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ASHESI UNIVERSITY

AN AUTOMATED PLASTIC BOTTLE COLLECTION SYSTEM

CAPSTONE PROJECT

BSc. Electrical and Electronic Engineering Department

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May 29, 2020

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CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfilment of the requirements for the award of Bachelor of Science degree in Electrical and Electronics Engineering.

Wendy Amarteley Amarteifio

2020

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature: ....

Candidate's Name: Wendy Amarteley Amarteifio

Date: May 29, 2020

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

Supervisor's Signature: ....

Supervisor's Name: ....

Date: ....

ACKNOWLEDGMENTS

I am highly indebted to my supervisor Richard A. Akpabio for his guidance and constant supervision as well as providing necessary information regarding the project and his support for completing the project. To my wonderful family for their kind cooperation and encouragement which helped me to embark on this project. Thanks, and appreciation to my friends and colleagues who willingly helped me out with their abilities. I have no valuable words to express my thanks, but my heart is still dull of favors received every person.

ABSTRACT

Improper disposal of refuse has in recent times caused harm to live and properties. In our cities and towns, it is common to find waste at inappropriate places such as gutters. This project focuses on the use of Internet of Things and smart systems to aid the waste management system, by providing an automated plastic bottle collection system. This project is focused on providing an efficient method of automating plastic bottle collection by placing value on all bottles. Value is placed on plastic bottles returned to motivate individuals to recycle; vouchers are generated per each bottle returned. The prototype of the automated plastic bottle collection monitors number of bottles, bin level and generate vouchers. Information on number of bottles and bin level are secured in a web application to determine when bins should be emptied.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

CHAPTER 1: GENERAL INTRODUCTION

1.1 Introduction

Flooding in recent times has become a pandemic that has caused harm to the social and economic aspects of our lives; that is, loss of lives, livelihood, and property. The subsequent occurrence of flooding is a result of inadequate drainage systems and poor waste management. According to UN Environment Program, during a week study of flooding in Accra, Ghana 17000 people lost their homes, 14 people were killed, and 43000 people were affected as a result of a significant flood on October 26, 2011 [1]. The June 3 disaster, in 2015, caused a lot of tantrums; 152 people lost their lives in a flood, which was coupled with an explosion of a Goil Fuel station [2]. These subsequent flooding issues are known to arrive from improper management of waste, improper disposal of rubbish, and inadequate drainage systems [3].

The available drainage system is continuously choked with rubbish because of the appalling nature of the country towards waste management and disposal. Reduced involvement in recycling as a nation has resulted in blocked drainage systems, which in the short run causes flooding and results in mishaps. Although initiatives have been put in place to encourage recycling and proper disposal of waste, some people choose to be ignorant despite knowledge of the effects.

1.2 Problem Statement

The carefree nature of Ghanaians towards recycling has contributed to the mass overflow of rubbish and waste, which eventually finds its way to significant drainage systems and waterways. The dilemma of choked gutters does not end just at the unbearable stench produced or the outbreak of venereal diseases it brings, but the flooding which takes many lives along with it.

Contributing to help solve flooding, a significant problem in Ghana will benefit the country in various ways. If waste were properly disposed-off and managed, there would not be a case of choked drainage systems; neither will flooding be a significant problem. If the risk of flood is curbed, national resources will be used for other developmental projects rather than resolving the misfortunes of a flood. Waste management will help curb environmental problems such as environmental pollution. Environmental pollution and hazards will be reduced, diseases resulted from pollution will lessen, and one can earn and save money from selling or using recycled items [4].

An automated plastic bottle collection machine is a machine that accepts plastics bottles from users, for proper disposal, and in return pays the user per each bottle received an amount of money. These returned plastics will be properly disposed by sending to recycling plants for reuse. The implementation of payment in the system is to encourage people to dispose of properly.

In an attempt to contribute to proper disposal of waste and its management, the main focus of wastes will be on plastic bottles. Despite measures to improve the proper disposal of waste, people are still ignorant and drop their waste anywhere. Probably they are not motivated enough by the consequences of their actions, and this in the long run can their lives and property. People are mostly drawn towards avenues for making money and are adamant about other issues.

1.3 Motivation of Project

Heart breaking stories of people losing their lives to disasters which could have been avoided motivated me towards flooding and its consequence. Plastic production and importation of plastics have increased in Ghana; every year, 2.58 million metric tons of plastics are imported to Ghana, of which 73% ends up as waste [5].

1.4 Expected Outcome

This project seeks to develop an automated plastic collection system which will aid in waste management. This project has many expected outcomes after completion and these outcomes include:

1. An efficient automated system for bottle collection
2. A functional prototype is developed
3. Accurate cost projection

1.5 Research Methodology Used

The research methodologies used in this research include:

1. Literature Reviews

2. Design and prototyping

1.6 Facilities to be Used for the Research

For this research, the main facilities used include:

1. Electrical and Mechanical laboratory at Ashesi University
2. Computer, internet and library facilities at Ashesi University

1.7 Scope of work

This project is mainly focused on building an automated system for the collection of used plastic bottles from individuals to be recycled by other recycling companies. The user receives an amount of money per each bottle received.

CHAPTER 2: LITERATURE REVIEW

2.1 Background to the Research

Plastics are widely used in different applications because of their inexpensive and durable nature, which has resulted in the rapid increase of plastic production, that is 9 percent increase per annum. The increase in the use of plastic and its disposal has resulted in several environment problems and recycling these plastics is currently the most efficient method to discard off plastics.

In most developing countries, they practice open burning of waste, which is highly toxic to the environment. Others build incinerators in the outskirts of the city for burning trash, which eradicates the toxicity effect. Developed countries practice other means of waste management such as sanitary landfills. Sanitary landfills are engineered disposal sites where waste is arranged in layers, compacted, and covered with soil to reduce air and water pollution [6].

Developing countries such as Pakistan, hire workers to manually pick up waste from streets with hand carts and wheelbarrows [7]. This solution, although somewhat useful, is not entirely the best solution to run by, because in the long run, the system becomes ineffective. In the long term, with every individual being ignorant of proper waste disposal, waste dumped will shoot up and would not be within means of control again. European countries have adopted the use of the concept of not dumping your money, and this motivates their citizens to recycle [8].

2.2 Survey of Related Works

Kokulin [9] reported on the significance of Reverse vending machines (RVM) and its implementation. A reverse vending machine (RVM) is a machine which receives used and empty plastic containers and cans for recycling and refunds each entry with an amount. This paper focuses on the various ways the RVM recognizes the plastic bottles and compares the options based on the cost of RVM production and theft cases. Determining the material used for the container, recognition by the shape of the bottle and barcode identification are very efficient methods for the RVM but are costly. Implementing the RVM using these efficient methods also makes recognition complicated due to varying vendors of containers and now having to synchronize new bar codes into the system.

Dumpayan and other engineers [10] designed a Reverse Vending Machine as a waste management mechanism in Philippines as opposed to their traditional method of hand picking these waste products. The aim of the researchers was to build a reverse vending machine which converts plastics into credits that can be used to buy different items within the vending machine. In designing this system, they considered some criteria which include; reliability, efficiency, accuracy and functionality. They designed with the expectations that the machine will function with minimum human intervention, right materials should be detected and accepted as well as reject unwanted items and the machine should function completely with no interrupts. They made use solar and another commercial source of power for the system. The reverse machine designed by these researchers had three main parts; the vending machine, bottle acceptor side and control side. They made use of photoelectric sensors, which can detect clear PET and capacitive sensors. The researchers conducted experiments on each part of the RVM to detect the accuracy of these aspects. The RFID card recognition, sensors, dispensing of purchased items from vending machine were shown to be 100% efficient, per the experiment conducted.

DeWoolfson *et al.* [11] designed an automated can redemption centre for return deposit pay-out. Energy conservation in the environment triggered these researchers to recycle aluminium cans to conserve energy, which was proven to be very efficient. Mandatory laws of recycling were put in place to engage everyone in the aim of conserving energy by recycling cans. Machines that were designed for recycling cans detected these cans by their shape, which was an inefficient method because most users crushed their cans after use. The machine rejected these crushed cans, so these researchers improved the system by using electromagnetic field to detect of the material was aluminium and detecting indicated which was present in cans.

Kokulin [12] addresses the use of IoT and Convolutional Neural Networks (CNN) in reverse vending machines projects (RVM). RVM's are used for waste management purposes in the United States and Europe and Russia recycles its plastic and metals with a different mechanism. These mechanisms that aid in waste management and recycling need to be cheap and efficient, which is why they are implemented with IoT and CNN. These mechanisms recognize the materials, compacts them to reduce volume and separates the materials. Containers in good shape that aren't contaminated are sent back to producers to reuse and the others are sent to recycling plants for reuse.

[13] compares recycling with other alternatives in waste management; the use of other biodegradable materials, landfills and reuse of products. Lands needed for landfills are becoming scarce in some countries, nothing is recovered from this mechanism and there is also the problem of soil contamination in the long run. Incinerators are better options to in terms of energy recovery but is not the best option because it releases waste gas into the atmosphere. Using other biodegradable materials will help solve some waste management issues but it also comes with its own complications; how to handle them and educating the consumers. The paper goes through vividly the steps necessary for recycling and they include; collection of bottles, sorting, cleaning, size reduction and further separation. They made mention of the fact that some European countries have advanced their recycling systems to also accept and recycle other items such as trays, tube and pots. Various types of polymers that make up plastics are compared to determine the effectiveness in recycling, that is, the energy recovered from recycling these plastics and other uses of the recycled items. Prices of recycled plastics are more expensive than virgin plastics, this has hindered the purchase of recycled items. Another hinderance to the use of recycled plastics is the lack of information about the application.

Implementing computer vision reduces the cost significantly with same functionality as using a scanner and barcode recognition. Kokulin made use of a Raspberry PI connected to cameras and sensors for image recognition as well as tensometric weight sensors to distinguish plastics from other unacceptable items; glass. Kokulin implemented IoT because of its efficiency and affordability, although it is sophisticated, but libraries are available for IoT. He also mentions that using C++ to write your program for computer vision is better than python because C++ best fits with smaller micro controllers [9].

Technological enhancement of the mechanism of waste management can aid in increase the efficiency of recycled materials as well as close the gap between virgin plastics and recycled plastics. Recycling helps to save money as well as prevent environmental pollutions. [13]

CHAPTER 3: REQUIREMENTS AND METHODOLOGY

3.1 Requirement Specifications

Requirement specifications are the checklist an engineer checks to ensure he has met the users' needs as well as ensure efficiency of the system. A solution is proposed based on the requirement specifications of the user needs. The requirement specifications ensure a bridge between the users' requirements and the system requirements.

3.1.1 System Requirements

Every engineering equipment has specifications that make the system or machine efficient for the users wants. In this project, the system requirements for the automated plastic bottle collection machine include:

1. Should receive plastic bottles only; the machine is expected to recognize plastic bottle, the sensors for these mechanisms should be highly responsive in the recognition process.
2. Should not accept unwanted items; sensors should recognize unwanted items, such as glass, cans.
3. Should indicate downtimes; problems with the machine should be displayed on the screen, as well as actions such as, 'wait for your money', 'bottle not recognized'. Downtimes should be indicated in Global System for Mobile Communications (GSM).
4. Should be able to dispense chit per input; each plastic bottle inputted by a recycler, deserves a purchasing-chit per bottle.
5. Should run an operation successfully with no interrupts; interrupts should be avoided when chit is being printed, after bottle has been recognized as plastic bottles
6. Should indicate when the storage is full on web application to owners of the machine (recycling company).

3.1.2 User Requirements

Satisfying the users' needs is the main focus of a project. The users' needs serve as a benchmark for the design of a system. The user requirements are the user's thoughts of solution to a problem and satisfying these needs is the point of success for an engineer. The following are the user's requirements of the machine;

1. Should indicate when storage for plastics is full
2. Should indicate when system is not working
3. Should be easy to use.
4. Should be reliable; this operate with minimum supervision.

3.2 System Design

The system design is shown in Figure 3.1, is a general overview of how the system of the automated plastic bottle collection system functions. The design was meant to meet the user requirements and the systems requirements. The Figure gives details of the processes of the operation of the proposed solution.

The automated plastic bottle collection system is made up of a photoelectric sensor which will sense the presence of plastic bottles, ATmega as the microcontroller of the system and servo motors for opening or closing a mechanical flap. The project comprises hardware and software features. The hardware feature comprises the mechanical and electrical aspects of the project.

3.2.1 Hardware Design

The Hardware design comprises the photoelectric sensor, Liquid Crystal Display (LCD), printer, servo motor, ultrasonic sensor and GSM which directly communicate with a microcontroller. The ultrasonic sensors and the photoelectric sensors communicate directly to the microcontroller (ATmega). The printer, LCD, GSM and servo motors are actuators, they function based on communication with microcontroller. Figure 3.1 shows the communication process between the microcontroller and the hardware; thus, sensors send information to the microcontroller and actuators execute actions.

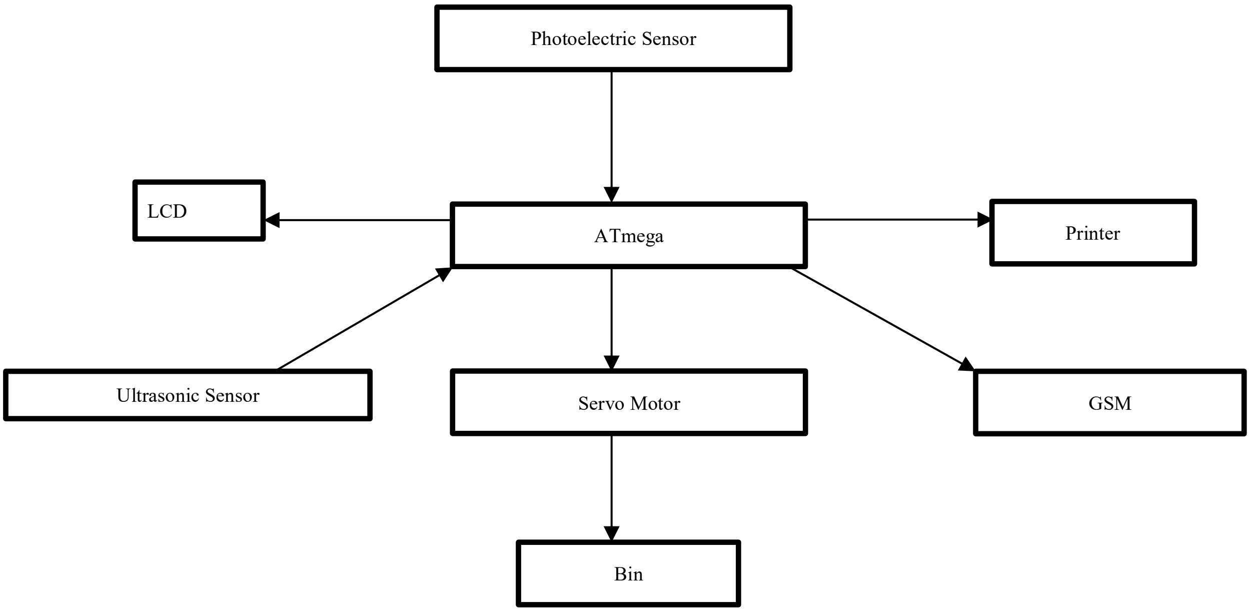


Figure 3.1 Hardware design

Power Supply

The main power source efficient for this project is a 12 DC power source. Each component has varying required voltages and the power source needs to be stepped down to different voltages depending on the component's requirements. Table 3.1 details out the voltages of power to all components used. gives further details on all components and their required voltages.

Table 3.1: Various components and their required power

Components	Required Voltage
Servo Motor	4.8V
ATmega	1.8V - 5.5V
Ultrasonic Sensor	5V
Thermal Printer	5V- 9V
Photoelectric Sensor	9V
GSM	3.4V-4.4V

Photoelectric sensor

Photoelectric sensors are used here for the detection of clear bottles. Photoelectric sensors are better options for the detection of clear bottles because, they operate at longer ranges even in low light. TRU-C23photoelectric sensors detects the presence of transparent materials. Transparent materials absorb UV light emitted by the LED of the photoelectric sensor. The photoelectric sensor is not affected by dirt, aging and has no blind zone and has an operating range of 1200mm.

Figure 3.2 Photoelectric Sensor TRU-C23

Servo Motors

Figure 3.3 Servo Motor

Servo Motors are actuators, used for many applications, such as elevators. They are efficient for movement in angular directions. In this project, Servo Motors will be coupled with a mechanical flap, to open and close the mechanical flap. Based on whether a bottle is recognized or not, the servo will either move at an angle to open or stay still. AC servo motors will be used here, since they are best suited for low power applications.

Printer

Thermal printers are coupled with micro controllers to print out receipts. Thermal printers are preferred in this project because, they are not expensive and does not produce noise while operating. However, they are subjected to excessive heat and printing fades out after a while. This printer requires 5V to 9V and also requires an external adapter, shown in figure 3.6

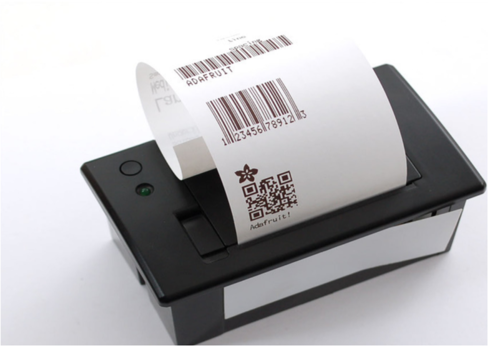


Figure 3.4 Thermal Receipt Printer **Figure 3.4 Adapter for Thermal Printer**

ATmega

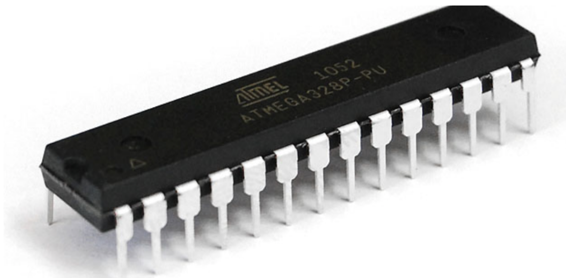


Figure 3.5 ATmega

ATmega is a single-chip microcontroller chip found on Arduino Uno boards. Atmega328 microcontrollers are from the 8-bit AVR microcontroller family. The exact part number of the chip is ATMEGA328P-PU. ATmega is the main brain of an Arduino Uno board. The ATmega will be used here for controlling and communication between the various actions; for example, when the bottle is recognized, the microcontroller communicates to the printer to print the chit as well as the servo to open a mechanical flap for the bottle.

LCD

Liquid Crystal Display (LCD) is a panel that uses liquid crystal to produce images. Liquid crystals are beneficial because they consume less power than LEDs. 16x2 LCD requires 5V to function. LCDs will be used in this project as a display screen for information since they are low cost, and provide good contrast, although slow and less reliable. I2C LCDs are simpler to wire; because there are fewer pins to wire; SDA, SCL, VCC and GND.

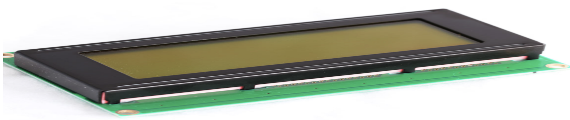


Figure 3.6 I2C 16x2 LCD

Ultrasonic Sensor

Figure 3.7 Ultrasonic Sensor

Ultrasonic Sensors are electronic devices used primarily as proximity sensors. They will be used as level sensors to detects and measure the level or status of a bin; full and empty. The ultrasonic sensor emits ultrasonic sound waves and converts the reflected sound into electric signal. The HC-SRO4 ultrasonic sensor uses SONAR to detect the distance of an object. It requires a power supply of +5V DC, working current of 15mA and a non-contact ranging distance of 2cm to 400cm. The ultrasonic sensor has 4 pins; trig which is for transmitting signals, echo receives transmitted signal and ground and VCC for power. The distance measured is obtained by eqn 2.1

$$distance = speedofsound \times Time \qquad (2.1)$$

When reflection occurs, sound travels twice the distance, therefore the actual distance is obtained by eqn 2.2

$$actual\ distance = \frac{speedofsound}{2} \times Time. \qquad (2.2)$$

GSM

Global System for Mobile Communications (GSM) is a digital communication system used by mobile phones. The SIM800L GSM is a mini cellular module used in sending and receiving SMS and making and receiving voice calls. SIM800L has one UART port and one USB port that can be used for debugging, and audio channels with microphones and supports a band rate of 1200bps to 115200 bps. SIM800L operates in a range of 3.4 to 4.4V. The best option for communication was determined from the Table 3.2.

Figure 3.8 GSM SIM800L

Table 3.2 Pugh chart for connectivity module selection

No.	Criteria	Baseline (GSM Shield)	Weight	SIM800L	ESP83266
1	Cost	0	5	+1	-1
2	Coverage	0	4	0	-3
3	Availability	0	4	+1	0
	Total			2	

(0 – device is same as baseline, **-1**- worse than baseline, **+1**- better than baseline.)

Buck Converter LM2596

Buck converters are DC-DC converters that convert high voltage to low voltage. This efficiently steps down voltages and this extends battery life, reduces heat.

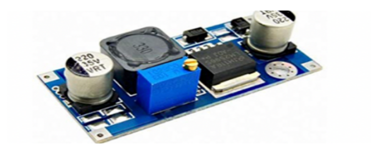


Figure 3.9 Buck Converter LM2596

2. Software Design

The software phase focuses on the coordination between all hardware components, code. Figure 3.10 gives an overview of the operation of the system. A recycler inserts a bottle which is recognized by a photoelectric sensor, using infrared rays, as a plastic bottle. Photoelectric sensor sends signals to the ATmega which further communicates to the servo motor, to move the mechanical flap, LCD, to display information, and printer, to print a chit for the recycler. GSM SIM800L coupled with an ultrasonic sensor checks the state of the bin and communicates to the leads when it needs to be emptied.

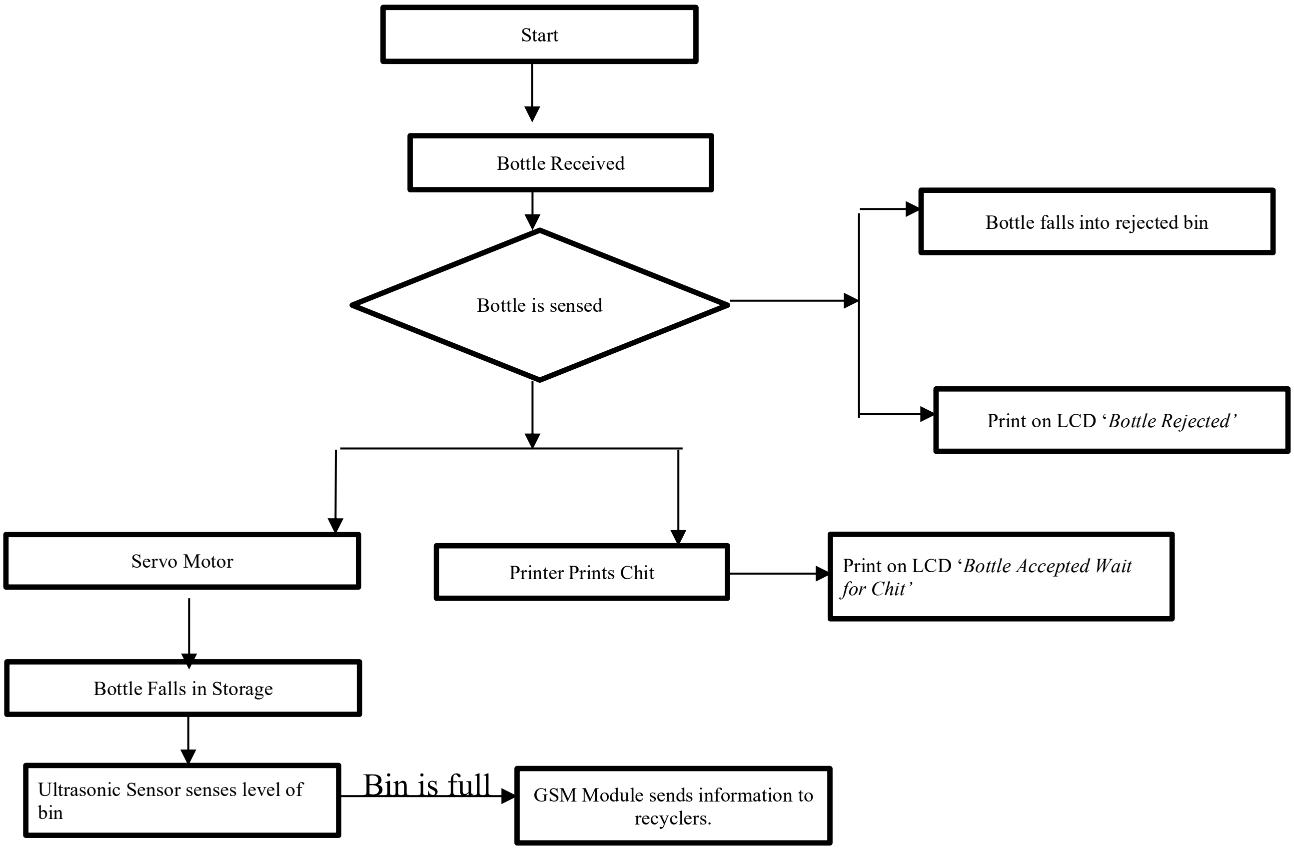


Figure 3.10 Flow Chart

CHAPTER 4: DESIGN AND IMPLEMENTATION

4.1 Hardware Implementation

The Hardware section consist of sensors and actuators for coordination of the system. These sensors and actuators need to be linked properly for efficient communication and functioning of the system. This section focuses on how these devices are linked and connected for overall efficiency. Some uncontrollable restrictions led to improvising the components of the initial prototype design. This design is somewhat efficient as the initial prototype.

The prototype for this project was implemented using improvised sensors;

- Photoelectric sensor was replaced with an LDR circuit alongside a torchlight. The photoelectric sensor was to detect plastics. The LDR with the torchlight executes the same purpose. LDR, Light Dependent Resistor, measures light intensity of its surroundings in analog readings and the microcontroller converts it to digital readings [17].
- Thermal Printer was replaced with an LCD. The thermal printer's purpose is to print vouchers for each recycler and was replaced with the LCD. The LCD generates random codes for each user (recycler) to make a purchase.

4.1.1 Schematic Design

Figure 4.1 is a detailed schematic design of the implemented prototype of the system. This schematic was simulated using Autodesk Eagle. Autodesk is an efficient, user friendly schematic and PCB generator. The schematic includes all components required to test the efficiency of the system before implementing the prototype.

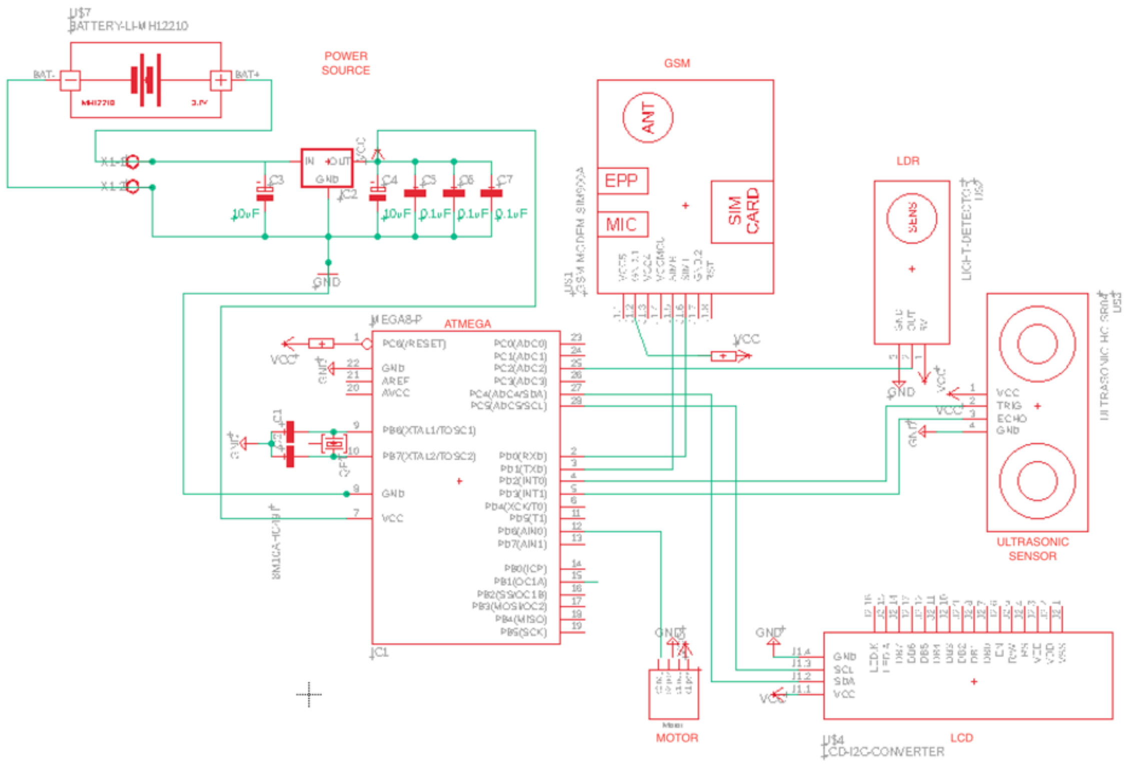


Figure 4.1 Circuit

4.1.2 Mechanical Design of Structure

The AutoCAD below is a visual representation of the casing for the automated plastic bottle collection system. This is a 40x60 cm casing with steel, with a circular slot for insertion of bottles and a bin as the storage for inserted bottles. It also has a slot for chit dispensing after it has been printed and an LCD screen for display of messages.

The circular slot is inclined at an angle towards the bin with a mechanical flap placed on the end of the slot. This is it to enhance easy sliding of bottles into storage when mechanical flap opens after bottle has been recognized.

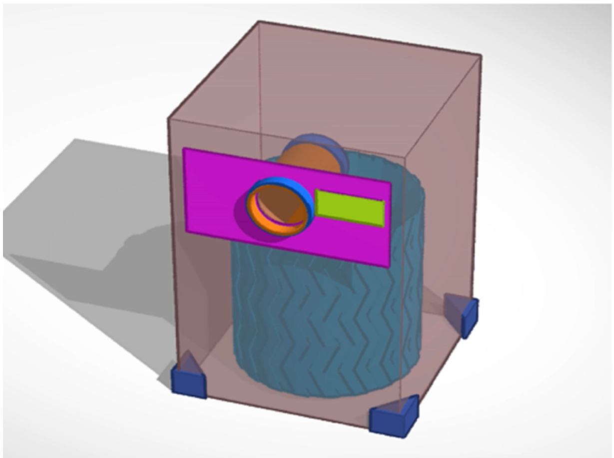


Figure 4.2 40x60cm AutoCAD image of casing for system

Hardware Setup

Figure 4.3 a is the prototype being completed. This prototype was implemented using a box as opposed to the initial design of using steel due to some limitations. This is a pictorial view of the system implemented.

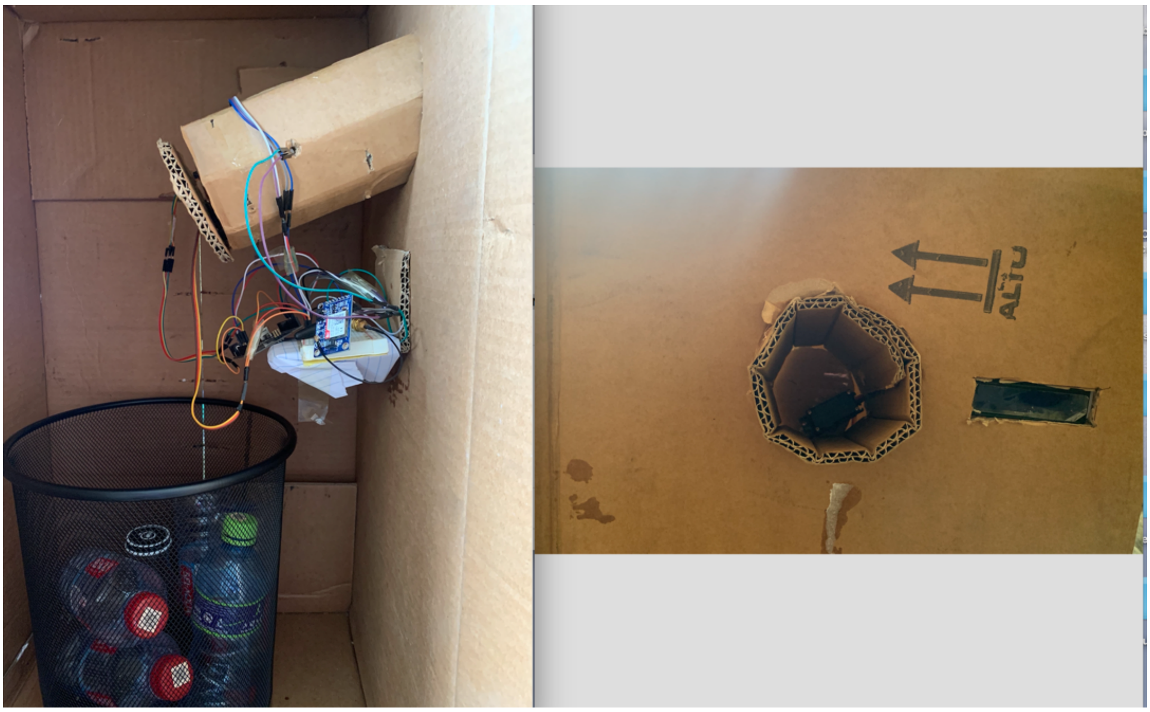


Figure 4.3 Prototype of design

4.1.3 Status of Bin Configuration.

In the setup for knowing the status of the storage in the system, a GSM SIM800L was used with an ultrasonic sensor to communicate with the leads; to get notices when bins need to be emptied. The ultrasonic sensor senses the level to which the bin is filled and sends signals to the microcontroller which communicates to the GSM. The ultrasonic sensors are calibrated to inform the recycling company based on the height of the bin; the different levels of the bin.

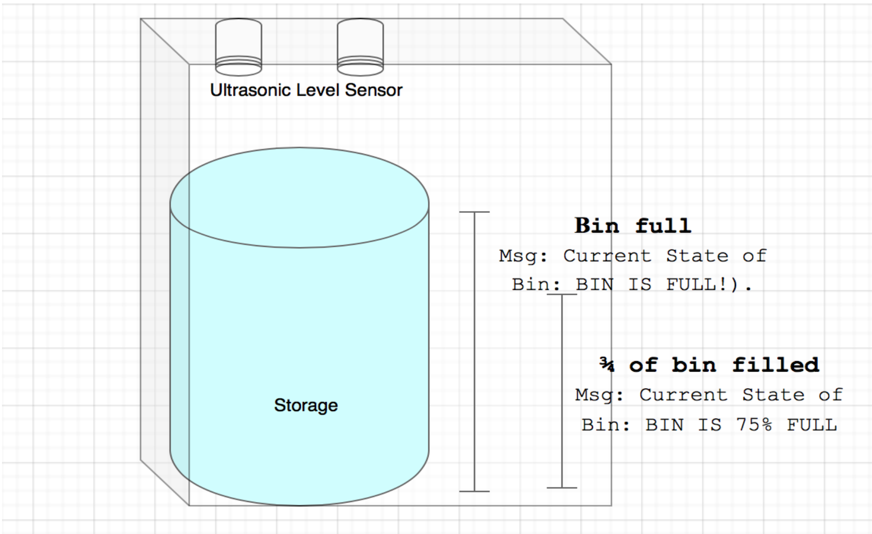


Figure 4.4 Setup of bins' status

Communicating Sensor Values to Database

The ultrasonic sensor is implemented as a level sensor to tell the status of the bin. Different levels of the bin are communicated through GSM to Twilio; a developer platform for communication. A Twilio international number is generated to communicate with GSM. The GSM model sends a text message of the current state of the bin to the generated Twilio phone number. The international number calls the API and saves the information into MySQL database.

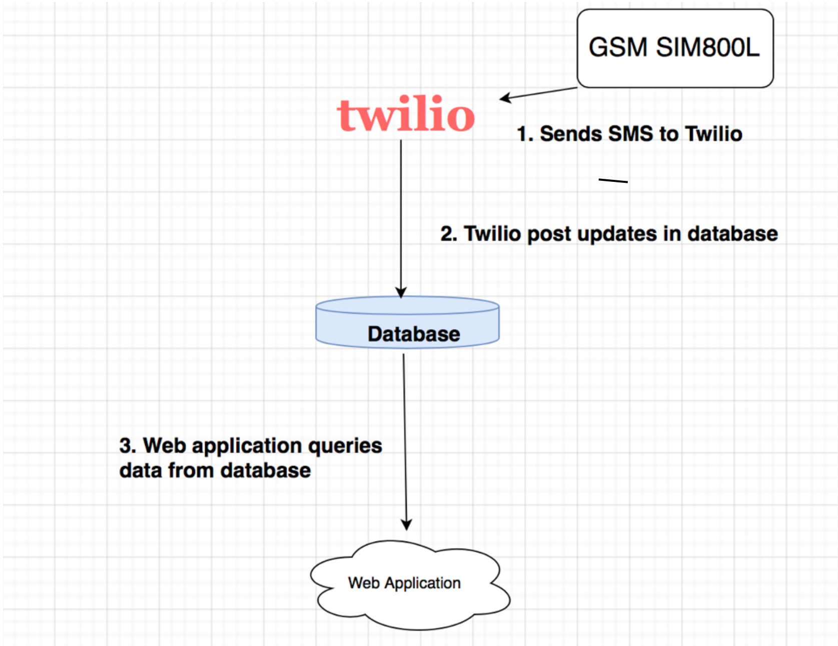
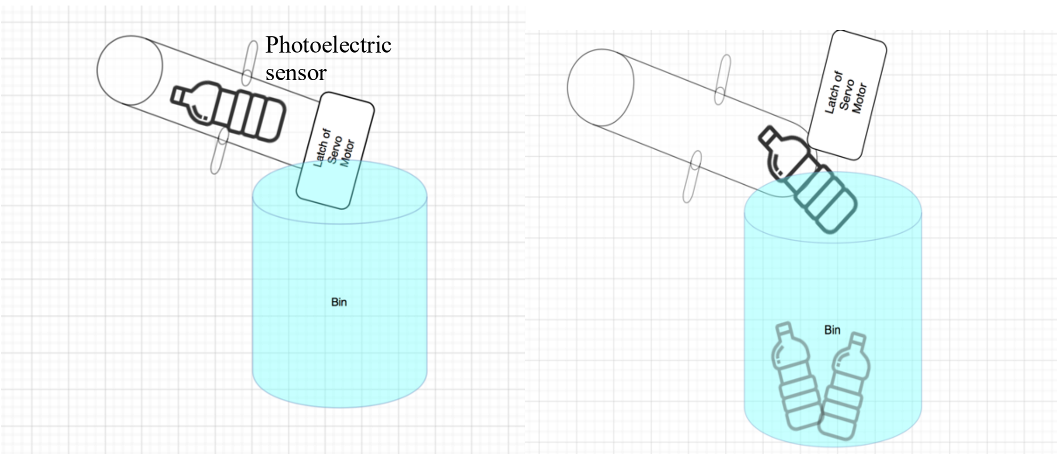


Figure 4.5 Bin status configuration

4.1.4 Recognition and acceptance of bottles.

The automated plastic bottle collection system accepts plastics only, hence all other items are unwanted materials in the machine. This stage ensures that all inserted items are sensed and recognized as plastics before these items will be accepted.

The sensor senses the presence of plastic bottles and sends signals to the microcontroller which communicates to the actuator, the servo motor. The servo motor moves in angular motions.



4.6 Mechanism for bottle acceptance

4.1.5 Printing of chit and display of information.

The thermal printer prints out a valuable chit, voucher, for each plastic bottle that is accepted. After bottles are recognized and enters the storage, the micro controller sends signals to the thermal printer to print a voucher for the recycler. LCD prompts on the status of the operation of the system, that is, ‘Bottle Accepted, Kindly wait for chit’ and ‘Bottle rejected’.

4.2 Software Implementation

The software implementation section involves mainly the web application with its database, and the communication route between hardware and software. This web application is used to monitor hardware actions. This section explains into details the web application and its database and the cooperation between the software section and the hardware.

The main aim of the web application is to store data in the database and track the number if bottles received as well as impacts made. This information is accessible to the public.

4.2.1 Database of System

The database is developed using MySQL. MySQL is an open source relational database which runs virtually on all platforms. This was used to create tables to store received data. Data stored here, is received from the web application and updated through the API.

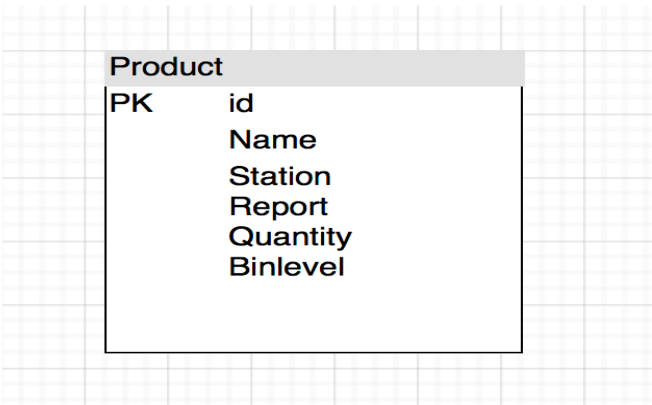


Figure 4.7 Database

4.2.2 Graphic User Interface

The web application was developed using a framework; firebase. Firebase is a mobile application and web application development platform which is user friendly and provides variety of tools to develop and advance an application [14]. Firebase offers web application services such as; real time database, authentication, cloud messaging, storage and hosting. The firebase real time database is a cloud hosted NoSQL database which allows one to store and sync between users in real time [16]. Real time syncing enables users to access their data from any devices through a mobile or web application.

The front-end application is the key interface the user, the recycling company, interacts with. The recyclers do not have access to the web application, it is only made available to the recycling company to track the bin level and number of bottles in the system. The web application gives heads up to recycling company or team as to when the bin needs to be emptied and the number of bottles received.

Figure 4.8 presents the user interface or dashboard the recycling company sees when they log into the system. This is to provide an overview and aim of the project.

Figure 4.8 User Interface of web application

The recycling companies have workers in charge of emptying filled bins at various stations. Figure 4.9 displays the interface each worker sees, that is they need to log in their details as a worker and enter details of stations they emptied. The interface allows for update of information as well as delete option of information in case of any errors.

Figure 4.9 Workers User Interface

Details on bin status and number of bottles is very essential in the web application. Figure 4.10 provides an interface for bin information. Details on registered stations are shown here; that is recorded information on number of bottles and bin level is shown here.

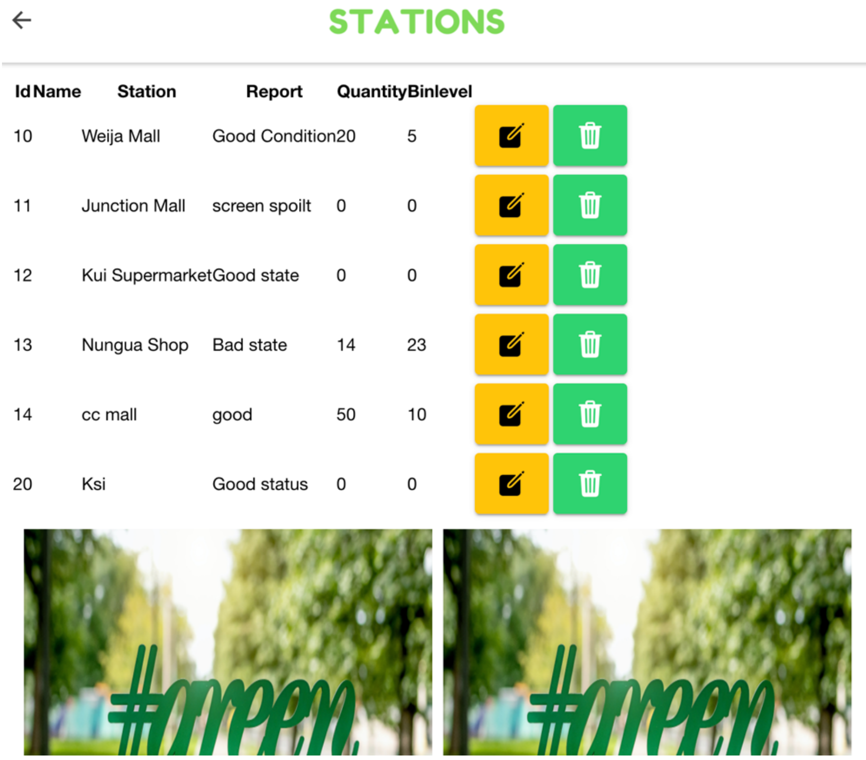


Figure 4.10 Bin Status Interface

CHAPTER 5: TESTING, RESULTS AND DISCUSSION

5.1 Description of Tests

Results obtained for this project is sectioned into three main test cases. This chapter focuses on the defined test cases that ensure that the requirements listed in chapter 3, are satisfied. To validate the user and system requirements, the following test cases were performed.

1) Testing the response time and efficiency of the hardware. This assessment involves two sub tests, which are; responsiveness of the bottle sensor and responsiveness of the servo motor.

2) Testing the response time and efficiency of the web application and its database. This assessment involves testing the responsiveness of communication between the web application and the database.

3) Testing the response time between the web application and the hardware system. This assessment involves timing the response time of communication between the hardware and the web application; thus, how receptive the data web application is receiving information from the hardware system.

5.2 Tests and Analysis

Testing the hardware components requires to sub tests, the response time of servo motor and the sensor. To test the responsiveness of the servo motor, the process of accepting the bottles was repeated five times to obtain varying data on the efficiency of the servo motor.

For this prototype, due to uncontrollable limitations, an improvised sensor was used to detect the presence of plastic bottles. This test is to compare the efficiency of sensing compared to actual plastic bottle sensing mechanisms; photoelectric sensors.

Test Case 1

For this test case, different materials, plastics, glass and opaque objects, were inserted in the system to test the responsiveness of the sensing mechanism. As shown in Table 5.1, different objects had different value ranges when sensed.

- Plastic bottles were sensed within the range of 244 to 258

$$244 \leq Plastic\ Bottles \leq 258$$

- Glass bottles were sensed within the range of 263 to 268.

$$263 \leq Glass\ Bottle \leq 268$$

- Opaque Object were sensed within the range of 93 to 101.

$$93 \leq Opaque \leq 101$$

The tested range of values were used to set the range of values for approved items in the Arduino code. That is, if the LDR sensor, senses within the plastic bottles range, the bottle is accepted.

Table 5.1 Results from LDR sensing of different object

Tests	Plastic Bottle	Opaque Object	Glass
1	258	101	263
2	258	32	268
3	257	93	265
4	258	93	224
5	208	93	267
6	251	93	264

7	248	93	267
8	252	93	263
9	252	93	264
10	244	94	268

Based on the set values range, another test was conducted to test if the bottles will be received, as shown in Table 5.2. The test was 100% efficient, as all bottles were received. This shows that the sensing mechanism is 100% efficient.

Compared with the standard system [10], which is 100% efficient, this system is equally efficient. The standard system implemented uses either a photoelectric sensor or a capacitive sensor. This system implements the same idea with an LDR sensor but is equally efficient.

Table 5.2 Results from sensing and counts

Accepted (Y) Rejected (N)

Tests	Plastic Bottle	Glass bottle	Opaque Object
1	Y	N	N
2	Y	N	N
3	Y	N	N
4	Y	N	N
5	Y	N	N

5.3 Response Time of hardware operation

Tests	Bottle Acceptance	Voucher code generated	Total Operating Time
1	13.01 secs	10.03secs	23.04secs
2	12.11 secs	10.13secs	22.24secs
3	9.01 secs	9.10secs	18.11secs
4	13.91 secs	9.03secs	22.94secs
5	13.31 secs	10.23secs	23.54 secs

This prototype operates within 18.11secs to 23.54 secs, per the tests conducted. This system executes the major hardware operation of bottle collection and acceptance in less than a minute, which is ideally very efficient as compared to the standard system [10].

Test case 2

The responsiveness of the web application and its database is ideally very efficient. Data is posted to the database from the web application through an API. There are little to no delays in this process. The web application also gets request efficiently for the database as well.

Test case 3

Responsiveness of the web application and database to data sent from the hardware (GSM) is equally efficient as shown in table 5.4. Total response time of all this operation is within a minute, which is ideally fast.

Table 5.4 Total response time of hardware and software communication

Tests	GSM to Twilio Number	From Twilio to Database and Web Application	Total Response Time
1	15.02 secs	5.10 secs	20.02secs
2	14.4 secs	5.10 secs	19.50 secs
3	15.3 secs	5.10 secs	20.4 secs
4	15.3 secs	5.3 secs	20.6secs

Results from the test cases fall within the range of 1 minute each. This shows that the machine is reliable and also efficient as the existing systems. The machine can execute all operations with minimum supervision, hence very reliable.

CHAPTER 6: CONCLUSION

The automated plastic bottle collection system implemented in the project is aimed at encouraging the proper disposal of waste; thus, plastic bottles for this project. This system implemented using IoT smart systems to promote and motivate recycling and improve the waste management system. This will curb issues such as flooding and, in the long run, will benefit the nation. However, the implemented system is not as efficient as expected. This section further explains the limitation faced and probable future works that can be implemented to improve the system.

6.1 Conclusion

The automated plastic bottle collection system generally satisfied the primary objectives and requirements set out to be met. Displaying downtimes and printing out vouchers were two requirements that were not met. The prototype was designed on limited scope and limitations. Tests proved that the system ideally efficient as the standard system on a small scale. The implemented system is reliable; this operates under little or no supervision

6.2 Limitations

The solution proposed to aid the waste management system by motivating the proper disposal of plastic using an automated plastic bottle collection system has some limitations. The final prototype has many limitations as compared to the initial design of an actual system. These limitations include;

1) Lack of resources due to the COVID-19 pandemic, some ordered resources were not attained. This resulted in the improvising of alternate components to execute tasks. These components are not as efficient as the proposed components that would have been good.

2) Inadequate funds to purchase the best and efficient items for the tasks. This resulted in lowering the scope of the project.

3) Less number of prototypes to check the validity of the system on a larger scale. The prototype was tested on a small scale, which did not help validate the efficiency of the web application and hardware communication on a larger size.

4) Improvising with the LDR limited the system to only being applied in a stable light intensity room. The prototyped system cannot be implemented outside, where light intensity continuously varies

6.2 Future work

Limitations on time and complexity of the automated plastic bottle collection system resulted in scaling down the scope of the project. This project can be further improved to widen the scope and make it more efficient. These possible future works include:

1.) Developing a system that crushed the bottles to reduce the bottle sizes. The aim is to increase the storage space to allow for more bottles.

2.) Including a vending machine, so vouchers generated can be used to purchase items in the vending machine.

3.) Generate coupons to be sent to recyclers' accounts.

4) Provide a sorting mechanism for the system

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