the ups and downs before my way.

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CHAPTER 1

INTRODUCTION

Color is the perceptual property of an object that appears to the observer when an incident ray of light interacts with the surface of the object. Recognizing different colors of objects is important in our day to day life in order to enhance understanding of our environment and interact with it. To detect and identify colors, humans and some animals use information from special cells situated in the retina. This project focuses on achieving artificial color vision using simple electronic components within the given time duration of two semesters. In this chapter general introduction of the project is given including the significance, the objectives and the scope of the project.

1.1 Background of Study

Color is derived from the wavelength and intensity of light in the visible spectrum. Human beings can see in the visible spectrum at wavelength ranging approximately from 380 nm to 740 nm. The retina has special type of cells which are sensitive to light namely rods and cones. Rods are retina cells responsible for vision during dark or minimum light. Whereas cones activate when there is optimum light and based on the range of wavelength they are more sensitive to, cones are categorized into red cones, green cones and blue cones. The visible range and number of cone types differ between species.

There are many theories that explain how a human eye differentiates color. One of them is the Trichromatic theory [1] which states that color of an object is perceived based on its red, green and blue light wavelength contents of the reflected light from the object. Hence the part of our brain responsible for vision translates the color of the objects based on the activation level of cone cells. Another popular theory on color vision is the Opponent theory [1]. This theory explains color vision as the difference between the activation level of cones and rod cells of the retina.

Color blindness which is the inability to identify all or some of the colors can be caused by genetic disorder (inherited from parents), eye damage, nerve cell damage, brain damage (color recognition area of the brain) or exposure to chemicals. Color blindness does not have a medical cure so far but when color blindness is caused by eye damage only, while the brain color recognizing ability is still intact, supposedly artificial sensors can replace the color detection function of the retina and transmit the information directly to the brain. So far many scientific research have been performed in the area and promising results have been found [2, 3].

Color detection has a variety of application in industry to facilitate production and packaging process. In food industries, for example, color of products can be used as quality control measure. In others such as automobile, textile and paint industries, products or input materials can be sorted according to their colors with the help of color detecting sensors. In addition, during bottling of products, color detection is used to inspect the ones that have a bottle cap from those who doesn’t have.

Figure 1 Bottle Cap Inspection

In this project, color detection is carried out using LDRs and LEDs. The LEDs (light emitting diodes) are used to emit red, blue and green colored light whereas the LDRs (light dependant resistors) are used to sense the intensity of the reflected light from the object. The output of the sensor is analyzed and interpreted by a PIC16F877A microcontroller and the result displayed using a PC1601-A LCD panel.

1.2 Significance of Project

This project is significant for applications that require simple color detection ability for not more than sixteen different colors. The color sensor developed in this project is a low cost sensor made from simple electronic components that can be readily found hence it can be developed and applied easily. Hence it can be an ideal option for a simple industry application and it can be integrated with robotics vision.

Moreover, this project is highly significant for the student to enhance knowledge on the area of color theory and sensor development. While carrying out the project, the usage of a microcontroller especially the PIC16F877A and C programming skills were strengthened.

1.3 Problem Statement

Color sensors have a variety of useful application in many industries. Color sensors are also be used in robotics for navigation or any other desired activity. Although highly selective sensors are available in the market, cost wise they might not be ideal choice for every use. This project tries to develop a sensor that is simple and low cost that can be used in a not-high-profile color sorting applications.

In addition, color detection using artificial sensors has been a major interest in many research centers worldwide to help the color blind to restore their vision.

Although the prototype that can be produced in this project cannot be adapted to human eye, the basic principles can be adopted in the area.

1.4 Objectives of Project

The project focuses on achieving artificial color detection using simple electronic components. Accordingly the core objectives are:

i. To develop an artificial retina that can sense and differentiate a variety of colors. The artificial retina built should be within the limitations stated under the scope of study.

ii. To display the output on to an LCD screen.

1.5 Scope of Project

The scope of this project is divided into three levels. The primary level is to achieve basic functionality which is to detect and differentiate seven colors namely red, green, blue, white, yellow, orange, and pink (magenta). Once the primary level is completed the project is expanded into detecting sixteen different colors which is assigned as the intermediate level the project. Finally the advance level of the project is to detect sixty four different colors.

The main constraints of the project are time, with the duration of two semesters and finance, with a budget of RM250 per semester.

1.6 Organization of Report

This report is a compilation of all the works performed for the color detection project using artificial retina. It is divided into five chapters. The first chapter is the introductory chapter giving general information on the project, its objectives and scope and also the significance of the project upon completion.

The second chapter will be discussing the research undertaken, the theory of color sensing, and the differentiation and summary of other projects that are of relevance to this project. The color space being used and the basic instruments that are utilized to make a potential prototype are also discussed.

Chapter three summarizes the step wise procedure towards completing the project. The actual color detection work done and the tools used along with rough cost estimation of the prototype is discussed. In addition, this chapter presents the code used and the working principle of the sensor built.

Chapter four contains the results obtained and discussion part explaining the interpretation of various results shown. Finally, the last chapter concludes the whole report and gives recommendations for future projects that may use this project as a reference material.

CHAPTER 2

LITERATURE REVIEW

The color of an object is due to the interaction of surface of a body with a ray of light and an observer. Color categories and physical specifications of color are associated with objects, materials, light sources, etc., based on their physical properties such as light absorption, reflection, or emission spectra. There are different color spaces that help in quantifying color attributes numerically for example, RGB color space and HSV color space. In this project the color space being used is RGB color space. The color values are measured using combination of an LDR and LED network. In this chapter the theory of color sensing, the differentiation and the different components that are used are discussed and finally, few other projects that are of relevance to this project are summarized and presented.

2.1 Color Sensing

Color sensing depends on measuring the intensity of light at different wavelengths. One approach is to use a spectrometer and split the light with a prism or diffraction grating into its component wavelengths. However, spectrometers are complex and too difficult to build. Another approach measures the light intensity in three primary color bands: red, green, and blue and determining the color based on its content of these basic colors. For example, a pure pink/magenta colored light can be recognized by 1:0:1 combination of red, green and blue colors respectively in RGB color space.

There are different types of electronic equipments that can be used as color sensors. Electronic components like LEDs, LDRs and phototransistors detect color by changing their behavior based on the intensity and/or wavelength of light reflected up on them. In this project LEDs and LDRs are being used as the main components of the color sensor, hence the next subsections look closely into these devices.

2.1.1 LED (Light Emitting Diode)

LEDs are simple junction diodes that emit visible light as voltage is applied across them. In addition to emitting light, junction diodes exhibit some degree of photosensitivity when they receive light comprising an appropriate range of wavelengths. The spectral response of a junction diode depends on a variety of factors including material chemistry, junction depth, and packaging. The packaging of most devices aims to inhibit sensitivity to radiant flux to maintain the intended function of the device which is emitting light. However, some devices' packaging and construction techniques allow convenient exposure to light. In the case of LEDs, they are packaged to emit radiant flux, hence, can serve as narrowband photo detectors.

Figure 2 Different colored LEDs

An LED's sensitivity to light and particularly to its emission wavelength depends primarily on the device's bulk material absorption and junction depth. For LEDs that have low bulk absorption, photosensitivity at or near peak wavelength is low, and as a result, the creation of hole-electron pairs is low. Ordinary LEDs will give a very low response if used as light detector, hence ultra-bright LEDs (high power LEDs) should be used for building the sensor.

Figure 3 below shows a responsivity and emission curve for a GaAs based Infineon SFH409 LED [5] which has its peak sensitivity at 920 nm wavelength while emitting at 940 nm. Making use of the fact that LEDs are more or less sensitive to the same color they emit, and well band passed for other wavelengths, it makes them ideal for color detection application.

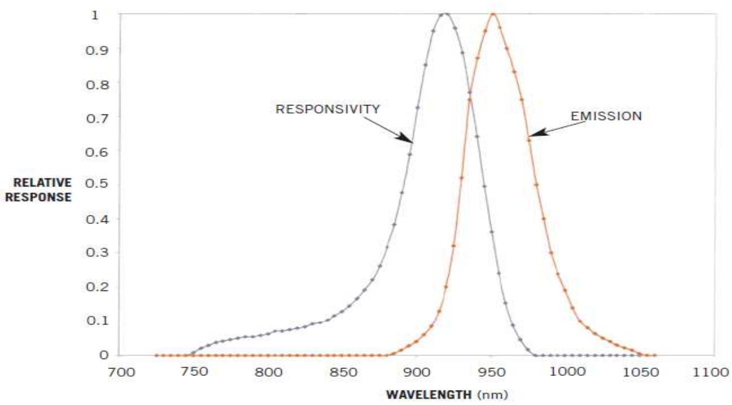


Figure 3 Relative responsivity and emission spectra for GaAs LED

Based on the LED color (the light they emit when it is used as a lamp), the circuit schematics shown in figure 4 below [5] can be used to detect color. For example if the LED is a red color LED, the circuit will output its peak voltage signal when its exposed to red color light or red color object. The op-amp is used to amplify the LED output as it is too small to be useful. The resistor is used to control the amplification range of the op-amp and the capacitor is used to stabilize the circuit as the output of the LED may vary due to various reasons like ambient light interference and distance of the object. Similarly, replacing the red LED with green and blue

LEDs will result in green and blue sensors respectively. This configuration is used as a base to build some color sensors available in the market.

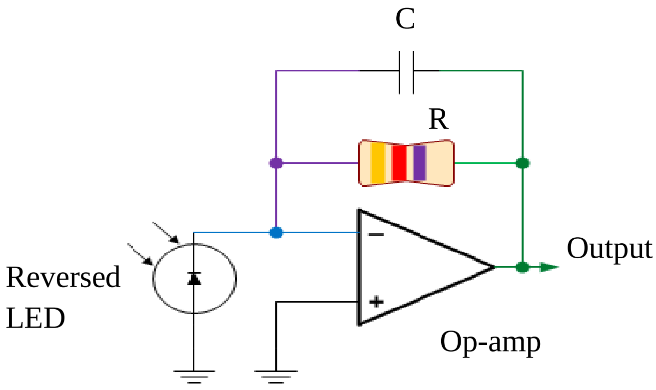


Figure 4 Simple color detecting circuit using LED

2.1.2 LDR (Light Dependant Resistor)

An LDR also known as a photo resistor, made up of cadmium sulfide cells, is a type of resistor whose resistance value changes with the intensity of incident light falling on it. The relation between the resistance of an LDR and luminance is shown in the graph in figure 6 below [6] (Luminance represents the illumination per square area). A photo resistor is made of a high resistance semiconductor. If light falling on the device is of high frequency enough, the photons absorbed by the semiconductor give bound electrons enough energy to jump into the conduction band. The resulting free electron conducts electricity, thereby lowering resistance [7].

LDRs have many applications such as in automatic street lighting system, in night glowing watch and so on. LDRs are like monochromatic camera, they are responsive to the intensity of light but not to the wavelength and they can give the same activation/resistance value if they are exposed to light rays that are equally bright but having different colors.

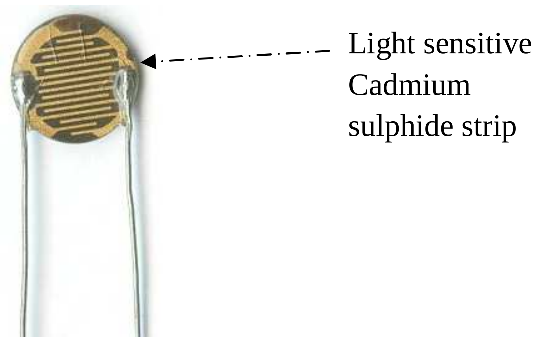


Figure 5 Light Dependant Resistor

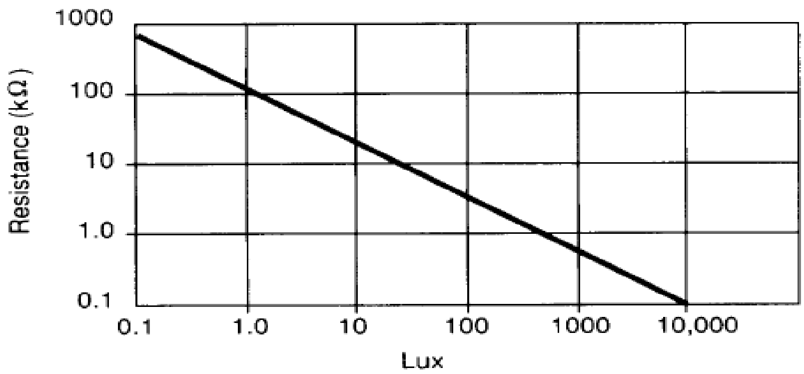


Figure 6 Resistance vs. Luminance curve

In order to use LDRs as color sensors, either color filter glasses should be used on top of them so that one LDR will be dedicated to detecting one color. Color filter glasses allow limited spectrum light to pass through them and block the rest. For example the LDR with blue filter on top will be activated only when a blue light falls on it.

2.2 Color Differentiation

The color sensor outputs a current or voltage level in response to the detected color. The next step is analyzing the output to differentiate between the types of color perceived. This can be achieved first by collecting data samples to assign which color produces the specific response in the sensor. Once the samples are collected, a suitable code is written and a programmable PIC, particularly the PIC16F877A, can be programmed with the code.

There are a few color spaces used to quantify a particular color numerically; RGB, HSV/HSL, LAB color spaces are some examples. In this project the color space being used is RGB color space.

2.2.1 RGB color space

An RGB color space is any additive color space based on the RGB color model. A particular RGB color space is defined by the three chromaticities: red, green, and blue additive primaries which can produce any chromaticity that is found in the triangle defined by those primary colors as shown in the figure below [8]. The point D65 in the figure shows the white point which is the mixture of equal proportion of the three chromaticities.

In RGB color space, a color is defined by analyzing the amount of red, green and blue contents of the color perceived. When an object is brought into the detection range of the color sensors discussed above, depending on their voltage output of each of the sensors, the colors can be differentiated.

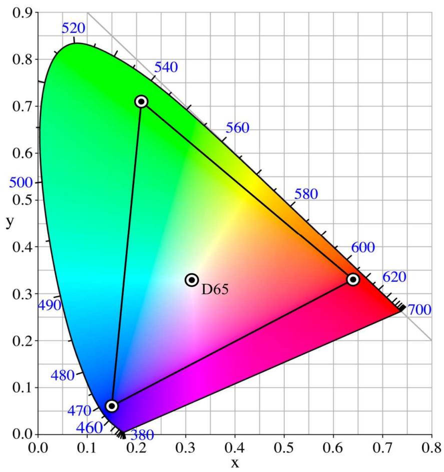


Figure 7 RGB color triangle

2.2.2 Microcontroller

In this project, the PIC16F877A microcontroller was used to function as the brain of the color differentiation part. It is one of the most commonly used microcontrollers especially in automotive, industrial appliances and consumer applications. This microcontroller is a compact standalone computer and has functionalities needed for this project which includes an I/O interface, data processing ability, storage, memory, ADC (analog digital conversion) and serial communications. Moreover, the PIC16F877A is an ideal choice for this project because of its re-programmability, low power consumption; low cost, small size, reliability and fast processing speed.

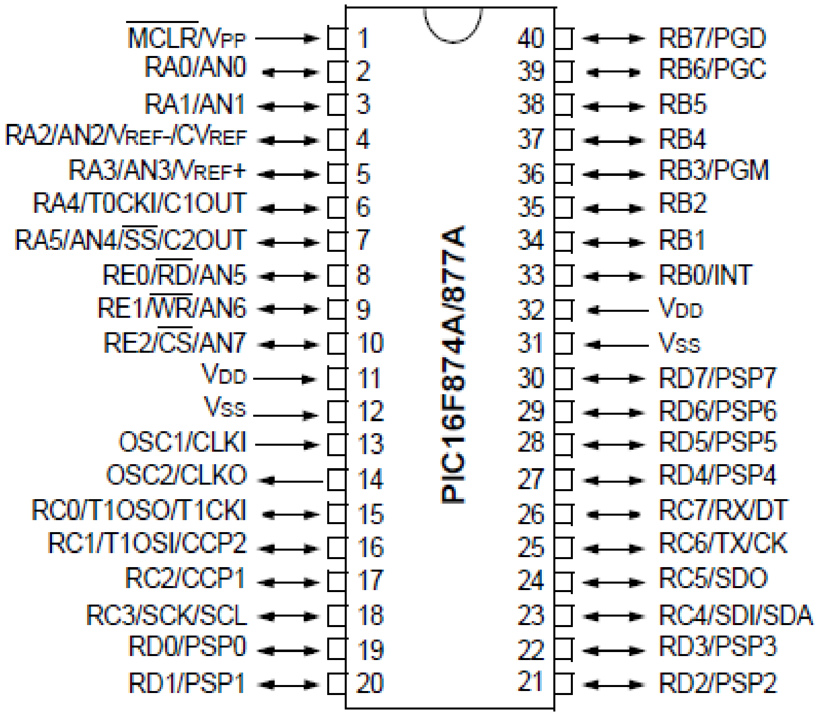


Figure 8 Pinout of PIC16F877A [9]

2.2.3 LCD (Liquid Crystal Display)

As part of the requirements in this project, upon completion of the detection of color, the output of the sensor and microcontroller was displayed using an LCD display. The LCD chosen is a 16x1 POWERTIP PC1601-A because of its availability. It also has low power consumption and ability to be interfaced and controlled by the microcontroller used. This LCD is a one line display with space for 16 characters and can be programmed to display up to 224 different characters. Figure 9 below shows the pinout for the LCD.

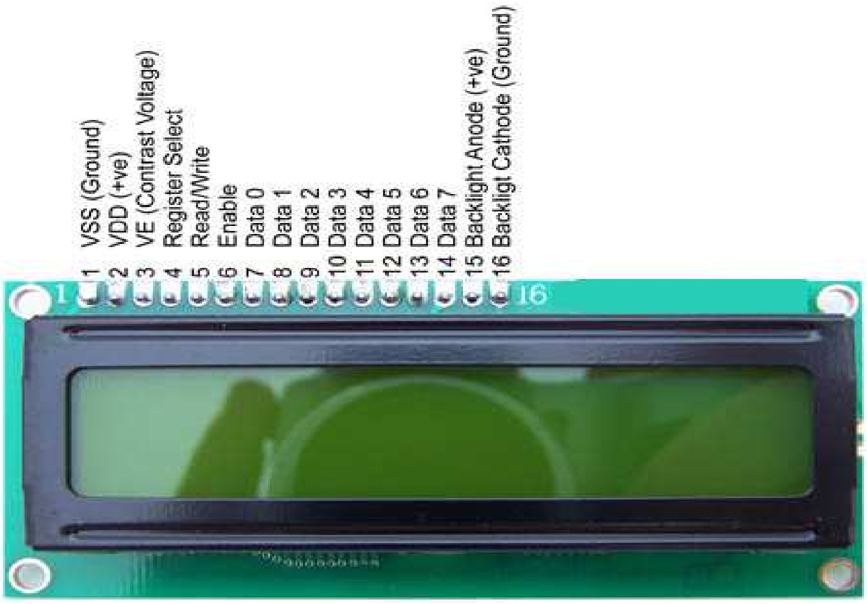


Figure 9 16x1 LCD panel

2.3 Survey of Previous Projects

Color detection projects, although for different purpose, have been carried out by other parties before and some of the relevant projects are used as references for this project. These projects have different details and functionality depending on the purpose they are built for; some of the useful ones to the project are discussed below.

2.3.1 Color detection method for introductory robotics

This project [10] has been implemented on robots to sort colored candies, and according to the authors, it has been implemented successfully to detect 6 different colors. The sensor used the colored LEDs to emit light and LDRs to sense the color. The author uses Euclidian distance to differentiate between colors perceived based on basic color values.

- First the LDRs maximum and minimum range is calculated and the optimum resistance of R (as shown in figure 10 below) to give the widest range of detection is computed.
- Few known colors such as red, green, blue, yellow, brown, orange will be detected and the value of LDRs resistance for each of them is measured.
- Finally for all other colors detected, the Euclidean distance from basic colors is calculated and the color is decided for the shortest distance calculated.
- Euclidean distance between two points P and D is calculated as shown in equation 2.1 below:

$$d(p,q) = \sqrt{(p_1 - q_1)^2 + (p_2 - q_2)^2 + \cdots + (p_n - q_n)^2}$$

$$\sqrt{\sum_{i=1}^{n}(p_i - q_i)^2} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (2.1)$$

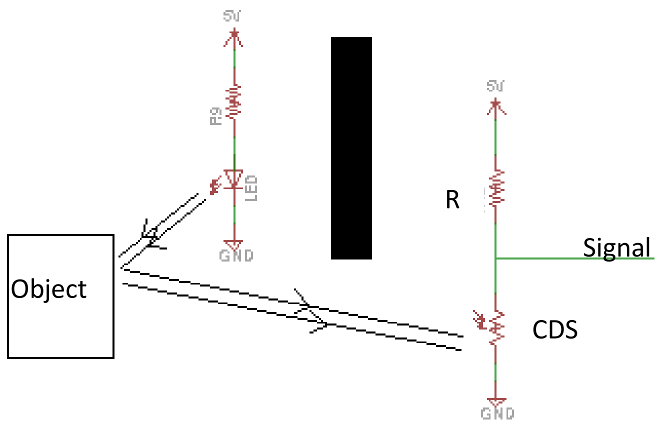


Figure 10 Basic color sensor used for candy sorting robot (redrawn for clarity)

2.3.2 Modeling retina: color tracker project

In the color tracker project [11], the authors tried to model color detection, saccade and color tracking function of an eye. The color detection will be discussed here briefly.

The color sensor detects nine (9) colors which are *red high, red mid, red low, green high, green mid, green low, blue high and blue low*. Figure 11 shown below is the schematics for the color sensors, and in the project four of such schematics were setup to sense red, green, blue and white colors. Eight (8) LEDs are connected in parallel to increase the current output upon detection of the respective color. The resistor R1 connected is of large value (7.5 Mega Ohms) so that the current will result in a large voltage drop across the resistor which will be used as an input to the ADC. A capacitor is put in parallel to the resistor in order to make the voltage across the resistor more stable. This capacitance value had to be very small (2.2 nF) in order for it to charge and discharge very rapidly in accordance to the change in the LED current output.

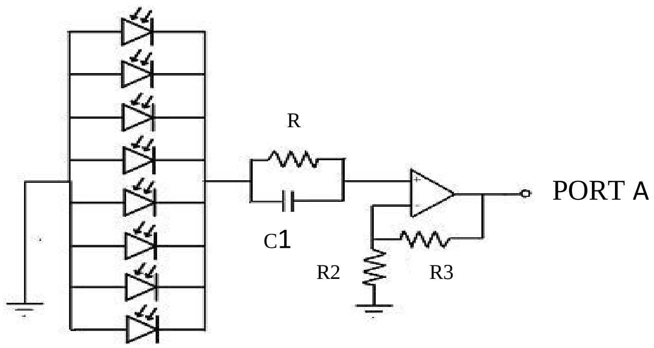


Figure 11 Single color detector used in “Modeling Retina” project

The voltages across the resistors and capacitors which correspond to each color were amplified by using an operational amplifier whose output voltage goes as follows:

$$Vout=Vin * (1+R3/R2) \qquad (2.2)$$

2.3.3 Color vision electronics project

In this project [12], the authors were interested in detecting the 3 basic colors: red, green and blue. In the circuit shown below, the LED and transistor pair makes up for a phototransistor. In addition, the transistor is set up as a variable resistor. The LED and transistor combination supposedly works as an LDR with a built in filter. The sensor output is sent to another interface for further processing.

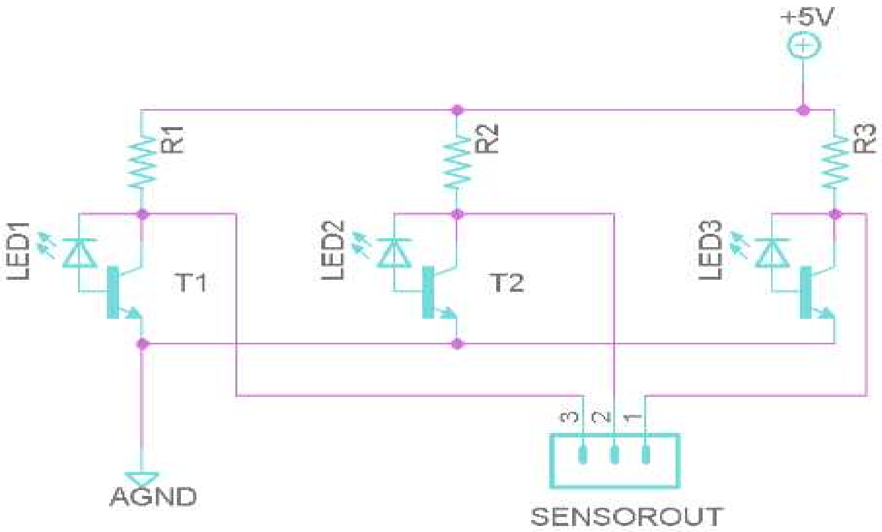


Figure 12 RGB color sensor circuit used in “color vision electronics” project

2.4 Summary

Research performed, the theory of color sensing, the differentiation and summary of other projects that are of relevance to this project have been discussed. The color space being used, and the basic instruments that are used to make a potential prototype are also discussed. And from the gathered information, a decision has been made on how to proceed with the project at hand.

CHAPTER 3

METHODOLOGY

A research methodology defines the activities to be carried out and answers the question on how to proceed with the activities in the project in a step wise fashion. The project at hand is performed over two academic semesters starting out with research study to gather knowledge on the area and followed by performing simple experiment setups for each part of the project and finally assembling and improving the prototype so as to realize the objective of the project. While carrying out this project a few problems were faced with the prototype and coding. In this chapter, the methods used, the procedures followed and the problems faced are discussed.

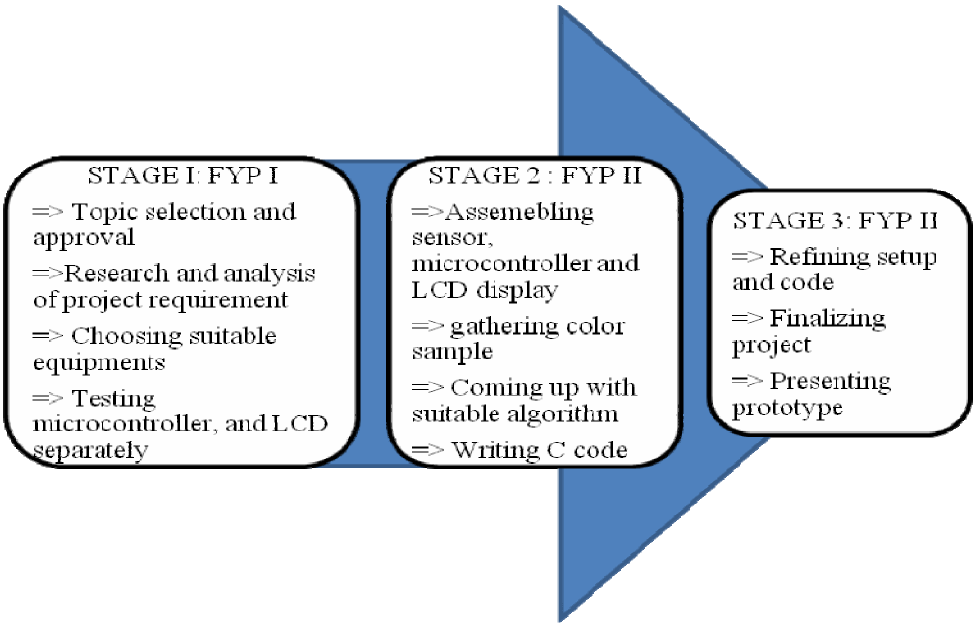


Figure 13 Overall project summary flowchart

3.1 Procedure Identification

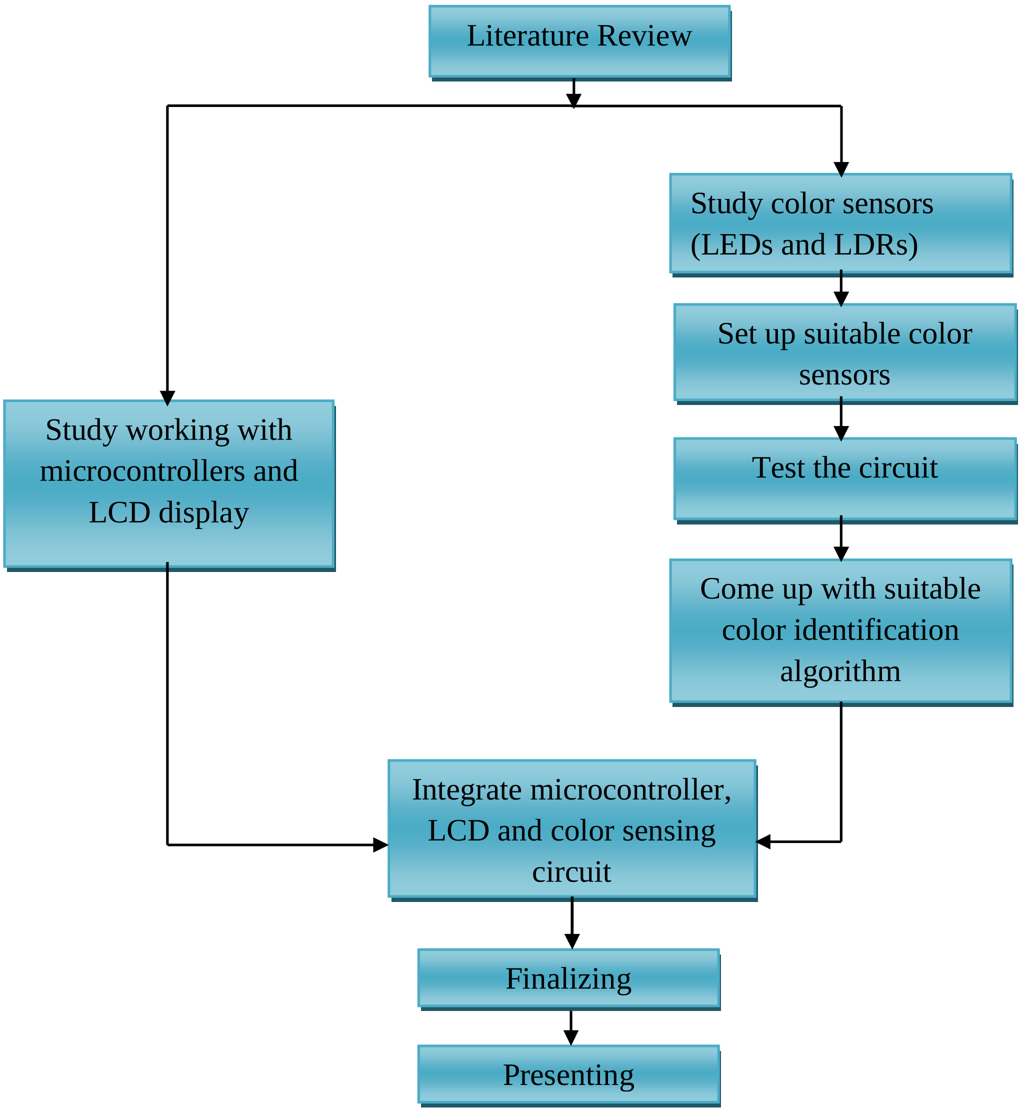


Figure 14 Flowchart of the project

3.1.1 Study of color sensors

A study on the sensors is crucial to select the best sensor set up that can achieve the objective, which is ability to detect as many as sixty four colors with a sensor made up of simple electronic materials. As discussed in the literature review, some color sensor projects are relevant and can be helpful to get started with this project. But unfortunately, none of them were built to detect more than ten different colors. Hence, the circuits can be useful only to give a basic idea on how to proceed with the project.

3.1.2 Setup up and testing of color sensor

At this stage, a suitable circuit is set up and tested for optimum results. Since in this project, up to sixty four different colors should be detected, the circuit should be expandable to give good results without being bulky.

3.1.3 Suitable algorithm to differentiate colors

In order to differentiate the colors detected, many tests should be conducted to find how much current levels are suitable for each color. Based on the gathered data, the colors detected can be differentiated.

3.1.4 Study of usage of microcontrollers and LCD display

In order to achieve color differentiation, a microcontroller particularly the 16F877A will be used and hence how to write the syntax should be known and be familiar with. Finally, the output will be displayed on the LCD screen.

3.2 Tools and Equipments

For the purpose of this project, few software and hardware are used.

Hardware:

- PIC16F877A
- PIC16F628
- MAX232
- 40 pin ZIF Socket
- USB –232 connector cable
- Discrete components e.g., LDR, LED, resistors, capacitors, crystal oscillators, diodes

Software

- PIC C compiler
- BumbleBee downloader
- Eagle 5.10 Lite

3.2.1 Wisp628 programmer

The Wisp628 in-circuit flash PICmicro programmer [13] is an in-circuit HVP (high voltage programming) programmer to download a hex file from the computer to the microcontroller without removing it from its socket. Wisp628 helps to protect the PIC from possible damages that might be caused by removing and replacing it back frequently to download and test a program. Moreover, it is small and portable making it suitable for the project.

The Wisp628 programmer applies 13 Volts to the /MCLR pin of the target PIC to put it in programming mode. Wisp628 uses a charge pump to create this voltage, so it cannot provide too much current that may damage the PIC. The circuit schematic of this programmer is attached in Appendix A. this programmer is used along with BumbleBee downloader software to program the PIC.

Figure 15 WISP628 programmer and microcontroller with LCD board on the left

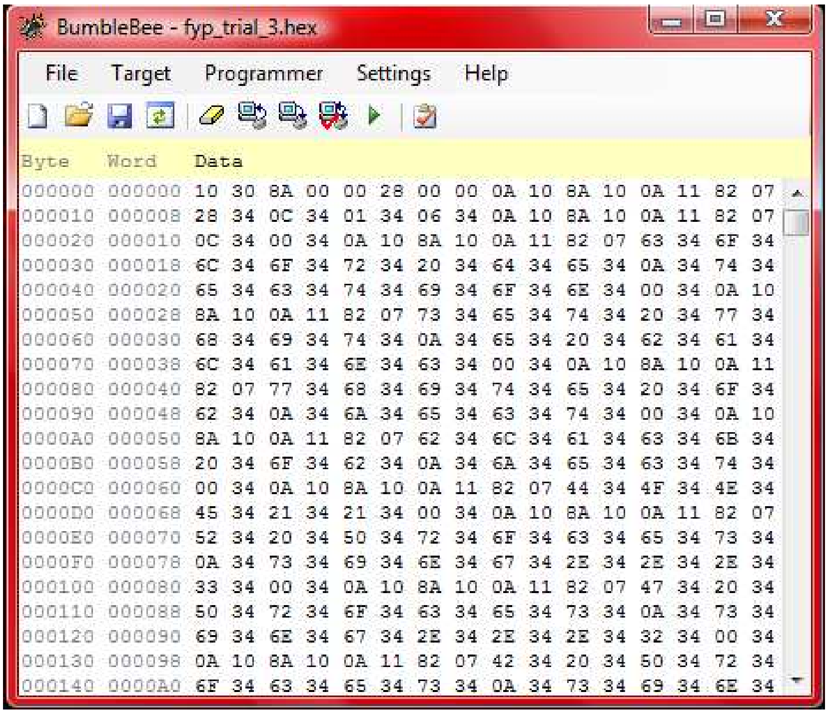


Figure 16 BumbleBee downloader software interface

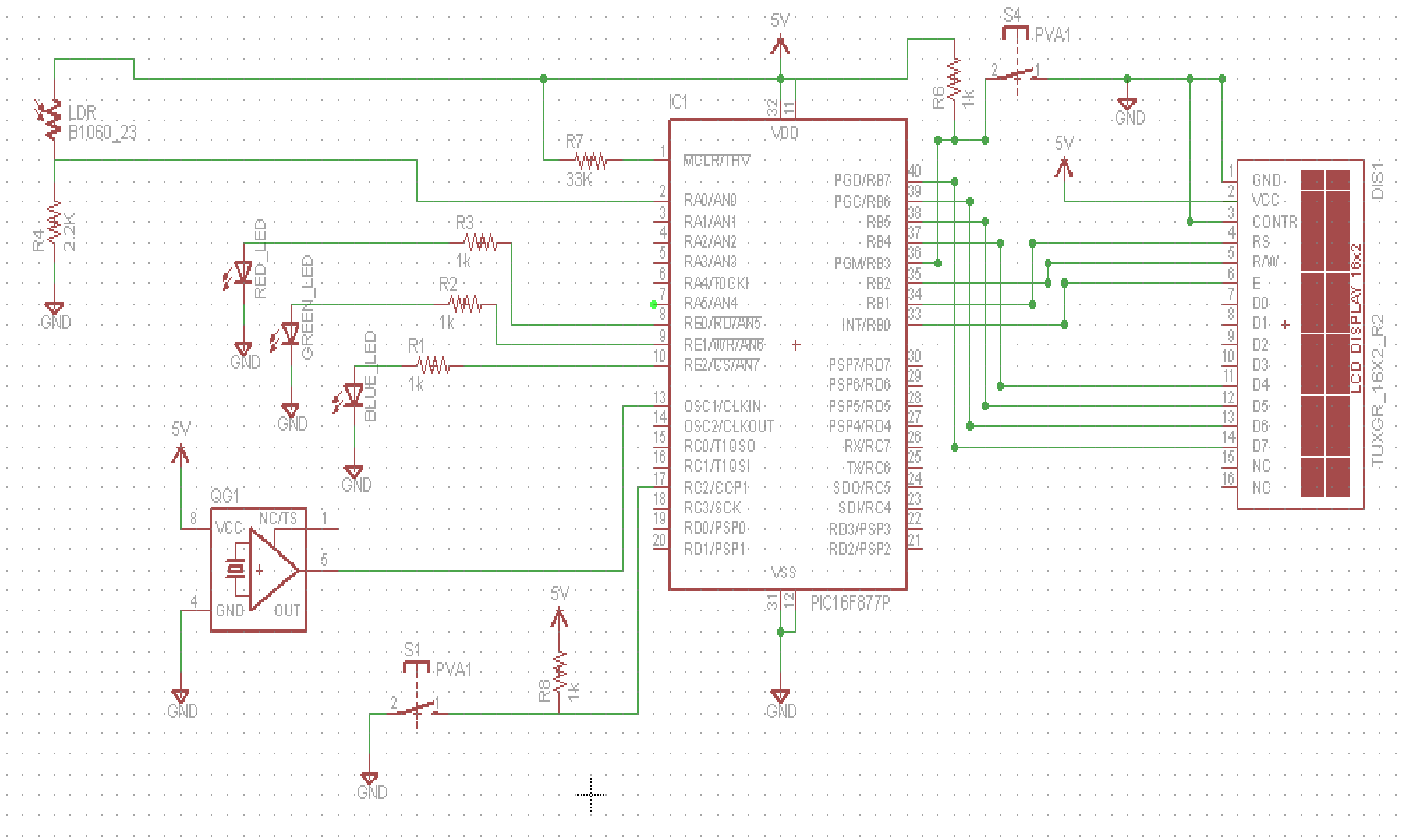


Figure 17 Full prototype schematic of this project drown using EAGLE software

3.2.2 Prototype schematics

A prototype built or assembled for this project includes sensor which is an LED and LDR network, a microcontroller and an LCD display. The basic schematic of all the part is shown in figure 17 above.

3.2.3 Cost estimation

Table 1 Rough cost estimation of the project

Equipment	Quantity	Cost per unit (in RM)	Total cost (in RM)
PIC16F877	1	7.00	7.00
D connector (9 pin)	4	2.70	10.80
Crystal clock	2	4.00	8.00
Ultra bright LED	6	0.50	3.00
LDR (big size)	1	4.50	4.50
ZIF socket	1	62.00	62.00
USB-232 connector cable	1	25.00	25.00
Max232	1	5.00	5.00
PIC16F628	1	7.00	7.00
Capacitor	10	0.20	5.00
Resistor	10	0.15	1.50
		Total	**RM138.80**

The cost estimation shown above is the cost for the whole prototype including the microcontroller.

The critical items in this prototype are the sensor camera made of LDR, and LEDs and the microcontroller setup. Hence calculating the cost of critical items only, excluding the shaded rows in the table above, the prototype costs **RM39.8**.

3.3 Project Work

The prototype used in this project is a sensor made of an LDR and LED network, a microcontroller and an LCD display. Under this section, the prototype construction and circuit schematics is discussed in detail.

3.3.1 Color sensor prototype

A sensor is built from an LDR and LEDs with basic schematics as shown in figure 18 below. The colored LEDs namely red, green and blue are used as light sources and are attached to an output port on the PIC16F877A which is configured as digital output. For sufficient brightness, the LEDs used are ultra bright.

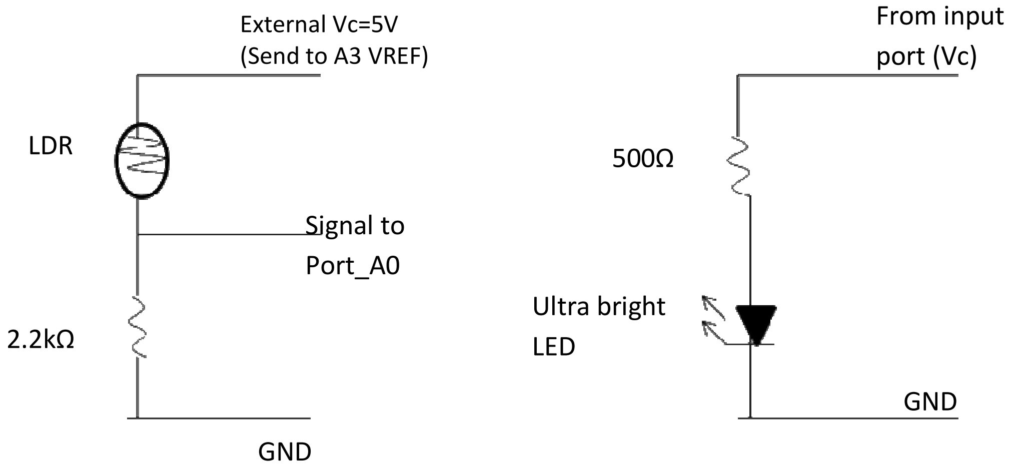


Figure 18 Color sensor schematics

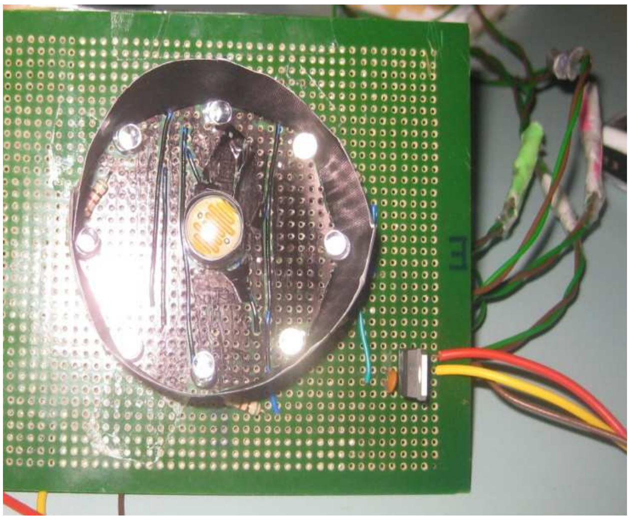


Figure 19 Color sensor built based on schematics

The schematic in figure 18 above is built and the prototype is shown in figure 19. As can be seen the LEDs (two for each color) are arranged on a circular manner two for each color and the LDR is put at the center. The circular arrangement is introduced to ensure that fair amount of light reaches the LDR from each color. The sensor is surrounded by a black cover and also the base of the board is painted black to avoid interference from ambient light and any other unnecessary reflection sources.

3.3.2 Sensor working principle

The sensor is made up of one LDR and colored LEDs. The LDR works by changing its resistance based on the intensity of light falling on it. For each object whose color is to be detected, the three colored LEDs, red, green and blue lights are lit sequentially and data are taken by the LDR in the process. For example for scanning red object, each LED is lit on the red object and then the reflected light from the object fall on the LDR. And it is known that a red object will tend to reflect all the red light falling up on it while it absorbs the green and blue lights. This in turn gives minimal light falling on the LDR for green and blue light scanning while maximum light is obtained for red light. Hence the LDR will have a larger resistance for the green and blue light scanning, while it has a minimum resistance for red light scanning.

Figure 20 Reflection of white light on different colored objects

The signal coming from the sensor that is fed to the microcontroller is a voltage level across a 2.2 kΩ resistor as shown in figure 18. As the LDR resistance level changes from exposure to different intensities of light, so does the voltage level across it. And by voltage division, as the LDR's voltage changes, the 2.2 kΩ resistor voltage will change with the same proportion.

The voltage is then recorded using the signal line attached to the analog input port of the PIC. In figure 18, the signal is read directly from the 2.2 kΩ rather than from the LDR. This is because PIC16F877a has a requirement of maximum impedance for an analog source to be 2.5 kΩ [8]. The external voltage is also fed to the analog input of the PIC for reference while carrying out A/D conversion. For ADC requirement of PIC16F877A, Appendix B can be referred.

3.4 Microcontroller and Programming

The PIC16F877A microcontroller acts as the brain of the sensor. It is used to analyze the detected analog voltage reading from the LDR and interpret it to a specific color scheme. The programming language being used is C on a PIC C compiler and with BumbleBee to download the hex file to the Wisp programmer. The particular microcontroller being used is 16F877A, which has 40 pins, 5 I/O ports and ADC (analog-to-digital conversion) capability. The result after being analyzed will be output on to an LCD display.

Before measuring the color values, **white balance** of the sensor has to be taken care of. White balance is the reference white point of a scenario which is subject to change depending on different factors like day light, material property which is intensity of light emitted by the LEDs and the resistivity of the LDR at different times of the day. White balance is taken care of by measuring the sensor signal for white and black object which represents the maximum and minimum values that the sensor measures, respectively. After taking the max and min values, they are mapped to 0 and 1023 (maximum value for 10 bit ADC conversion). Now any color that is sensed will be normalized as shown in equation 3.1 below.

$$Normalized\ value = \frac{(sensed\ value) - (min\ value)}{\max value - \min value} * 1023 \quad \text{............ (3.1)}$$

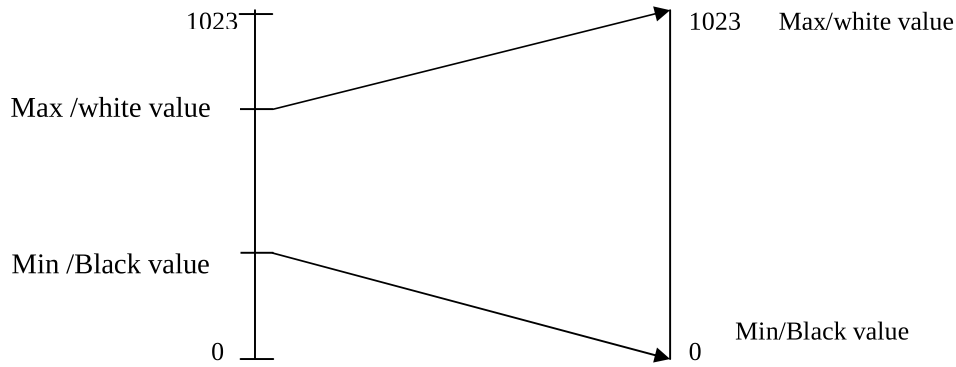


Figure 21 Diagram showing adjustment of white balance

Adjusting the white balance allows increased range and hence allows for higher resolution to fit in more colors in the range allocating process.

In the conversion process, the analogue reading from the 2.2 kΩ resistor is fed to pin A0 and reference voltage is fed to pin A3 to get accurate reading. The ADC clock is set to be FOSC/32 (10 MHz/32). The minimum time required to complete the ADC conversion according to 16F877A datasheet is 12.7 µs at 2.2 kΩ input resistance, and the clock division of 10MHz/32 as shown in the calculation below.

$$T_{ACQ} = \text{Amplifier Settling Time} + \text{Hold Capacitor Charging Time} + \text{Temperature Coefficient}$$

$$= TAMP + TC + TCOFF$$

$$= 2\ \mu s + TC + [(\text{Temperature} - 25^{\circ}C)(0.05\ \mu s/^{\circ}C)]$$

$$T_c = C_{HOLD} * (RIC + RSS + RS)\ln(1/2047)$$

$$= 120\ pF\ (1\ k\Omega + 7\ k\Omega + 2.2kk\Omega)\ \ln(0.0004885)$$

$$=9.4\ \mu s$$

$$T\_ACQ = 2\ \mu s + 9.4\ \mu s + [(50°C – 25°C)(0.05\ \mu s/°C)$$

$$= 12.65\mu s \quad \text{……………………………..………… (3.2)}$$

The result in Eq. 3.2 indicates that a minimum time of 12.7 μs is needed for the microcontroller to capture an analog value. The equation considers pin leakage and ½ LSB errors in 1024 reading steps. The detailed calculation can be found from the 16F877A datasheet. Allowing for a maximum accuracy, the delay is increased since only a small delay will affect a result and not a large delay.

Another delay that should be considered is while performing acquisition of analog data. It's the minimum time taken for the LDR to adjust its resistance level to the intensity of light received. A delay of 1.5 second is allowed for this purpose.

Taking into account such consideration, the code which is shown in the next subsection is written to take values for few sample colors chosen.

3.4.1 Program code

Programming the PIC is done in two stages. The first is to take reading values for different color values so that to know what colors represent that voltage value. Then this data are used later to decide what color is a detected voltage level.

The programming put below is used to take data from different color inputs. The program is composed of the functions main( ), float read_analog( ), and differentiate( ).

In the main( ) function the ADC module on port A is declared and others ports initialized (Port C for external switch to start each color detection process, Port E digital outputs for the LEDs). The colored LEDs are also ON and OFF here, while turning on each one of them, read_analog( ) function is called to read the voltage level through the ADC conversion and then the same function returns the average in float form back to main( ). Finally in the differentiate( ) function, the converted digital data are compared against various past data for decision of the color of the object.

```
#include <16f877A.h>
#device ADC=10
#fuses HS ,NOWDT ,NOPROTECT , NOPUT , NOBROWNOUT , NOLVP
#use delay(clock=10000000)
#include <lcd.c>
#include <stdio.h>

/*function definitions*/
float read_analog();
void differentiate();
void read_value();
//void white_balance();

//default values
float min_red=145.5, min_green=248.5, min_blue=246.5,        //145.7   248.6   246.9
      max_red=536.2, max_green=644.8, max_blue=623.5,        //536.1   644.7   623.9
      red_range=390.0, green_range=396.8, blue_range=377.5,        //390.4   396.1   377.0
      RED=0, GREEN=0, BLUE=0;

void main(void)
{
  lcd_init();

  SET_TRIS_C(0xFF);          //switch input to initialize and end process
  SET_TRIS_A(0xFF);         //first pin as analogue input others as digital output
  SET_TRIS_E(0x00);        //port E all digital output
  OUTPUT_E(0x00);

  setup_adc(ADC_CLOCK_DIV_32);
  setup_adc_ports(AN0_AN1_VSS_VREF);

  lcd_putc("\f");
  lcd_putc("color de\ntection");
  delay_ms(2000);

  while (true)
  {
    if (!input_state(PIN_C3))
    {
       read_value();
       differentiate();
    }
```

```
    else if (!input_state(PIN_C2))
      {
           lcd_putc("\f");
           lcd_putc("set whit\ne balanc");
           delay_ms(2000);
           lcd_putc("\f");
           lcd_putc("white ob\nject");
           delay_ms(2000);
           read_value();
           max_red=RED;
           max_green=GREEN;
           max_blue=BLUE;
           lcd_putc("\f");
           printf(lcd_putc,"4%f4%f\n4%f",RED, GREEN, BLUE);
           delay_ms(2000);

           lcd_putc("\f");
           lcd_putc("black ob\nject");
           delay_ms(2000);
           read_value();
           min_red=RED;
           min_green=GREEN;
           min_blue=BLUE;
           lcd_putc("\f");
           printf(lcd_putc,"4%f 4%f 4%f",RED, GREEN, BLUE);
           delay_ms(2000);

           red_range=max_red-min_red;
           green_range=max_green-min_green;
           blue_range=max_blue-min_blue;

           lcd_putc("\f");
           lcd_putc("DONE!!");
      }
    delay_ms(100);
  }
}


void read_value()
 {
      RED=0; GREEN=0; BLUE=0;
      output_bit(PIN_E2,1);           //  RED is ON
      lcd_putc("\f");
      lcd_putc("R Proces\nsing...3");
      RED=read_analog();
      output_bit(PIN_E2,0);           //off LED

      delay_ms(60);                   //to avoid consequitive modify operation to output pins

      output_bit(PIN_E0,1);           //  BLUE is ON
      lcd_putc("\f");
      lcd_putc("G Proces\nsing...2");
      GREEN=read_analog();
      output_bit(PIN_E0,0);

      delay_ms(60);

      output_bit(PIN_E1,1);           //  GREEN is ON
      lcd_putc("\f");                 //  GREEN is ON
      lcd_putc("B Proces\nsing...1");
      BLUE=read_analog();
      output_bit(PIN_E1,0);
```

```
        delay_ms(60);
 }


float read_analog()
{
   float ad1=0,ad2=0; // ADC_VALUE=0;
   delay_ms(1500);

   set_adc_channel(0);            //pin_a0 is analogue input

   delay_us(80);               // small delay is required after setting the channel  minimum of 12.4us for 2kohm resistor as ADC input

   ad1=read_adc();
   delay_us(30);
   ad2=read_adc();

   ad2=(ad1+ad2)/2;
   return ad2; }
 void differentiate()
{
  float R,G,B;
  R=RED; G=GREEN; B=BLUE;
  R=(RED-min_red)*100/red_range;         //in percentile
  G=(GREEN-min_green)*100/green_range;
  B=(BLUE-min_blue)*100/blue_range;

  if(R>100.00) R=100.00; else if(R<0) R=0;
  if(G>100.00) G=100.00; else if(G<0) G=0;
  if(B>100.00) B=100.00; else if(B<0) B=0;

   lcd_putc("\f");

 if (R>=85)
   {
   if (B>=84)         //white or l_violet or pink
      {
      if(G>90)
      lcd_putc("color is\n WHITE");
      else if(G>77 && G<=90)
      lcd_putc("color is\n L_VIOLET");
      else if(G>55 && G<=77)
      lcd_putc("color is\n PINK");
      else
      printf(lcd_putc,"%3.1f%3.1f\n %3.1f",R,G, B);
      }
   else if (B<=25)     //red or orange
   {
      if (G<=25)
      lcd_putc("color is\n RED");
      else
      lcd_putc("color is\n ORANGE");
   }
   else if(B>50 && B<=70)      //cream or yellow or salmon
   {
      if(G>90)
      lcd_putc("color is\n YELLOW");
      else if (G>=70 &&G<90)
      lcd_putc("color is\n CREAM");
      else if (G>=55 &&G<70)
      lcd_putc("color is\n SALMON");
      else
      printf(lcd_putc,"%3.1f%3.1f\n %3.1f",R,G, B);
   }
```

```
  }
 else if (R>70 && R<85)       //l_green or brown
  {
  if(G>85)
  lcd_putc("color is\n L_GREEN");
  else
  lcd_putc("color is\n BROWN");
  }

 else if(R>=30 && R<=55)  //green, l_blue, blue_violet
 {
  if(B>84 && G>75 && G<90)
  lcd_putc("color is\n L_BLUE");
  else if(B>50 && B<70 && G>75 && G<90)
  lcd_putc("color is\n GREEN");
  else
  lcd_putc("color is\n BLU_VIOL");
 }
 else if (R<30)      //black, D_green blue
 {
  if(G>55 && G<=75 && B>25 && B<=45)
  lcd_putc("color is\n D_GREEN");
  else if (B>70 && B<=85 && G>55 && G<=75)
  lcd_putc("color is\n BLUE");
  else if (B<25 && G<25)
  lcd_putc("color is\n BLACK");
  else
  printf(lcd_putc,"%3.1f%3.1f\n %3.1f",R,G, B);
 }
 else
 printf(lcd_putc,"%3.1f%3.1f\n %3.1f",R,G, B);

}
```

3.5 Summary

Chapter three summarized the step wise procedure towards completing the project. The actual color detection work performed and the tools used along with rough cost estimation of the prototype were also discussed. In addition, this chapter presented the working principle of the sensor built and actual C code used.

CHAPTER 4

RESULTS AND DISCUSSION

As discussed in the previous chapter, the construction of all the necessary parts of the sensor has been completed. The next step is collecting different color samples and measuring their RGB values and storing the data in PIC memory for later use of color differentiation. In this chapter the overall results found from the project is presented.

4.1 Results

The color sensor consisting of the LDR and LED network is tested separately using DMM and different voltage levels are sensed for different colors as shown in table 2. The voltage values were also measured (through ADC conversion) using the microcontroller. The tables below show various data gathered in the experiment work.

As can be seen in table 2, the voltage found from the sensor reflects the color composition of the object vaguely. For example, a green object has a higher response under green light than under red and blue lights. The maximum output is expected from a white object, and as can be seen roughly the expected result is obtained.

Table 2 Voltage levels measured with DMM of the sample colors for each colored light.

colors tested	Voltage output for respective colored light		
	RED	GREEN	BLUE
Red	2.60	1.50	1.45
Orange	2.67	1.92	1.53
Light blue	1.42	2.88	2.92
Light violet	2.42	2.79	2.82
Green	1.63	2.84	2.33
Blue	0.91	2.51	2.70
Light green	2.22	3.03	2.61
pink	2.65	2.62	2.87
yellow	2.73	3.09	2.45
Dark green	1.12	2.52	1.92
Brown	2.24	2.22	1.86
Cream	2.61	2.76	2.46
Salmon	2.62	2.40	2.27
Blue violet	1.37	2.35	2.56
White	2.63	3.16	3.06
Black	0.71	1.22	1.21

The output values are normalized using the white balance adjustment as discussed in the previous chapter. For discussion purpose Normalization equation 4.1 below is repetition of equation 3.1 from previous chapter.

$$Normalized\ value = \frac{(sensed\ value) - (min\ value)}{\max value - \min value} * 5.0 \qquad \ldots\ldots\ldots\ldots (4.1)$$

Table 3 Normalized color values

colors tested	Voltage output for respective colored light		
	RED	GREEN	BLUE
Red	4.94	0.74	0.65
Orange	5.11	1.81	0.86
Light blue	1.86	4.29	4.62
Light violet	4.47	4.07	4.37
Green	2.38	4.17	3.04
Blue	0.51	3.34	4.03
Light green	3.93	4.68	3.80
pink	5.06	3.62	4.51
yellow	5.28	4.83	3.36
Dark green	1.05	3.37	1.92
Brown	3.99	2.59	1.77
Cream	4.97	3.97	3.39
Salmon	4.98	3.04	2.88
Blue violet	1.71	2.91	3.65
White	5.00	5.00	5.00
Black	0.00	0.00	0.00

After the normalization of the color RGB values, the white object has the maximum obtainable value and black object has the minimum value. And as can be seen from the results in table 3, it is much clearer to see the color composition of the samples than the previous result in table 2.

Table 4 below shows the result after integrating the microcontroller with sensor. The values shown are ADCs converted by the PIC using a 10 bit conversion and then the values are changed to percentage as shown by the equation 4.2 below. The external voltage source used for the sensor is from a computer USB outlet for reliability purposes since the voltage level from a battery source fluctuates and may lead to erroneous result. Hence the reference voltage is taken as 5.0 V.

$$Percentage\ ADC\ value = \frac{Voltage\ sensed}{Voltage\ referenced} * 100 \quad \ldots\ldots\ldots\ldots\ldots \text{(4.2)}$$

Table 4 Percentage color values (voltage levers) after ADC conversion

	Red	Green	Blue
Red	98.9	14.7	13.0
Orange	102.2	36.2	17.2
Light Blue	37.1	85.7	92.5
Light Violet	89.4	81.3	87.3
Green	47.7	83.4	60.9
Blue	10.2	66.8	80.6
Light Green	78.6	93.5	76.0
Pink	101.3	72.4	90.1
Yellow	105.7	96.6	67.3
Dark Green	21.0	67.4	38.5
Brown	79.8	51.9	35.3
Cream	99.4	79.4	67.8
Salmon	99.6	60.7	57.5
Blue Violet	34.2	58.3	73.1
White	100.0	100.0	100.0
Black	0.0	0.0	0.0

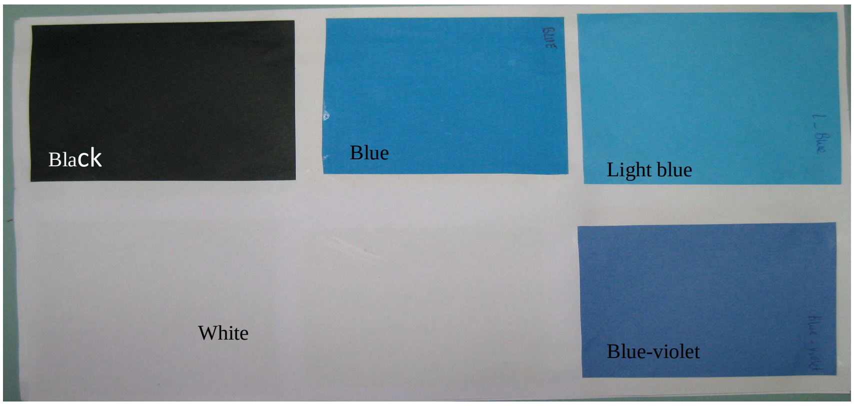
<u>Legend</u>

Red	Green	Blue	Rating
			5
			4
			3
			2
			1

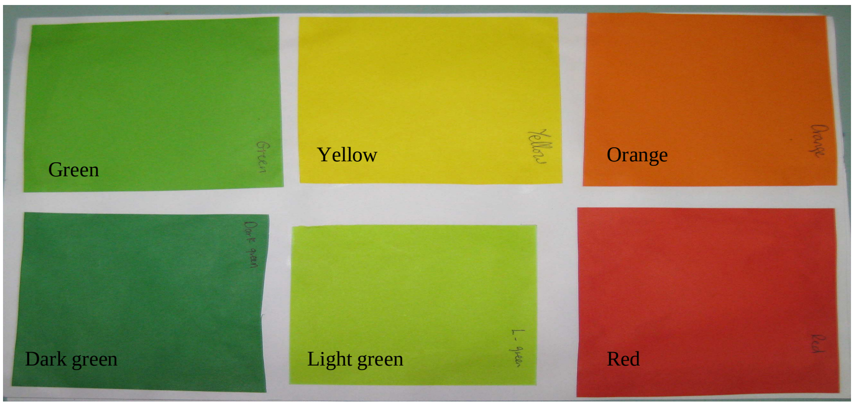
As shown in the table above, the color of the cells show that each object is graded in to 5 different levels depending on the color content of the object, 5 representing the highest color content and 1 the lowest. Based on this leveling, white object represents the most saturated for all the three colors as shown in the table.

4.2 Discussion

The results of the prototype built have been presented in the previous section along with some explanation. From the results obtained, the PIC16F877A was programmed to identify colors by allocating a given range to a given color. From the overall results, the sensor prototype was able to identify sixteen distinct colors. The sample colors tested are colored papers which are shown in figure 22 below.



(a) Black, Blue, L_blue (light blue), Blue-violet, White



(b) Green, Yellow, Orange, D_green (Dark green), L_green (Light green), Red

(c) L_violet (Light violet), Brown, Salmon, Cream, Pink

Figure 22 color papers used for testing the color sensor

4.3 Summary

In this chapter, the results from different collected color samples and their measured RGB values is (as measured by DMM and microcontroller) are presented. The data collected are then stored in PIC memory for later use of color differentiation.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Color is the basic property of objects. The ability to detect color is crucial in our lives to understand everything that is going on around us. Color detection using sensors has been major research to restore the color vision for color blind people and as part of restoring vision for the fully blind. Moreover, color detection has many applications in robotics, and other areas to enhance way of life.

In this project, the construction of color detection from simple electronic components is completed using LDR, LEDs, Microcontroller and LCD. And so far detection of sixteen colors is achieved. The prototype built can be a good low cost color sensor option for industries and robotics applications.

So far sample data from sixteen different colors have been collected and used to differentiate them. And sixteen colors have been differentiated using the microcontroller successfully although some disparities are seen due to the change in the environment ambient light and material property change dure to temperature differences.

5.2 Recommendation

In this project the sensing element used is an LDR due to the ease of availability and lower cost. An LDR is known to have the following disadvantages:

- ✓ LDR is a monochrome camera whose resistance value is affected by the intensity of light and not on the frequency or wavelength. In order to address the situation, three colored light were needed to be lit sequentially and data were collected from the response from each light reflection which significantly slows down the color detection process.
- ✓ LDR has slow response with rise time up to 45ms and fall time 55ms [6], and hence for each colored light exposure a minimum of 100ms(0.1 seconds) is needed or minimum of 0.3 seconds to lit the three colored lights and obtain a full data for a single object.
- ✓ LDR has significant memory after a light source is removed. Which means the LDR retains its resistance values even after a tested object is removed, which affects its next performance.

This problem can be alleviated by replacing the LDR with a photodiode or any other element whose response is affected by wavelength of reflected light and not by intensity. By using such element, only white light is needed to be reflected on the object instead of using three colors (red, green, and blue); hence the processing time can be reduced approximately by one third and a much more accurate result can be found.

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