ASHESI UNIVERSITY

SMART SYSTEMS AND THE INTERNET OF THINGS (IOT) FOR WASTE MANAGEMENT

CAPSTONE PROJECT

B.Sc. Electrical/Electronic Engineering

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2019

ASHESI UNIVERSITY

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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/Electronic Engineering.

Claude-Noel Tamakloe

2019

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.

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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:

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Abstract

Waste management is a raising concern faced by many nations in the world today. On the streets of major cities, it has become almost common to find waste which poses health hazards and other concerns to its communities and inhabitants. This project focuses on the use of smart systems and the Internet of Things (IOT), to provide an efficient and effective approach to waste management. This project designed and manufactured a prototype of a solar powered, self-compacting smart bin with a server side monitoring application. The prototype smart bin is capable of monitoring internal rubbish levels, compact it, freeing approximately 25% of the space with each compaction space. The bin also monitors total weight and is capable of sending all these information to a secure server side application. The accompanying web application monitors the state of each smart bin and proposes optimal routes for pick up. This approach will contribute to a smart and efficient waste disposal improving the cites waste management.

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CHAPTER 1: Introduction

1.1 Background

The world today is advancing at a very fast pace. With technologies evolving and new inventions springing up, efficient solutions have been developed to help address the problems faced by humans in the natural environment. With the world population increasing, there is a rapid growth rate in population, however this development comes with its own needs, most importantly the need for sustainable development of cities. Approaching this need from a technological point resulted in the rise to developments in the internet of things (IOT) which has been the basis of the development of smart cities. Endeavours towards the development of smart cities have explored individual sections of city planning such as traffic management, smart homes, city lightning, and waste management amongst others, working towards the end goal of fitting the individual sections together. According to the report by the United Nations Conference on Human Settlement (UNCHS, 1996), about a third to half of the solid waste generated in low and middle income countries is usually not collected [1], resulting in waste being disposed in the streets, open spaces and drainage systems. In most developed countries, there are effective waste management systems and services put in place which have ensured that the waste that is produced from homes, restaurants, offices and several other gatherings are properly managed, which in effect keeps the surroundings clean. Moreover, technology has evolved to bring into existence several devices that enhance processes and services rendered in our society. An integration of these technological devices into already existing processes for waste management will establish an efficient system to ensure that waste within the cities are effectively managed.

1.2 Problem Definition

Waste management is one of the major national development issues for most nations all around the world and even much daunting for most developing countries [1]. On the African continent, most cities are facing waste disposal problems and it is said that 9 out of every 10 African countries face serious waste problems [1]. Taking Ghana as a case study, the problem is evident when touring the streets of its great cities. Rubbish is found all over the streets due to overflowing bins which creates unsanitary conditions that attracts rodents and cause health hazards. Several drainage systems are blocked due to rubbish being disposed off in the streets and in the drainage systems and in effect lead to floods which take lives and destroy properties. The nation has several waste management services however the poor management of these services has been the major cause of these matters arising. Reports from the baseline environmental sanitation survey in 2007/2008, showed that approximately 76% of households in the Ghanaian community have improper waste disposal and collection methods and only about 5% use house to house collection services [2]. Most significantly, the nation's waste management services have an inefficient waste collection approach, using static routes and schedules which waste time, resources and money. There is a high level of resource wastage when planned routes for waste collection are not optimised and sometimes most collection services face the problem of arriving to find empty bins, making collection unnecessary. The heaped stacks of rubbish around the edges of streets and in the gutters, end up polluting the atmosphere causing the city's atmosphere to be clouded by a bad smell. Some might link this inefficient waste disposal and collection to the inability to manually monitor the fill levels of bins. This concern establishes the need to design and develop technological innovations to address these inefficiencies.

This pressing issue serves as the motivation for this project to design and develop a smart waste management system that will improve waste collection and disposal, being of benefit to both the waste collection agencies and other stakeholders and aiming at improving the waste management processes in Ghana and the African continent at large.

1.3 Project Objectives

This project seeks to develop a smart solar powered self-compacting bin capable of compacting the rubbish to maximize waste storage, accompanied by a web application which allows the remote monitoring of the bins and designing optimized schedules and route for collection. This project has several deliverables, which are listed below:

1) **Development of a solar powered self-compacting bin with integrated rubbish level sensor**
   - This objective will guide the design of the hardware system of this project to develop a solar powered bin that will have a compacting mechanism to press down rubbish within the bin, creating room for more rubbish to be inserted and send information obtained by an installed level sensor to determine when bins are filled to their maximum level.
2) **Development of a user-friendly/interactive server side web application for hardware tracking and system management**
   - This objective will guide the design of the software system of this project to develop a server side web application that will map out installed bins and their location, receive information on bin status and upon alert of need to collect rubbish, plan effective and optimised routes to pick up the rubbish
3) **Develop a well-integrated software and hardware system for effective waste management.**
   - This objective serves to ensure that the two distinctive components (software & hardware) are effectively coordinated to ensure adequate interaction and compatibility.

CHAPTER 2: Literature Review

With the issue of waste management being a priority for most developed and developing countries, the smart city evolution has brought about technology geared towards addressing this issue. Smart cities have employed the use of smart bins which obtain real time information on the fill levels of community bins, enabling waste management companies to effectively manage community waste. The smart waste bin is commonly comprised of weight and level sensors which are coupled with microprocessors to constantly collect data on the fill levels of the smart bins as well as to determine the weight at each point in time, providing enough data to monitor and analyse the waste being collected and how to plan for pickup [3]. In the development of these smart bins, communication is key, hence engineers ensure that good communication systems are employed in the system design to ensure that the data being collected by the sensors are secured and effectively transmitted. Current smart waste bin designs employ the use of the Global System for Mobile Communication (GSM) modules to communicate with the server system to collect real time data. [4]. Research has shown that the development of these smart solutions for waste management alleviates the problem faced by waste management companies regarding the lack of information about waste collection time and specific areas to focus on. Also, software systems developed to couple this hardware have improved the monitoring and tracking of trucks and trash bins that have been collected in real time [5]. Developers have worked on building server side applications which map out bin locations and with effective communication systems, are able to interface with sensors installed on bins providing well planned information and reports on waste being collected. Several algorithms have been developed to optimize routes which waste trucks use while on trips to collect waste [6].

These optimization algorithms have served the purpose of limiting the excess resources required by waste management companies in routing their trucks.

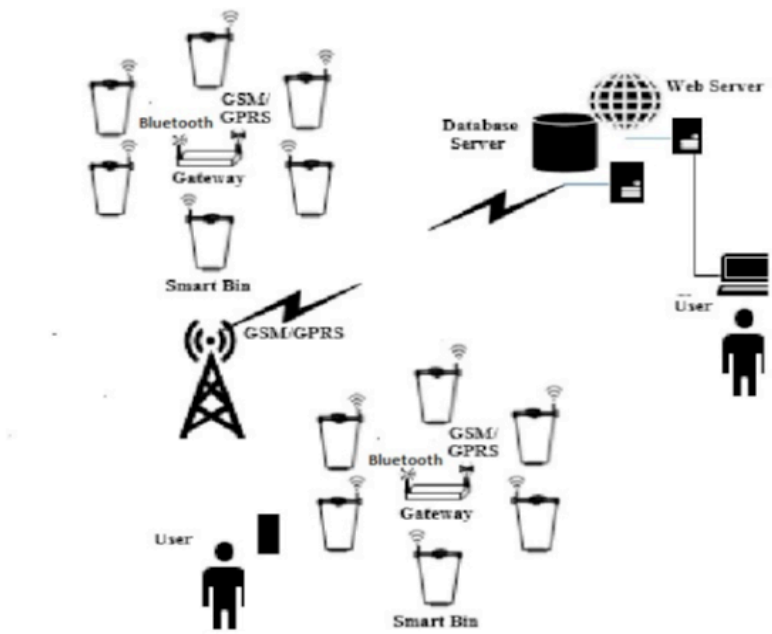


Figure 2. 1: The Smart bin environment as operated currently in some developed countries. [3]

The smart bin environment has however been iterated on the base principles of setting up sensor based waste bins at various points and having a common gateway to which web servers can obtain real time data, and with well-developed databases and web interfaces the data is effectively stored and managed to provide meaningful information on community waste which is well crafted to give users and clients an in-depth understanding of their waste and also ensuring that the environment is protected from the filth that arises from poor waste management. Figure 2.1 represents the sky plane view of a prototype of a smart bin design which has been developed and implemented in several locations in some developed countries. This architecture comprises of sensor installed bins with GSM communication modules linked to communication gateways assigned to bin clusters. Information retrieved through the gateways are communicated through the base station to server systems where the data is made into meaningful information for clients and users. The implementation of this smart solution reduces operational cost by up to 80%, since it reduces the number of trucks and the amount of fuel and time for waste collection [13].

Nevertheless, this technology is absent from the Ghanaian community and most African communities, with most waste management companies still employing the poor procedure of weekly schedules which has been ineffective in the management of community waste [2]. With this current state of the waste management issue in the Ghanaian community there is the need to establish smart systems that will enhance the management of waste and keep the countries communities clean at all times.

CHAPTER 3: Design

3.1 Requirements Specifications

The success of most engineering and technological developments are achieved when requirements are clearly outlined and met throughout the process of design and implementation, hence, the proposed system is one in which several requirements must be considered to ensure that it is efficient and effective in addressing the problem being solved. Two major sections of these requirements to be considered for this project are the user requirements and the system requirements. These two major sections serve as the basis to which the design of the proposed solution will be developed ensuring that user needs coincide with the system functionality.

3.1.1 User Requirements

The user requirements of this project serve as the terms of reference for the design of the proposed solution, to which a successful conclusion could be made on the efficiency of the proposed design and its ability to meet the desired functionality. These requirements are best derived from the expectations of users regarding the system being developed as the solution to the problem being addressed, and as such the following outlined requirements serve as the user requirement for this project. The user expects the system to:

1) Collect information on waste being generated in the community
2) Store the data collected on the waste being generated
3) Provide efficient routes for waste collection
4) Identify waste collection points
5) Be self-sustaining
6) Have a high waste intake capacity

7) Be safe and user friendly

3.1.2 System Requirement

Considering the user requirements identified and outlined, the system requirements of this projects serve as the technical requirement specifications which elaborates more on the necessary features required and the technical issues involved in meeting the user demands. The following are the system's outlined requirements:

1) Must involve sensor devices that will enhance the data collection process of the system. These sensor devices are expected to have high response times with little or no errors to ensure that data collected is exact and representative of the system conditions.
2) Requires an efficient database which can store data collected by system components and ensure an ease of data retrieval as well as security of system data.
3) Should have an efficient routing procedure/algorithm that enhances its software component to obtain optimized routes based on mapped out locations.
4) Should include a comprehensive map to clearly identify specified locations to enhance waste collection points specification and identification.
5) The system needs to be energy efficient hence components requiring little amount of energy are required in this design. Also, the system requires an alternative and sustainable energy source which will keep the system running at all times.
6) Requires a mechanism that is less complicated and easy to operate as well as less bulky to crush unto waste materials increasing the intake capacity of the system.

3.2 Design Specifications

Considering the outlined user and system requirement for this project. The proposed solution design is sectioned into two major parts which can be identified as the hardware and the software components. Each of these components has its design components which will ensure that it fits into the complete system as desired. Hence the design specifications of this solution are section specified with a combined procedure for the integration, to establish a complete interactive system.

3.2.1 System Design Architecture

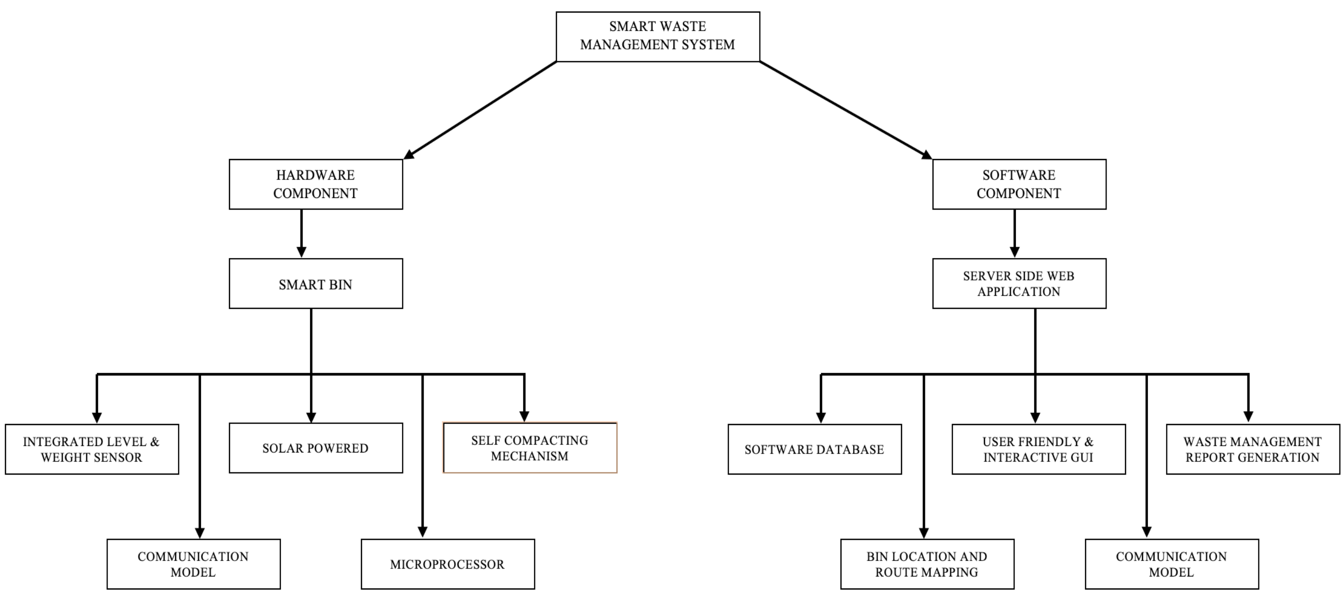


Figure 3. 1: Waste management System Design Component Structure

The system design component structure in figure 3.1 identifies the instrumental sections to the implementation of the proposed design. The **hardware component** whose main deliverable is the smart bin comprises of key components that will enable the bin to undertake its functionality efficiently and effectively. The identified components are the integrated level and weight sensors which will be well placed to provide adequate information on the level of waste in the bin as well as the weight of the waste packed within the bin. These sensors serve as the primary source of information for the system, enabling the system to initiate its processes of information analysis which then informs other processes of the system. This project however employs the use of the ultrasonic level sensor which is placed on the upper lid of the bin as depicted in figure 3.2.

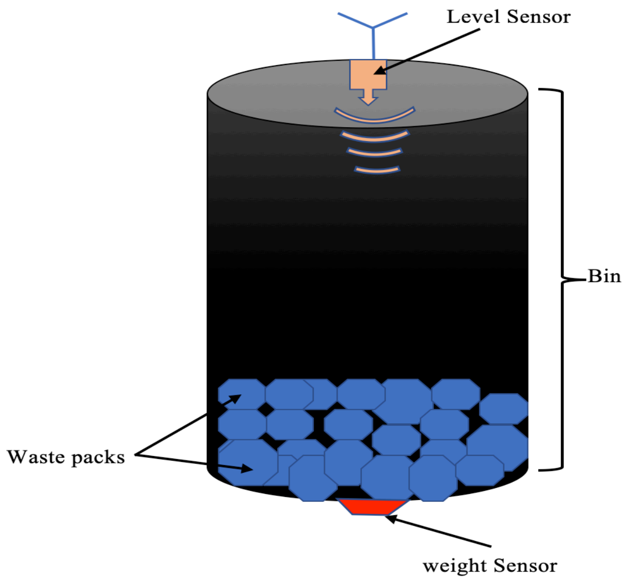


Figure 3. 2: Waste level and weight sensing

The ultrasonic level sensor senses the amount of waste packet inside the bin by sending high frequency waves which are reflected after hitting the waste within the bin. The microcontroller within the system measures the time between the transmission and reflection of these waves to determine the distance travelled by the waves. This information feeds into the estimation of the depth of the rubbish in the bin. The weight sensor is placed at the base of the bin as depicted in figure 3.2, and is used to monitor the weight of the waste collected within the bin. This sensor working with a resistivity principle changes its resistance as per the load applied, this change in resistance recorded by the microcontroller is then used to determine the weight of the waste collected. The Global System for Mobile Communication (GSM) is used to communicate the hardware sensor information with the server. This module will send periodic information about the waste weight and levels sensed to notify the client on when exactly to attend to the bin to collect waste.

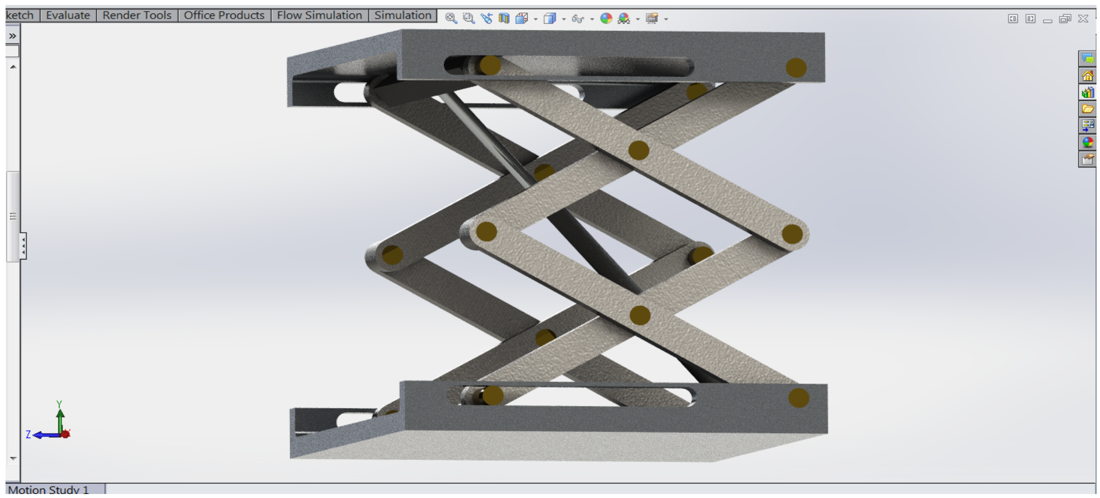


Figure 3. 3: Waste compactor design

To achieve the compaction of the waste within the bin and to increase the intake capacity of the bins, the system will include a mechanism as modelled in figure 3.3. This modelled component coupled with an actuator will expand and contract to press on waste packets within the bin compressing it and thus creating room for more waste to be added.

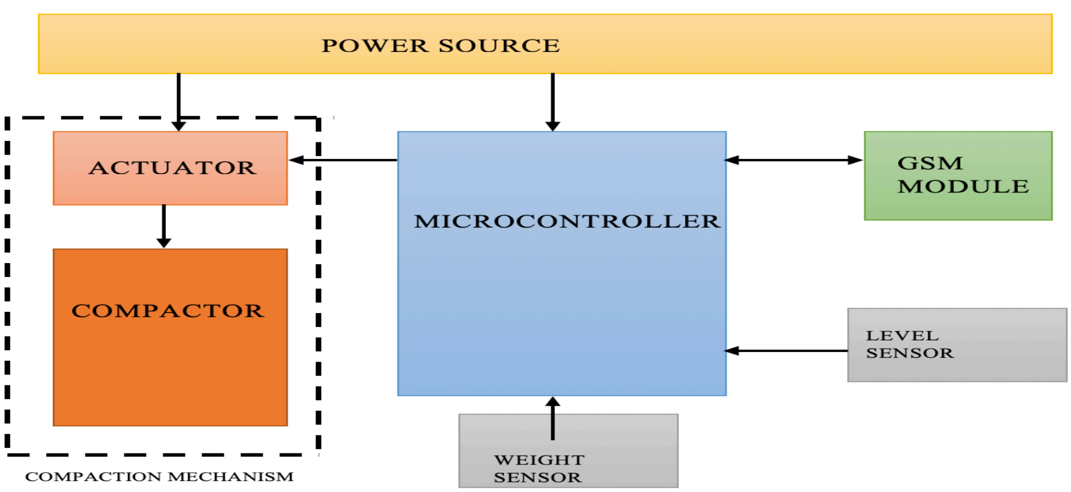


Figure 3. 4: General architecture of smart bin

The general architecture of the smart bin, the main deliverable of the hardware component is depicted in figure 3.4. The architecture shows the main building blocks and their interactions with the main coordinating system which in this design is the microcontroller.

The **Software Component** is characterised by major sections which interact to achieve the main deliverable of a web-based application for monitoring and managing the hardware component. Figure 3.5 depicts the user interface framework used in the development of the web application. This framework consists of two major sections which interact with the system database to retrieve and store information displayed for user viewing. The user authentication section will enable the system to verify registered users granting them access into the application for system management. Unverified users will be restricted, establishing a well secured system. The Dashboard section, the default page the user interacts with after access into the system has been granted is sectioned into three main parts that provide information and enable the management of the hardware components as well as the software functionality effectively.

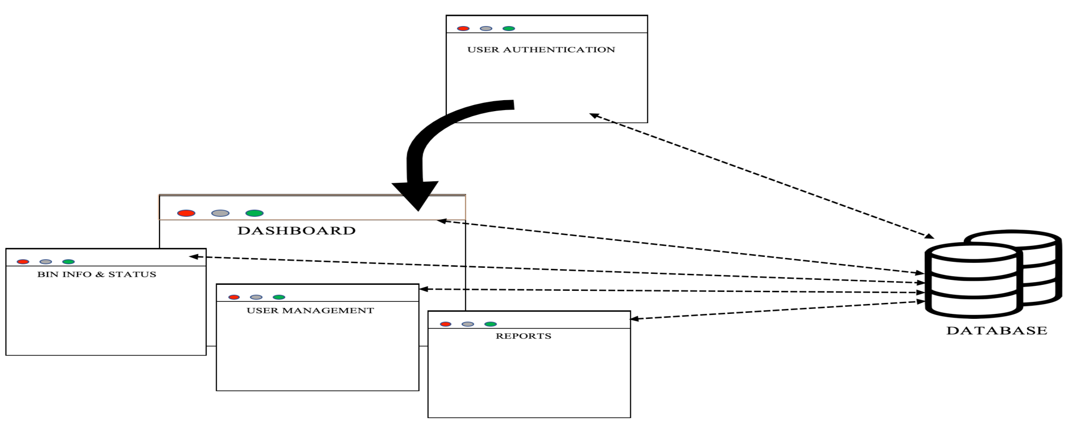


Figure 3. 5: Web App user Interface Framework

The development of the server application will be based on the Model, View, Controller (MVC) architecture as depicted in figure 3.6. This architecture provides a structured pattern in the development of user interfaces. This architecture however divides the application into 3 interconnected parts namely the **Model, View** and **Controller.** The Model serves as the part which defines the kind of data to be worked with within the application and hence is more linked to the system database and updates the View per the data to be displayed. The View defines how the data will be displayed for the user to view and understand, and the Controller is made up of logic that manipulates the model and updates the view in response to user inputs and updates.

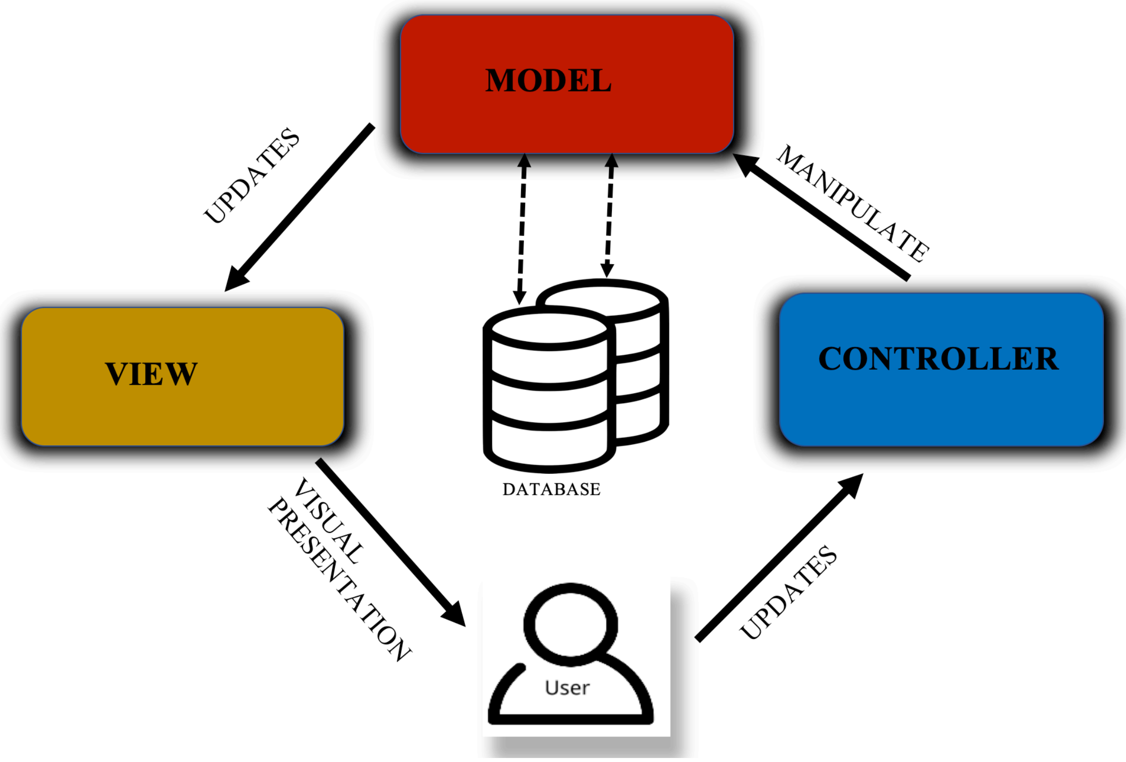


Figure 3. 6: Web Application Architecture

3.2.2 Design Components

Ultrasonic level sensor**:**

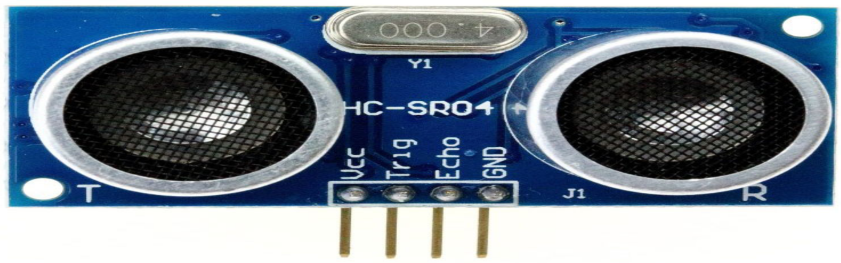


Figure 3. 7: HC-SR04 Ultrasonic sensor module

The ultrasonic level sensor used in this design is the HC-SR04 module. This module is designed to measure distances from the range of 2cm to 400cm with a measuring angle of 30 degrees. The module operates on a working current of 15mA and a power supply of 5V DC. This module includes an ultrasonic transmitter, ultrasonic receiver and a control circuit. The transmitter of this module transmits an ultrasonic sound of 40kHz and is reflected to the receiver after hitting an object in its line of sight. The distance measured is obtained through the formula $[distance = speed\ of\ sound \times Time]$, however, since the sound travels the same distance twice, the actual distance measured is obtained through the formula $[distance = \frac{speed\ of\ sound}{2} \times Time]$. To generate an ultrasound for the module to operate, the trigger pin of the module is set high for a minimum of 10μs, this causes the module to send out an 8-sonic burst at 40kHz which will then be received in the Receive pin. Thereafter, the module echo pin outputs the time in which the sound travelled in seconds, which is used to obtain the distance using the formula stated earlier. This component is used in this project to detect the level of waste in the bin.

Arduino Uno Micro-controller**:**

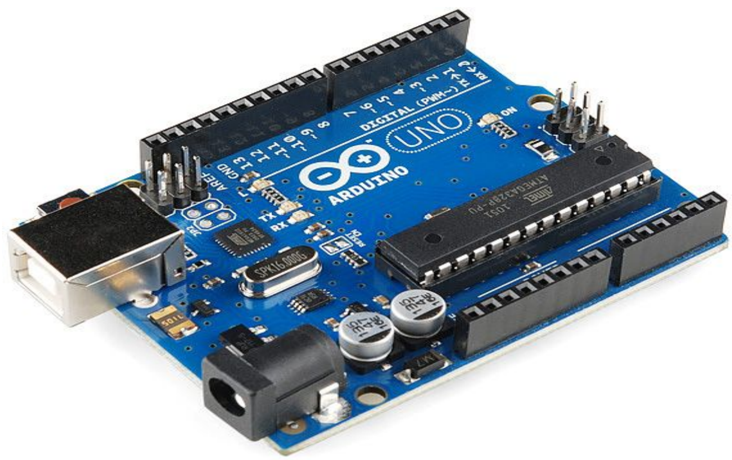


Figure 3. 8: Arduino Uno Micro-controller

The Arduino Uno is a micro-controller board that is developed based on the ATmega328. This micro-controller has 14 digital input/output pins and with the ATmega328 serving as the processor unit, the operating voltage of this board is 5V. However, the recommended input voltage range is 7V-12V [7]. The Arduino Uno micro-controller with its several I/O pins enables it to be interfaced with external systems and circuits to serve as a process coordinating tool. With an open source, Integrated Development Environment (IDE), the microcontroller chip can be programmed to control external systems and circuitry interfaced with it through its input and output pins. This component coordinates all the processes in the hardware system serving as the brain of the hardware system.

Load Cell/ Weight Sensor**:**

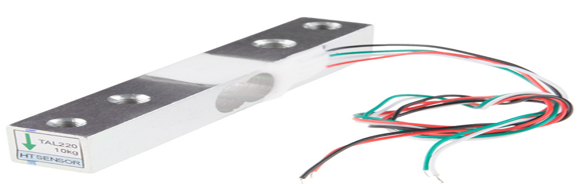


Figure 3. 9: Load Cell

This sensor is a transducer that converts a force applied on it into electrical signals. This device is made up of strain gauges [8]. These strain gauges work according to the base principle that the electrical resistance of several metals change when the metals are mechanically elongated or compressed. Hence the load cell is made by bonding these strain gauges to the position on the spring material where it will experience the largest strain. Using the linear relationship between the strain of the strain gauge and the resistance, the change in resistance can be determined to inform the calculation of the voltage signal which will be used to interpret the force acting on the load cell. The formula for this linear relationship is as follows;

$\frac{\Delta R}{R} = K \times \varepsilon$ ………………(1)

where;

$\Delta R = Resistance\ change\ caused\ by\ elongation\ or\ contraction$

$R = Initial\ resistance\ of\ strain\ guage$

$K = Guage\ factor$

$\varepsilon = Strain$

These obtained resistance values, as per the arrangement of the strain gauges on the load cell, set up a bridge circuit known as the Wheatstone bridge circuit. Thereafter the corresponding voltage of the varying resistances of the strain gauges is calculated using the Wheatstone bridge circuit analysis. This component is used in this project to obtain the weight of the rubbish in the bin

GSM model

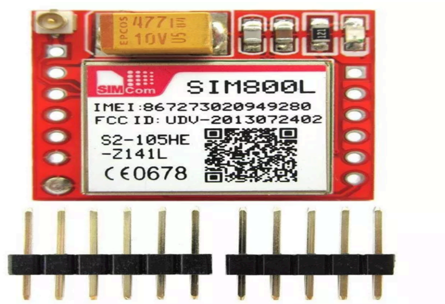


Figure 3. 10: GSM shield SIM800

The GSM module is a device that is used to establish communication between mobile devices as well as computing machines and GSM or General Packet Radio Services (GPRS) systems. This module is essential to this project design as it provides the means to connect to the internet over the GPRS network. The device uses the Time Division Multiple Access (TDMA) technique in its process of communication. The GSM module has an operating voltage of 3.4V to 4.4V. This module supports a band rate of 1200bps to 115200bps with an auto band detection.

Electric Actuators

Figure 3. 11: Electric Actuator

The electric actuator used in this design serves a vital role in the compaction mechanism. The actuator used for this design expands over 30cm to press on to rubbish within the bin. The actuator is however coupled with relays to switch terminal polarities to get the motor to expand and retract the mechanism. The actuator used for this design has a speed rating of 5.7mm/s and a maximum load of 1500N/push. The input voltage of the actuator is 12VDC and it has a 25% duty cycle.

Power Supply:

Figure 3. 12: Power Supply System a)12V DC battery, b) Charge Controller, c) Solar Cell

The power supply system used for this design is composed of a 12V DC battery with solar cells attached to serve as a recharging system for the battery. The charge controller is also part of this supply system to give readings on battery level and its charging state.

Motion Sensor

Figure 3. 13: Passive Infrared (PIR) Motion Sensor

The Passive Infrared (PIR) motion sensor is an electronic sensor that measures infrared light radiating from objects in its field of view [9]. This sensor is a low power, inexpensive device that has an operating voltage of 3V-5V, with a sensitivity range of up to 20 feet [9]. This device is instrumental in the compaction mechanism of this project design, as it serves as an indicator which controls the operation of the actuator to expand and contract the compaction mechanism, pressing on the waste within the bin.

CHAPTER 4: Design Implementation

4.1 HARDWARE IMPLEMENTATION

The hardware for this project design consist of sensors and processors which need to be properly linked to ensure effective coordination of sensor activities and system operations. This section focuses on the hardware system setup and process coordination. Identifying the key processes and components that ensure a good functionality of the system hardware and how the set-up is made

4.1.1 Sensor Calibration

The design included two major sensors; the load cell and the level sensor. For the purposes of this project, these sensors required system specified calibrations.

<u>Load Cell</u>

In calibrating the load cell, it was connected to the Arduino microprocessor, and a known weight of 200g was used to set the zero point of the sensor, the Arduino IDE (programming environment) was used to program the device to produce readable weight values per the weight placed on it as depicted in figure 4.1. Upon calibration, it was observed that the sensor values had a slight shift from the actual weight of the load by 0.4g-0.9g. This slight error could be attributed to the high sensitivity of the sensor, which makes it respond to other environmental factors like temperature and the air around it.

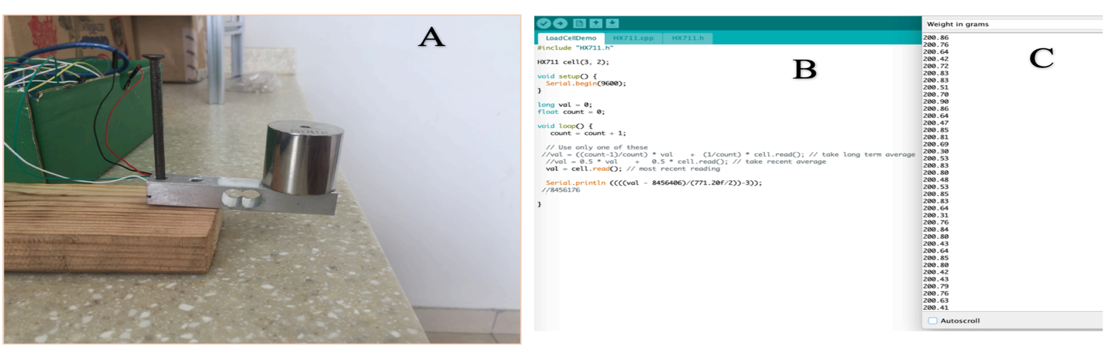


*Figure 4. 1: Load Cell calibration set-up [**A:** Sensor set up with load placed on it, **B:** Processor program used in obtaining readings, **C:** output values from sensor]*

Ultrasonic Level Sensor

The ultrasonic level sensor was calibrated based on the height of the bin being used in this design. There were two major set points established in this sensor calibration; the peak limit and the mid-way section. These two set points were that which were going to communicate the fill level of the bin. The bin being used was of a height 40 cm; hence the mid-way point calibrated using the Arduino coupled with the sensor was 20cm and the peak point was set up as 5cm from the top of the bin. The fill levels are however being indicated with Light Emitting Diodes (LEDs); with a red light signifying maximum fill level, yellow signifying a half-filled bin and green light signifying an empty to below mid-way filled bin.

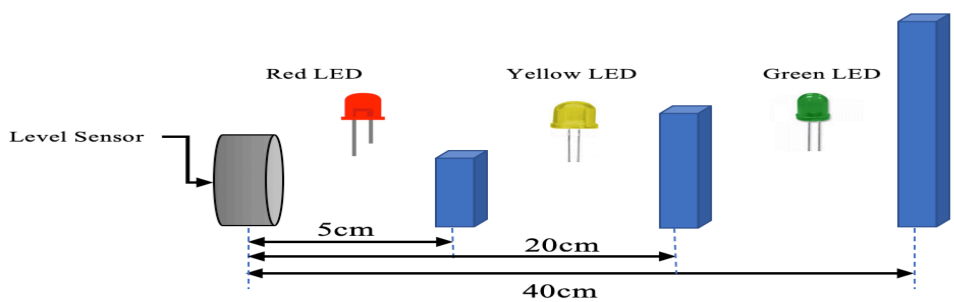


Figure 4. 2: Ultrasonic level sensor calibration set-up

In the set up shown in figure 4.2 objects are placed in the line of sight of the ultrasonic sensor, with their actual distances measured. The measured values were then compared to the distance values of the sensor to ensure its accuracy. It was observed that there was 0.02cm difference between the sensor values and the actual measurement. This error could however be attributed to the irregularities of the object surfaces, hence since the operation of the sensor involves wave propagation and bouncing off surfaces, these surface irregularities will factor in the slight error of the sensor readings. Taking this observation into consideration, the sensor was calibrated for its operational purposes, with the LEDs serving as visual indicators of waste level.

4.1.2 Communication Model Setup

In the set-up of the communication model, the GSM SIM800 model was connected to the Arduino microprocessor and using the Adafruit FONA library; an Arduino programming library that enables sensor value readings and communication over the internet [10], a serial communication system was set-up. To achieve this serial communication, the model had to be linked to a service provider to obtain internet connectivity through mobile service provided bundle. The mobile service provider used for this system is the MTN mobile service. Using the Arduino IDE (programming environment), the protocol for this system communication was implemented. The protocol is as follows:

1) Include the Adafruit FONA Library and initialize its variables
2) Obtain the module International Mobile Equipment Identification (IMEI) number.
3) Set up the GPRS network settings with the internet
4) Obtain system network status and determine if network is registered.
5) Read sensor values and attach them to URL
6) Using Hypertext Transfer Protocol (HTTP) request, send sensor values to server from the client.
7) Return a success message after successfully making the request.

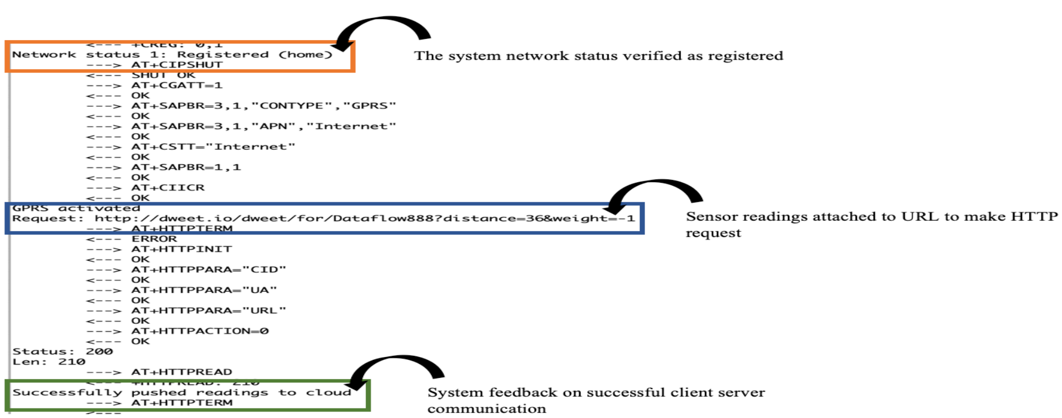


Figure 4. 3: System communication protocol output

A sample test output of the outlined protocol is depicted in figure 4.3. In this test output the network is verified as registered, thereafter the sensor values obtained from the level and weight sensors are attached to the URL, making the http request to push the sensor readings to the cloud. The dweet.io platform, a free messaging platform for Internet of Things(IOT) systems, is used in creating the cloud platform where the sensor data is constantly fed to.

4.1.3 System Powering

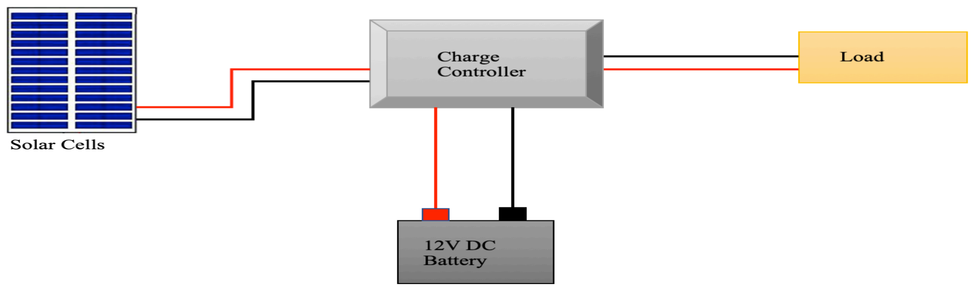


Figure 4. 4: System power circuit block diagram

To provide power to the system, the set up in figure 4. 4 was implemented. The solar cells captured energy from the sunrays to charge up the battery when the sun is out, hence during the times of the day when the sun is not up, the system is solely powered by the 12V DC battery. The voltage output of the set up was checked using a multi-meter to ensure that the output voltage was the desired 12V and this proved to be the case. Since the output voltage was too high for some of the components in the system, a buck-convertor was added to the system to maintain the voltage supply to these components at their required operational voltages.

4.1.4 Compaction Model Setup

The system compaction model is implemented using a motion sensor, the level sensor, the microcontroller, an electric actuator and a relay which controls the switching of power supply to the electric actuator. The set-up is implemented such that the motion sensor is placed in a position towards the bin opening where the rubbish is inserted such that when rubbish is inserted, the sensor detects a motion and triggers the microprocessor to power up the actuator, causing the compaction plate to press unto the rubbish. The control of this set-up is such that when the level of the rubbish is recorded as midway by the level sensor, a period of five minutes is set up, hence within this time range, if no motion has been detected by the sensor, the actuator isn't powered up. However, upon detection within this time interval the actuator is powered up and the compaction mechanism is made to press unto the waste. However, when the waste is below the midway mark as detected by the level sensor, the electric actuator is not powered to undertake waste compaction.

4.1.5 Hardware System Complete Setup

After the individual components where tested and verified to be efficiently working as required by the system design, these individual components were put together to completely finalize the hardware system producing a fully functioning solar powered, self-compacting smart bin as proposed in the system design. Figure 4.5 shows the system hardware after all the individual components were assembled.

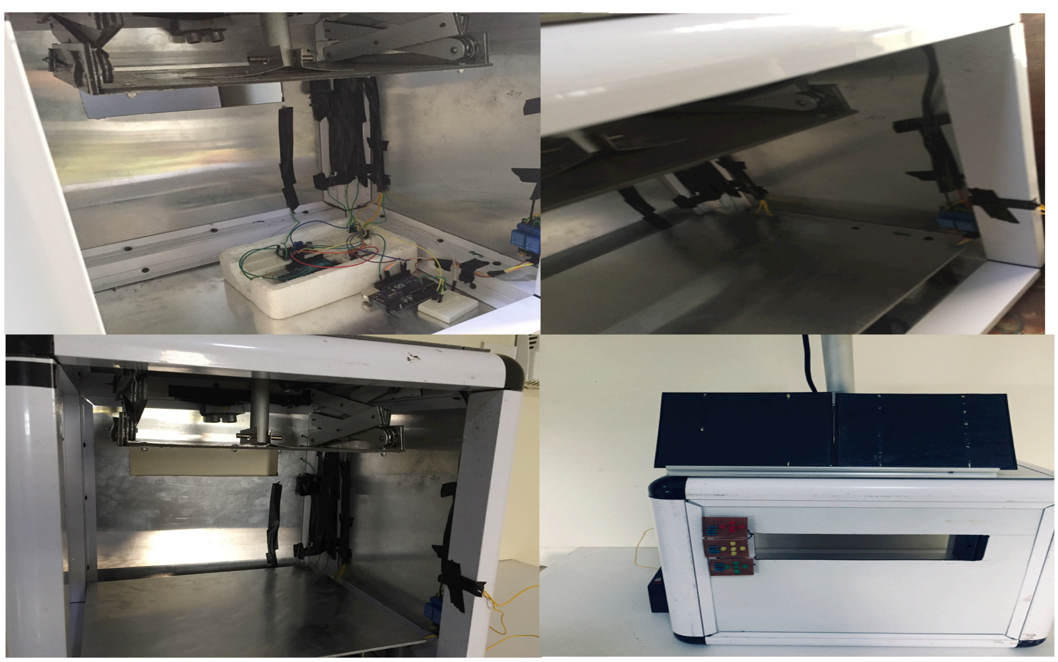


Figure 4. 5:Assembled hardware system

4.2 SOFTWARE IMPLEMENTATION

The software section implementation mainly involved the development of the server side application with its database as well as its link of communication with the system hardware and some management processes which are rendered through the web application. This section focuses on an in-depth explanation of the software set-up and the tools involved in ensuring good coordination between the web application activities and the system hardware.

4.2.1 Application User Interface Design (UI)

In the development of the Graphic User Interface for this web application, the AdonisJS web framework was employed in building a dynamic, user-friendly and aesthetically appealing user interface. The AdonisJS web framework, is a web framework developed based on the NodeJS programming language, which makes it highly efficient for server side application developments. With the front-end web application being a primary interface through which users will interact with the system, it requires a user centred approach in its design [11]. As per the user requirements in chapter 3, the application should enable identification of waste collection points mapped and this is accomplished as displayed in figure 4.6, with flagged areas on the map showing waste collection points.

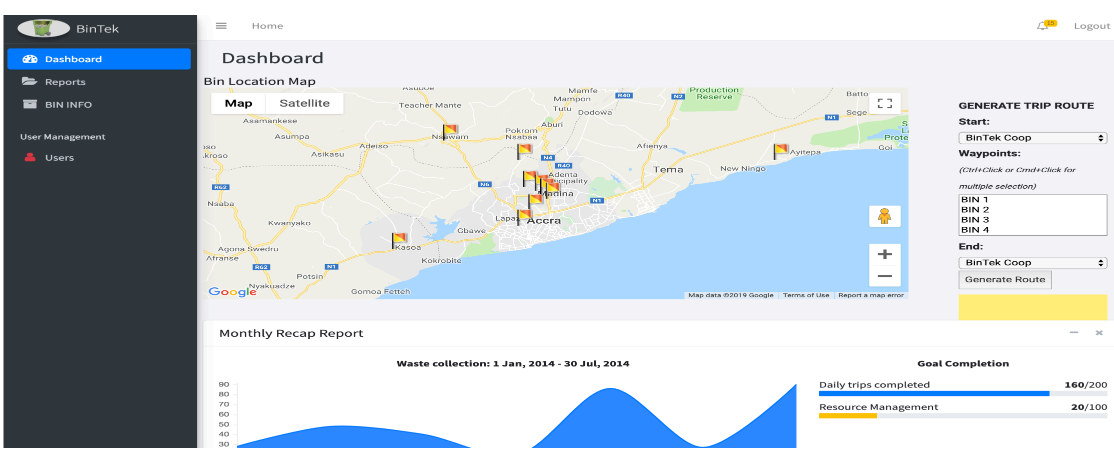


Figure 4. 6: User interface for system web application: Rendered Dashboard

Figure 4.6, presents the dashboard which the user interacts with upon logging into the system. This initial page gives the user a view of all located bins on a well laid out map, with an interface to generate routes based on notifications on filled bins. The dashboard also presents a brief overview of monthly reports on waste management.

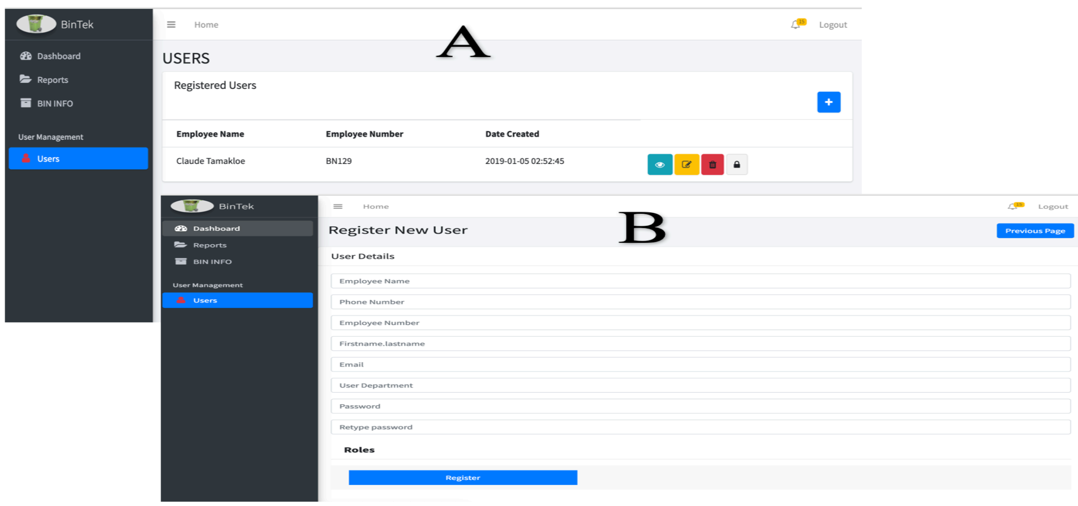


*Figure 4. 7: User Management web interface [**A:** Already existing system users page, **B:** Page for new user registration]*

The web-framework for this project as described in chapter 3 contains other pages that provide information and management of system assets and users. Figure 4.7 shows the User management web interface which allows entry of new user details to enable them to obtain access to the web application as registered and verified users. The interface also allows user details to be edited, viewed and deleted from the system. Another essential page in this web-application is the Bin information and management page.

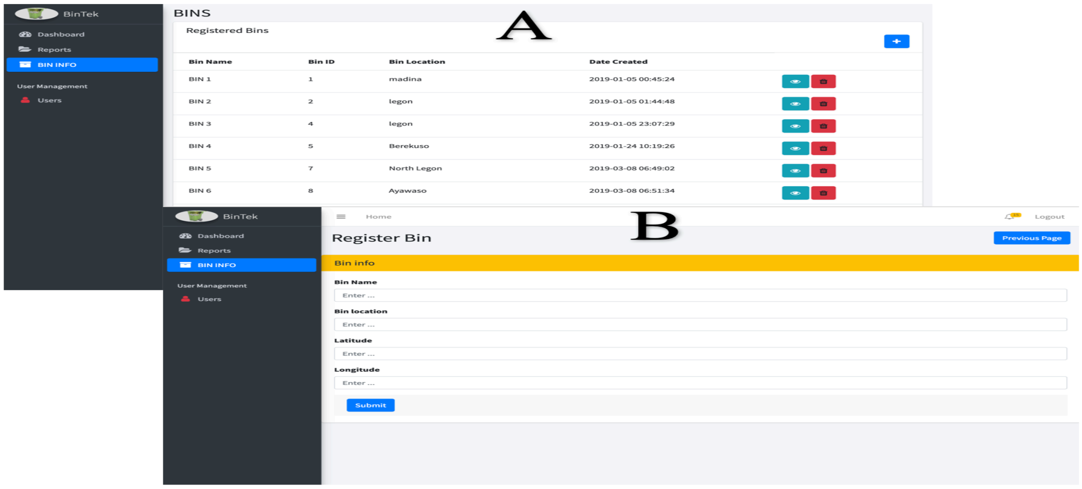


*Figure 4. 8: Bin information and Management page [**A:** Registered bins display page, **B:** Page for registering new bins]*

Figure 4.8 is a representation of the Bin information and management page which similarly to the user management page is in two parts. The registered bins display page(A) shows already registered bins and enables users to view bin details as recorded in the database and allows users to delete bins from the system as and when these bins are no longer in operation. The Bin registration page (B), prompts the user to insert bin details regarding coordinates of its location and its ID to make it identifiable on the map as displayed on the dashboard in figure 4.6.

4.2.2 Hardware Monitoring Interface

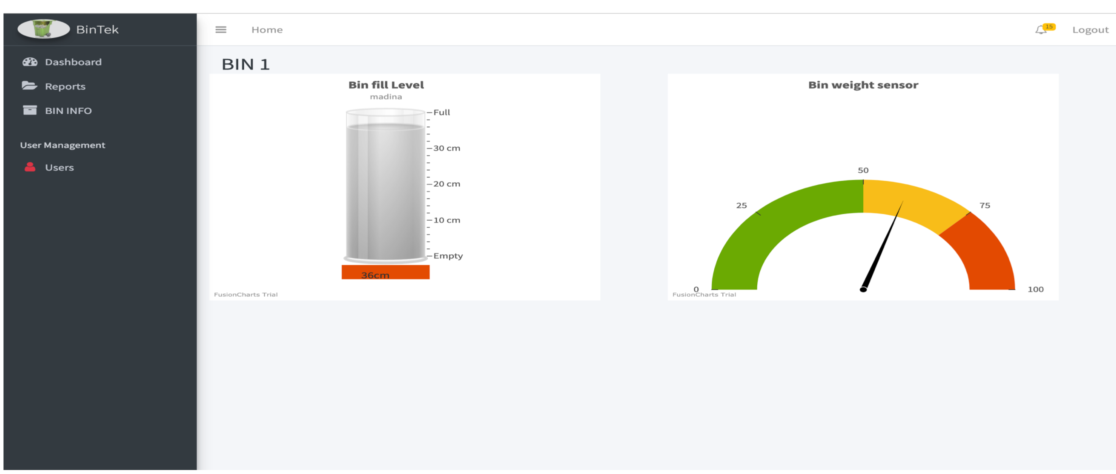
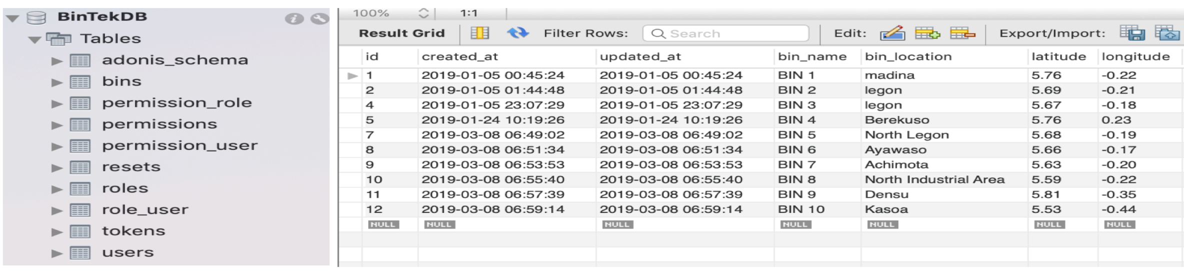


Figure 4. 9: Web Application Hardware Monitoring interface

The hardware monitoring interface of this system is as depicted in figure 4.9, This interface is made of gauge charts that visually display the sensor values as they are being fed up unto the cloud service by the hardware communication system. The monitoring interface displays the fill level using the cylinder gauge on the left in figure 4.9 and displays the weight of the bin using the speedometer gauge on the right. These charts are however being rendered using fusion chart APIs which provide visual representations for data points.

4.2.3 System Database



id	created_at	updated_at	bin_name	bin_location	latitude	longitude
1	2019-01-05 00:45:24	2019-01-05 00:45:24	BIN 1	madina	5.76	-0.22
2	2019-01-05 01:44:48	2019-01-05 01:44:48	BIN 2	legon	5.69	-0.21
4	2019-01-05 23:07:29	2019-01-05 23:07:29	BIN 3	legon	5.67	-0.18
5	2019-01-24 10:19:26	2019-01-24 10:19:26	BIN 4	Berekuso	5.76	0.23
7	2019-03-08 06:49:02	2019-03-08 06:49:02	BIN 5	North Legon	5.68	-0.19
8	2019-03-08 06:51:34	2019-03-08 06:51:34	BIN 6	Ayawaso	5.66	-0.17
9	2019-03-08 06:53:53	2019-03-08 06:53:53	BIN 7	Achimota	5.63	-0.20
10	2019-03-08 06:55:40	2019-03-08 06:55:40	BIN 8	North Industrial Area	5.59	-0.22
11	2019-03-08 06:57:39	2019-03-08 06:57:39	BIN 9	Densu	5.81	-0.35
12	2019-03-08 06:59:14	2019-03-08 06:59:14	BIN 10	Kasoa	5.53	-0.44
NULL	NULL	NULL	NULL	NULL	NULL	NULL

Figure 4. 10: System Database displaying registered bins and their details as recorded in the database

The system database is developed using MySQL database queries. MySQL database is an open source relational database management system. This database system was implemented in this project to create tables that store user information and data feeds in the web application. The tool used in implementing the database was the MySQL workbench which provides a simpler and user friendly interface for database creation. Figure 4.10 shows a display of the data arrangement in the system database with rows and columns well defined providing a structure that makes it easy to recognize relations between stored items of information.

4.2.4 Routing Engine

This project requires the web application to provide the user with efficient routes for waste collection. The routing problem for this project is however similar to the Travelling Sales Man Problem (TSP), a prominent problem in the world of computer science [12]. The problem is defined as one which involves the need for a salesman to travel several cities from his original location and return to this location using a route that consumes less resources. In this project, the waste collecting vehicle serves as the salesman and the bins are the various cities that should be visited. The TSP problem is however considered a Non-Deterministic Polynomial-time hardness (NP-Hard) problem making it a very complex problem however there are a few heuristic approaches used in solving this problem, but these solutions are just optimal solutions and not the actual best [12]. The approach used in this project to obtain an optimal solution is the use of the google directions API. The algorithm used in implementing this API takes the location of the bins as nodes and uses edges to represent the distance between these nodes.

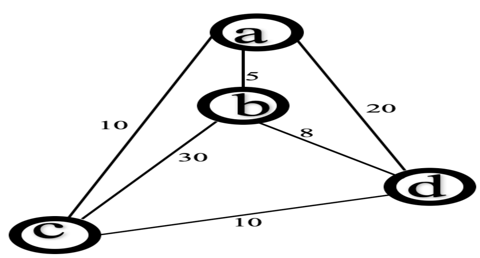


Figure 4. 11: Simple Four node graph showing how the algorithm represents the problem

From a mathematical perspective in figure 4.11, the algorithm generates the most efficient path moving from the starting point **a** and visiting all the other nodes once before returning to the start point. The most efficient path is determined by the values attached to each edge connecting the nodes, these values represent the amount of resources required to traverse that path, Hence, using the sample graph plot in figure 4.11, the algorithm generates all the possible paths for this movement and calculates the cost of the path. The total number of paths is determined by

(N-1)! hence for this problem since there are four nodes the total number of possible paths is 3!, which amounts to 6 possible paths.

Table 4. 1:Table representing the determined paths and cost of the TSP problem in figure 4.11

PATH	COST
A-B-C-D-A	65
A-B-D-C-A	33
A-C-D-B-A	33
A-D-C-B-A	65
A-C-B-D-A	68
A-D-B-C-A	68

From the path data in table 4.1 it is observed that there are two paths with the least cost, making those paths the most efficient routes based on the parameters defined by the algorithm. Hence the algorithm provides these paths to the user as the most efficient paths. However, for the google directions API which is implemented in this project, not only does it label out the parameter of cost as the distance, but also takes real time feed on the time it will take to travel those paths and the conditions of the road to narrow this solution down to the most optimal solution.

Figure 4. 12: Output of a sample route generation in web application using the routine engine

Figure 4.12 shows a generated route in the system web application based on selected bin location inputs and the start and end points. In this application, the start and end points are chosen as a defined company location. The application then analyses the location road systems using the google maps API and then determines the most optimal path to be taken, providing the distance between each stop point.

CHAPTER 5: Design Testing & Results

5.1 Test Description

This section focuses on defined test cases that are used to ensure that key components of the system design function properly as desired in the system functionality description. To validate the conclusion of a successful design implementation, three test cases were defined and performed. The test cases are as follows:

1) Testing the efficiency and accuracy of the routing engine implemented in the web Application. This test case involves routing between several points on the map using the application implemented routing engine and comparing its results with two already established routing engines namely; the Open Source Routing Machine (OSRM) and Google Maps routing engine.
2) Testing the response and efficiency of the compaction mechanism. This test case involves setting up triggers for the compaction mechanism with focus on the response to these triggers and checking how effective the mechanism is with regards to compaction and creating more room for rubbish after compaction.
3) Testing the time lag in the system hardware communication with the software. This test case involves sending several test data from the hardware system to the software and recording the time it takes for the software to receive and display the information from the hardware.

5.2 Test Results and Analysis

Carrying out the first test case, the defined starting location in the system application was selected with four other locations which represented registered bin locations, and using the system designed web application, the route was generated. The route generated recorded a total distance of 44.5km with a journey time of 2hrs 2 minutes (Image C in figure 5.1). The same process was carried out using the already built in google maps routing engine and the same distance and time of 44.5km and 2hrs 2mins was recorded (Image B in figure 5.1). This observation proved that the google maps direction API implemented within the web application was functioning as desired and producing the efficient route as desired. However, on the final test with the Open Source Routing Machine (OSRM), the route generated, recorded a distance of 48.4km and a time of 2hrs 20mins (Image A in figure 5.1). Comparing this with the system Web application, it proved that the implemented directions API within the Web application was more efficient than the OSRM considering the time and distance taken on both generated paths, making it a suitable fit for the system defined specification.

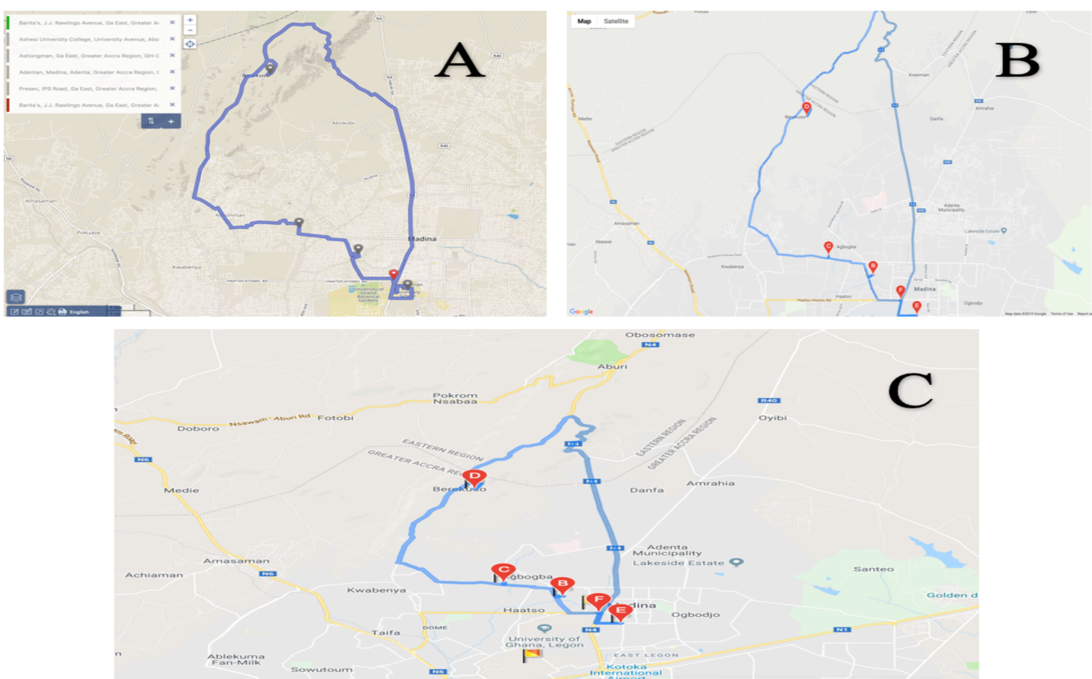


Figure 5. 1: Routing Test Cases (A: OSRM generated Route, B Google Maps routing engine generated route, C: WebApp generated Route)

With the second test case, rubbish was inserted into the bin and the half mark was reached to trigger the compaction mechanism. The compaction was allowed to take place and the new level of the waste was recorded. This process was repeated five times to obtain varied data on the efficiency of the compaction mechanism and the data is recorded as follows:

Table 5. 1:Results from compaction test

TEST CASES	**SPACE CREATED FROM COMPACTION**	**%SPACE CREATED**
TEST 1	4 cm	20%
TEST 2	5 cm	25%
TEST 3	5 cm	25%
TEST 4	6 cm	30%
TEST 5	5 cm	25%

From the data in the table above, it was observed that the average space created when compaction takes place is 5cm representing 25% of space created. This is because the electric actuator being used to press unto the waste, doesn't exert that much force unto the waste. However, the space created is enough for more waste to be inserted, considering the model bin being a maximum height of 40 cm. To further improve the space created, an electric actuator of a higher force and a base plate of a larger weight could be used.

The third test case involved testing the time lag of the communication between the hardware and the software. In carrying out this test case it was observed that there was no time lag in sending information from the hardware to the software, as the software was being updated instantly after every data feed from the hardware

CHAPTER 6: Conclusion

The User Web Application and the sensor composed hardware system (Smart Bin) developed in this project establish the basis of how technology can be used in the effective management of waste, introducing a revolutionized approach to waste management in the Ghanaian community and possibly spread across the African continent. With this smart system, waste companies will use less resources in waste management and improve their efficiency on waste collection. The system also plays a key role in the country's strive to keeping its communities clean and ensuring good sanitation.

However, the system as currently designed is faced with certain limitations and challenges which bring about the challenge to improve on the initial design to enhance the system efficiency and ensure its sustainability and effectiveness.

6.1 Project Limitations

The design and implementation of the smart system proposed to address the waste management problem defined has some limitations attached to the final design of its initial prototype. These limitations are as follows:

1) The unavailability of adequate funds and resources to ensure an efficient design of the initial prototype. This limitation resorted to the use of alternative materials and components to ensure that the prototype is established on a completely low budget in which high efficiency of the system is compromised.
2) Less number of hardware prototypes to make valid deductions on system efficiency. This limitation made it difficult to conclude on how effective the system software is in managing several hardware components of the system and to identify the possible

errors or challenges that might arise when the system has to handle several data feed from different hardware components.

3) The Lack of existing data on community waste and its management in the Ghanaian community was yet another major limitation to this project design as it would have been essential to identify trends in waste generation and its management over time, to inform the design decisions of the proposed solution.

6.2 Future Works

The complexity of this system introduces several dimensions to improving on the system functionalities, however this project serves as a base to which several improvements and developments could be explored in developing a highly efficient and effective waste management system to help address the nations sanitation issues adequately. A few of these possible improvements are as follows:

1) Implementing a component health status checkers. This development will help in identifying faulty systems on time and ensuring that the durability of the system is ensured.

2) Implement System Security. This feature will prevent the issue of theft, ensuring that the system is highly secured and ensures that systems tempered with are identified easily and on time.

3) Employ a more efficient and durable communication medium. This improvement will enhance the communication system of the current design, making it highly efficient in data transfer and collection

4) Develop a more detailed report generation scheme. This report generation scheme will introduce a more detailed report format to ensure that the data generated from the waste collection is well managed and presented.

In Conclusion, the development of this smart waste management system provides the community with an efficient solution to its sanitation problems. With a well-integrated sensor packed bin and a user centred remote monitoring web application that enables efficient routing of waste tracks for waste collection, waste companies can now save resources and reduce cost of operation while ensuring that the community waste is managed properly and our communities are kept clean at all times.

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