ASHESI UNIVERSITY

AFFORDABLE SMART REFRIGERATION FOR PROFESSIONALS

CAPSTONE PROJECT

B.Sc. Electrical & Electronic Engineering

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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 & Electronic Engineering.

Ewuradjoa Dadzie

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:

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Candidate's Name:

Ewuradjoa Dadzie

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Date:

29 May 2020

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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 College.

Supervisor's Signature:

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Supervisor's Name:

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Date:

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Acknowledgements

I would like to thank God for the successful completion of this project, and my supervisor for his patience and tolerance throughout the process. I would also like to thank my colleagues who helped me in the understanding of certain processes.

Abstract

Internet of Things is a growing industry all around the world, in which numerous applications and innovations are being made, smart home automation being one of them. In Ghana, the traction or adoption of these technologies is low, because of the cost and ineffectiveness associated with appliances such as a smart refrigerator. The aim of this project is to design a system that accounts for the ineffectiveness of current smart models, and economizes on the cost of creating such a system. Various parts of such a system were individually simulated and tested, using sensors, NodeMCU, a Raspberry Pi, and a Raspberry Pi camera. Web and mobile applications were built to interact with the user. Each system part was successfully simulated; however, the system could not be tested as a whole, due to modifications that had to be made while simulating. It was realized that with the implementation done the objectives of the project would be achieved if properly deployed. The impact of the work done would increase traction and adoption of smart refrigeration in Ghana as it would be more affordable and more relevant to the Ghanaian context.

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Chapter 1: Introduction

The Internet of Things (IoT) refers to the connectedness of physical devices to the internet in order to share data from their environment that can be analyzed and acted upon. This growing technology has already seen more connected devices than there are people in the world [1]. The benefits of having devices connected to the internet are numerous. In industry, it boosts reliability, efficiency, and profitability [2]. As the population of the earth increases, it is even more expedient to be more efficient with our use of resources, seeing as how they are scarce. With the applications of IoT being diverse and ubiquitous, the ability to sense, collect, transmit, and analyze data on any scale would give humanity the knowledge and wisdom it needs to thrive efficiently in the coming years [3]. One aspect of IoT that has great potential is smart home automation. Smart home technology generally refers to any suite of devices, appliances, or systems that connect into a common network that can be independently and remotely controlled [4]. It has seen the development of technologies like smart TVs, smart lights, smart security systems, and smart appliances. Of the smart appliances, there's been the development of smart blenders, smart washing machines, and smart fridges, to name a few. However, the traction in Ghana has been quite poor, because the high cost of appliances like these keeps them out of reach for many [5]. A typical smart fridge with capabilities like a touch-screen display for multiple functions can cost an average of $2000 [6], which is a steep price. In typical Ghanaian homes, food production and storage is a big part of the daily household management, and although there are quite a number of inefficiencies associated with the way most people manage this, the price of smart fridges may seem too high despite the seemingly many benefits associated with owning one. One reason the cost is so high is that in order to have a smart fridge, you have to replace your old fridge with a new smart model. Currently, there are no systems or processing available for converting a normal fridge to a smart fridge, which would drastically reduce the cost associated with owning a smart fridge. Other reasons that would typically deter Ghanaian homes from owning one is that the features are seemingly obscure or unnecessary, especially in the context of our economy [13].

1.1 Background

What makes a smart fridge smart is its ability to connect to a network and share information that is useful to its user. Some features include knowing its contents, alert its user when stock is running low, make recipe suggestions based on content, provide dietary information, and even automatically ordering low-stock foods. These features are made possible due to RFID or barcode scanning, internal cameras, and internal sensors. Smart fridges have been in existence in some form from as early as 1998 [7], with each iteration introducing new features and more abilities, but for some reason, they have not caught on as much as other smart appliances have. Consumers adapt to technology that is most convenient to their way of life, and most of the fridges that have been released require the user to manually scan food or place items in specific locations for the convenience of sensors, which is inconvenient [8]. Many variants have been developed, none of which are cost-effective. The following table lists the prices of current smart fridges.

Table 1: Prices of current smart fridge models and their features [6]

Model	Starting Price	Features
GE Profile Series	$3176	Mobile app, Alexa, Google Assistance, water filter, ice maker, door monitoring
LG InstaView Door-in-Door	$1999	Smart glass, mobile app, doorin-door feature, Alexa, Google Assistant
Samsung Family Hub	$2199	Fridge to freezer conversion, touchscreen
Samsung 4-Door Flex Food	$2499	Fridge to freezer conversion, door-in-door feature
Samsung Smart Refrigerator	$1599	Door-in-door feature

The main components of this project are a NodeMCU and a Raspberry Pi, which collectively cost GH₵180 [9]. The other components would barely bring the total cost of the project to an estimate of GH₵300. Comparing that additional cost in installing smart components in an already existent fridge, and purchasing a brand new smart refrigerator, it would be much more economical to do the former.

Although the project will not have all the features the current smart fridge models boast of, it would focus on the essentials. The general consensus on current smart fridges was that many of their features were unnecessary anyway. It is possible to achieve the basic effect that smart fridges offer, which is convenience and efficiency, more economically, by modifying a normal refrigerator and making it smart through the installation of smart components. This option may increase the traction for smart refrigeration in Ghana and introduce the concept to more homes.

1.2 Scope of Work

The completion of this project includes the following tasks, namely:

- Circuit building by assembling the various components chosen based on design
- Implementation of a software module to coordinate sensor data collection for effective monitoring and control
- Testing of the integrated module

The final product would be a customizable system that can be installed in any fridge to make it smart. The system would take input from the fridge through sensors and process the data to perform specific actions based on the information, such as inform the user when stock is running low, and provide a current report of the fridge's contents.

1.3 Significance and Contribution

I conducted a survey among working professionals in Accra who are fairly aware of current technological advances, and while they are aware of the existence of smart fridges, most of them were not keen to invest them. However, they did concede to the fact that it would be ideal if they could have the features smart fridges offer at a more affordable price. This project will make that possible.

Chapter 2: Related Work

This project has not been the first in recognizing this market gap and trying to address it. There have been quite a number of attempts to model the problem and address it from various angles. In 2014 a group of scientists and engineers from the Korean Advanced Institute of Technology in Daejeon, South Korea conducted a study to fix everything that was wrong with smart fridges [10]. Three main problems they identified in current trends was that they demanded too much input from the user, RFID scanners were ineffective if the food items did not have RFID tags, and that other forms of sensing couldn't identify what was being taken out and put in. The scientists implemented three modules, the first being an object recognition system that works with a webcam. The second module accurately measures the positions of objects using infrared sensors, and the third is a set of LEDs that alert users to low stock or expiry dates. They also developed an accompanying mobile app that allows the user to identify food items through speech, and the fridge would highlight that item for them. However, they encountered a challenge with their first module, which was based on object recognition. At the time of the project, the accuracy of object recognition using a webcam and Google images was a limiting factor, because it had a five-second lag, and was not always accurate.

Another project was conducted by three students from Sambhram Institute of Technology, India, to give redress to the smart fridge concept [11]. Their objectives were to perform quantity monitoring, quality monitoring, and shelf life monitoring. They used LDRs, pressure sensors, and RFID transceivers, coupled with ARM7 LPC 2148 microcontroller to achieve their objectives. Their project was successful and they were able to achieve their objectives. Their project does not address the issue of specificity in content, however. For foods that have no barcodes or RFID tags, the module would have to rely on the user to place food items in designated places, and it would only measure presence or absence. An innovative approach to this issue was made by Pamruta, a developer on Hackster.io, and she uses a Raspberry Pi camera to take a snapshot image, recognizes items in the image, and reads the output aloud using the AWS Polly's text-to-speech [12]. The setup is seen in Figure 1.

Fig. 1: Hardware setup

Source: Adapted from [12]

The system's output is a speaker that plays a list of content when demanded by the user through voice recognition. However, it requires that the speaker is in close proximity to the Raspberry Pi, because of the Bluetooth connection, and it doesn't allow for remote access. All of these projects address some part of the problem, but with the best parts of them incorporated together and tailored to fit the Ghanaian context, significant progress can be made towards creating smart fridge adoption in the country. The current setup of Ghanaian markets will not allow for RFID scanning, which most of these solutions lean on to work. Most food items are bagged without any identification and making the user undergo the process of tagging every item before refrigerating it will be tedious and defeat the purpose of making the system convenient.

Chapter 3: Design

Due to the economical focus of this project, an analysis of consumer requirements needs to inform the final output. This chapter defines the objectives of the project, its scope, and definitions of its requirements. The reasons behind design choices are given, and a high-level structure is established.

3.1 Project Objectives

This project is for the purpose of implementing a module that can track the quantities of food items in the fridge, alert the user when stock is running low via a mobile application, determine when food is going bad, and be customizable for installation in any fridge, hence making it economical. In order to implement these features, there needs to be some form of sensing or data collection, and processing of the data for actions to be taken under certain circumstances.

3.2 Project Scope

The system will have three parts: hardware setup, control, and transmission. The hardware setup will include the circuit construction for data collection, control will handle the processing of the data and making decisions based on current information, and transmission will include sending alerts to the user using notifications from a mobile application.

3.3 Functional Requirements and Specifications

Functional requirements are product features or functions that engineers must implement to enable users to accomplish their tasks. They describe system behavior under specific conditions [13].

Table 2: Functional Requirements and Specifications

Requirement	**Specification**
Cost	Must cost less than GH₵ 300
Adaptation	Must be able to be installed in any fridge
User-friendliness	Must be convenient for the user to have installed
Power	Must have external power supply of 5V
Alerts	Must be able to send alerts to the user

Requirement	Specification
Data integrity	Data must be accurate
Responsiveness	System should be responsive to circumstances that data presents
Reliability	Consistency in alerts when necessary

3.4 Design Decisions

3.4.1 Hardware Setup

For the sensors that would be used to collect data, photodiodes would be used to establish the number of countable items like eggs or drinks. A photodiode converts light to electric current. How they would work is that if there's an item in place, it would block light from hitting the diode, and it will generate no electric current. Photodiodes were chosen over LDRs because they have a quicker response time and they have low costs [14]. They will be also more accurate considering the lamp lighting in the fridge.

Fig. 2: Photodiode

Source: Adapted from [15]

Photodiodes usually have a slower response time as their surface area increases, so the standard photodiode shown in Figure 2 will be used, as it has a smaller surface area than other types.

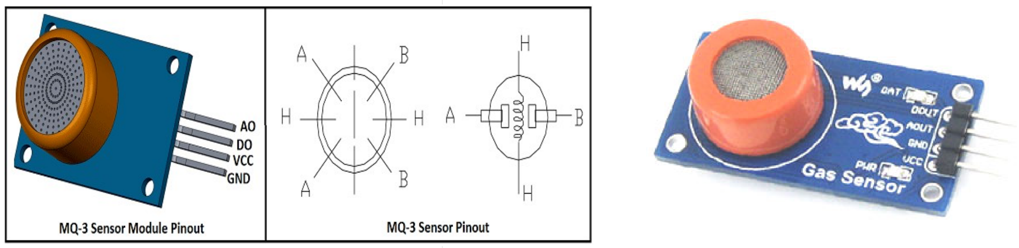


Fig. 3: MQ-3 Sensor and Pinout Information

Source: Adapted from [16]

MQ-3 sensors provide an analog resistive output based on alcohol concentration. When the alcohol gas exist, the sensor's conductivity gets higher along with the gas concentration rising [16]. MQ-3 gas sensors will be used to detect any food that's going bad, through the emission of ammonia and trimethylamine [17].

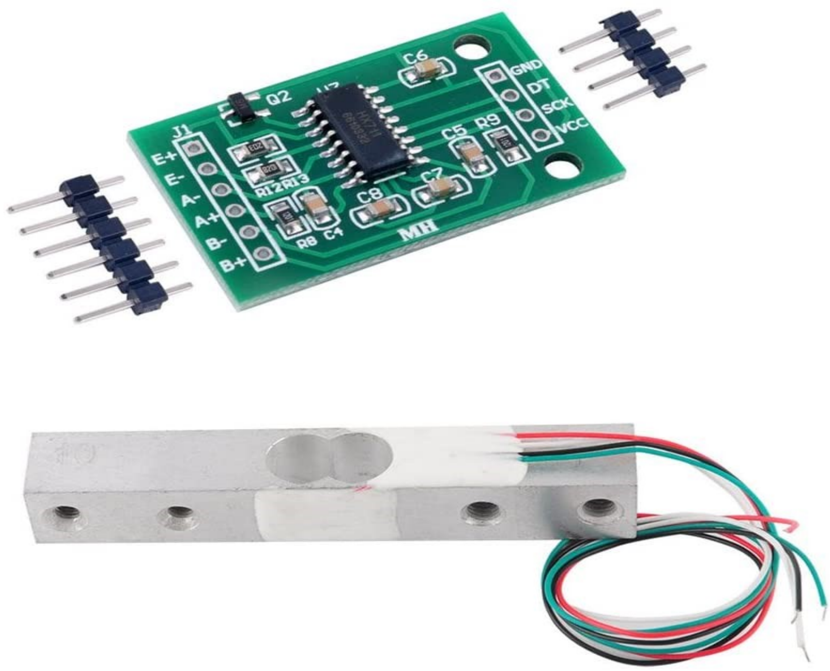


Fig. 4: Weight Sensor and Weighing Module

Source: Adapted from [18]

For items like vegetables and meat, SEN0160 weight sensors will be used more in the context of thresholding, as opposed to exact quantity determination. It was chosen because it is an accurate 24bit ADC which is designed for industrial control, and has features like quick response and high integration [19].

A Raspberry Pi camera will also be set up in the fridge for monitoring purposes. The live feed from the camera will be accessible via a link the user can access, so that there can be remote monitoring as well.

Fig. 5: Raspberry Pi Wide Camera Module

Source: Adapted from [20]

3.4.2 Control

Sensor data collection and processing will be done by NodeMCU. It is versatile and consumes low power. The Raspberry Pi camera will be controlled by a Raspberry Pi, which is a low-cost minicomputer and is versatile enough to hand live video feed, which would be viewed via VLC media player.

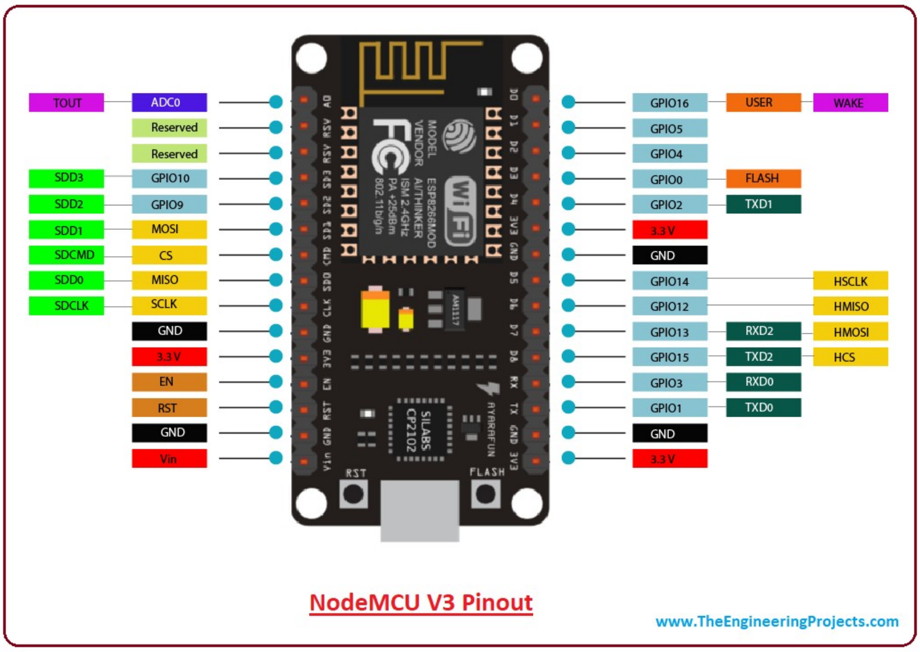


Fig. 6: NodeMCU ESP8266

Source: Adapted from [21]

Fig. 7: Raspberry Pi 4

Source: Adapted from [22]

3.4.3 Transmission

A web application will be created, which will receive data from the database and display it with a more user-friendly interface. This web application will be made visible in a mobile application for greater convenience to the user, and will send notifications when threshold values are exceeded.

3.5 System Architecture

This project consists of two parts. The first part comprises of the photodiodes, gas sensor, and weight sensors, whose data will be processed by the NodeMCU and update a MySQL database. The information from the database will be accessed through a web server in a mobile application. The second part comprises of the Raspberry Pi camera which will be streaming a live video feed to the user via the VLC media player application.

Below is a block diagram of the system:

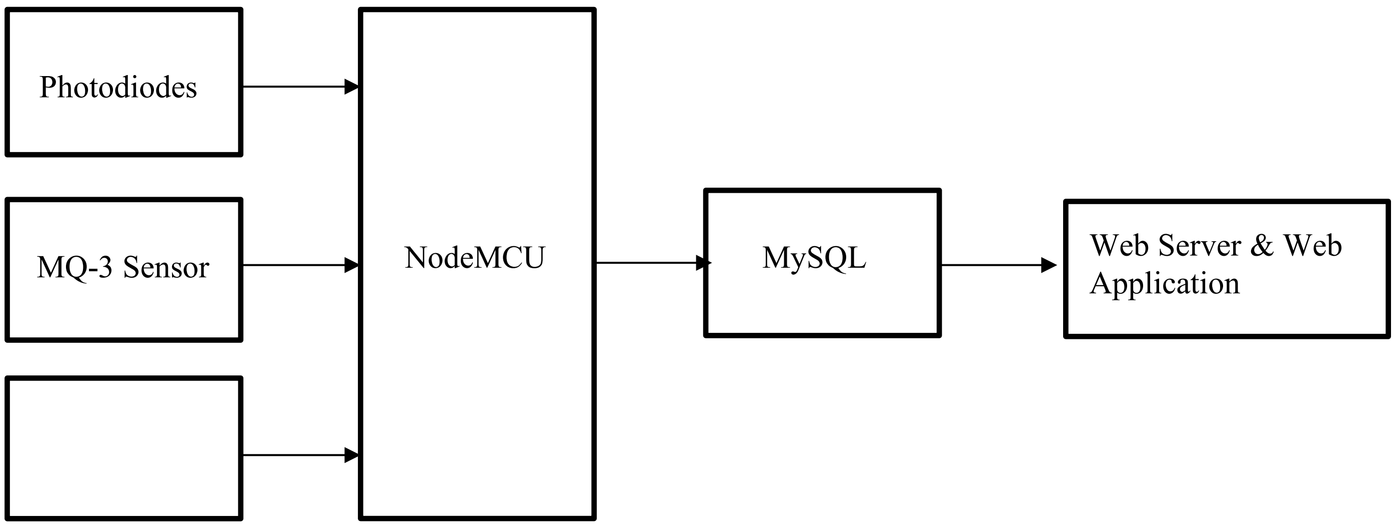


Fig. 8: Block Diagram of Part A of the system

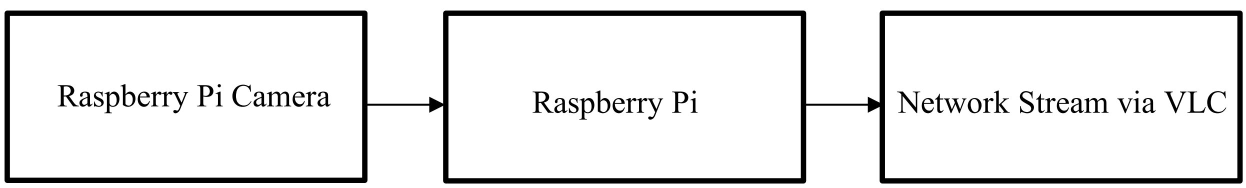


Fig. 9: Block Diagram of Part B of the system

3.5.1 Description of Block Diagram

Part A

Because of photodiodes' linear response to light illumination, when light falls on them, they will produce an amount of current, and this is translated as a high to the NodeMCU. When the MQ-3 sensor detects alcohol in the air around it, its conductivity increases with the gas concentration levels, and a corresponding voltage value is outputted to the NodeMCU [23]. The weight sensors will have a preset weight, and when it is falling below the predetermined threshold, its signal will be translated as a low to the NodeMCU. The NodeMCU converts the analog values coming in to digital signals, and processes the signals being received from the sensor to determine a 'count' variable for each section the different sensors are covering. The count variables for each sensor type will then update a MySQL database through a localhost IP. In order to create the website, the frameworks HyperText Markup Language (HTML), Cascading Style Sheets (CSS) and JavaScript will be used, and will have access to the database using an application programming interface (API).

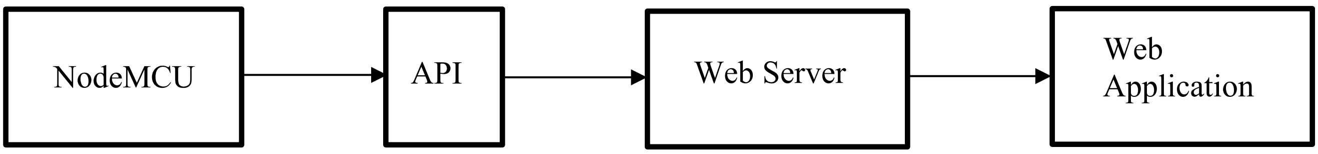


Fig. 10: Block diagram of the interface between NodeMCU and web application

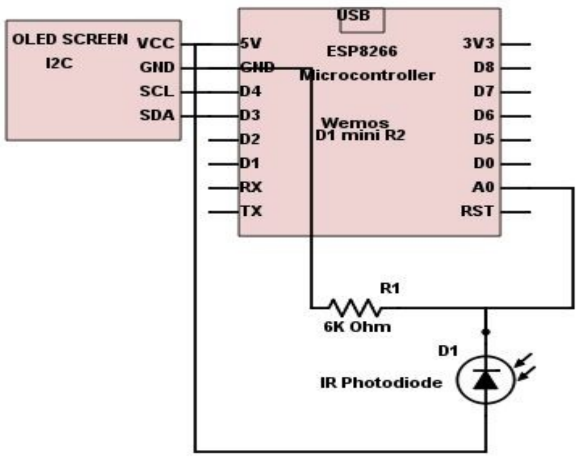


Fig. 11: Schematic of Photodiode connection with NodeMCU

Source: Adapted from [24]

The NodeMCU has just one ADC pin, so in order to expand the input so more analog sensors can be used, an analog extender like ADC1115 will be used.

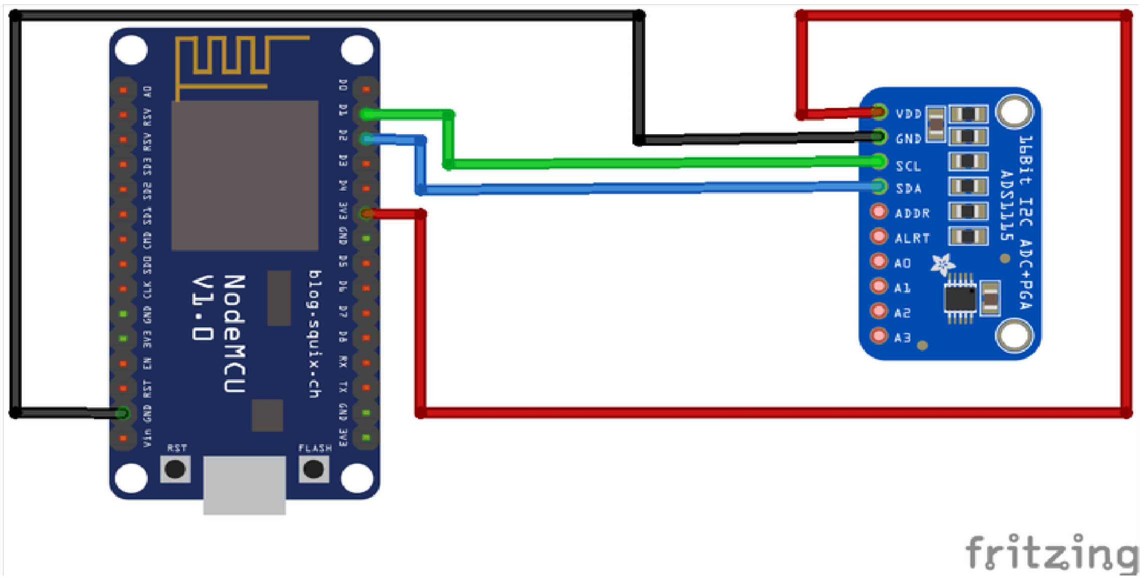


Fig. 12: Connection between NodeMCU and ADC1115

Source: Adapted from [25]

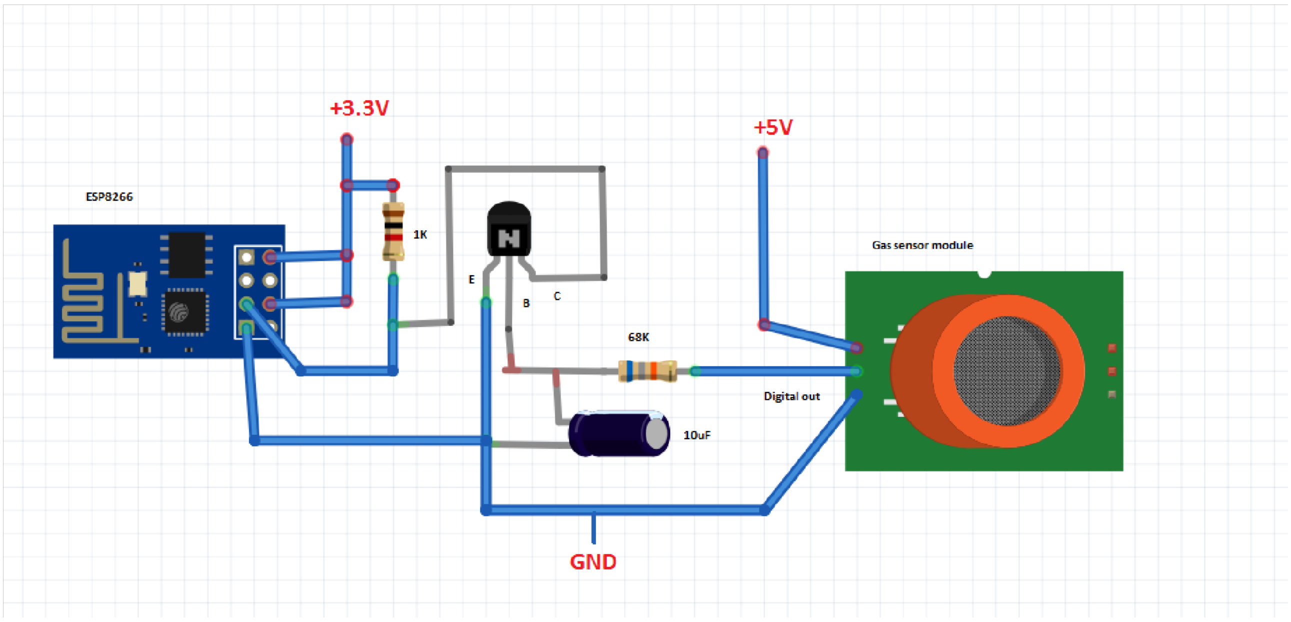


Fig. 13: Connection between NodeMCU and MQ-3 Gas Sensor

Source: Adapted from [26]

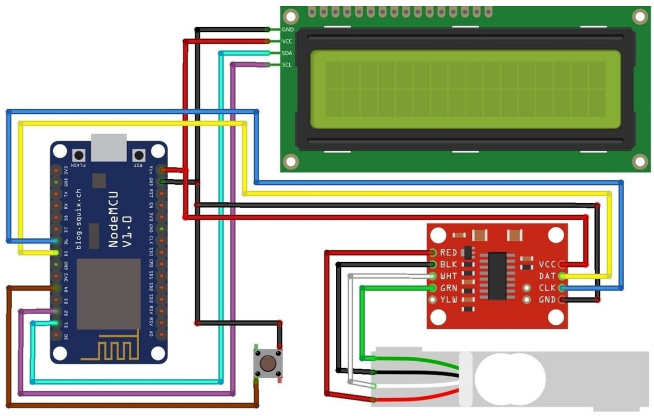


Fig. 14: Connection between NodeMCU and Weight Sensor

Source: Adapted from [27]

Part B

After modification and setup of the Raspberry Pi, the Raspberry Pi camera will be connected to it and configured. This configuration allows for a network stream to be setup using VLC Media Player on the Raspberry Pi. Then, with the download of the VLC Media Player on the user's phone, the user can access the video stream through the application by selecting an in-app feature called Network Stream, and entering the network URL of the Raspberry Pi. The video stream will then become visible to the user.

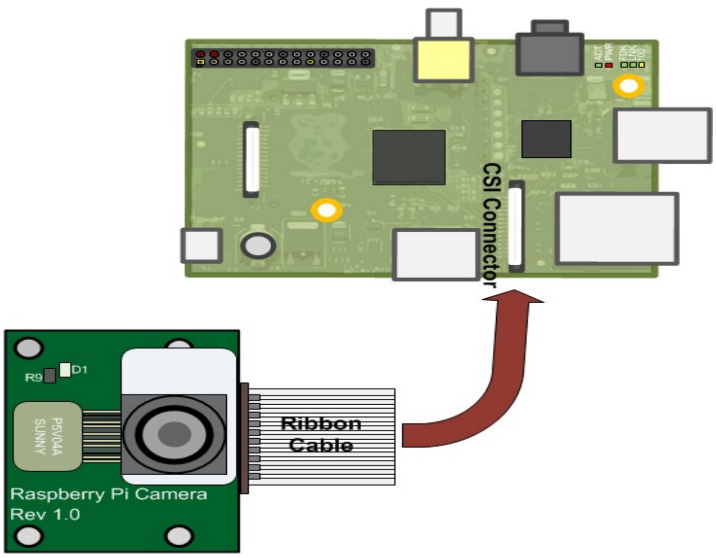


Fig. 15: Connection between Raspberry Pi and Raspberry Pi camera

Source: Adapted from [28]

Chapter 4: Implementation and Results

This project designs a smart monitoring system for households. The main part of the project is the software that runs the system, and the main sections of the software are the processing of the sensor data, the upload to a database, the website which collects information from the database, and the mobile application which displays the user information.

4.1 Obtaining Sensor Values and Processing

In order to effectively simulate, the weight sensors were replaced with push buttons, and the NodeMCU was replaced with an Arduino Uno board. For the purposes of this simulation, four items were used, which are eggs, drinks, fruit, and vegetables. The eggs and the drinks are represented by the photodiodes, and the fruits and the vegetables are represented by the pushbuttons.

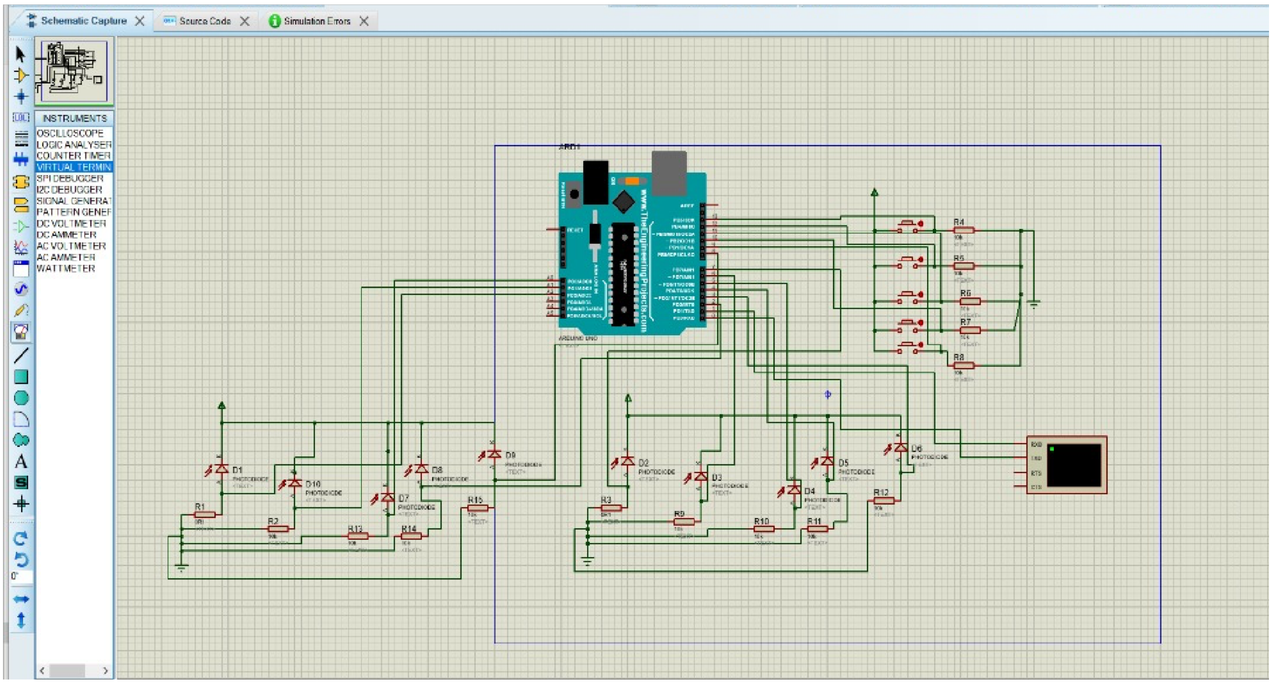


Fig. 16: Schematic of Connection of Sensors to Arduino

The code that processes the sensor reads the analog values coming in from the input pins, and defines them as either highs or lows. It was written in C/C++ using the Arduino IDE. A high is equated to a 1, and a low is equated to a 0. A count variable collates the 1s and 0s coming from each sensor, and based on that, determines how much of each item there is and stores it in each item's respective count variable.

```
if (buttonState3 == HIGH) {
  state3 =1;
} else {
  state3 =0;
}
if (buttonState4 == HIGH) {
   state4 =1;
} else {
   state4=0;  }

if (buttonState5 == HIGH) {
   state5=1;
} else {
   state5=0;
}
count = state1 + state2 + state3 + state4 + state5;
Serial.println(count);
delay(1000);
}
```

Fig. 17: Code snippet that collates count of each sensor

4.2 Uploading count variables to a database

The database was built using MySQL, which would receive data from the NodeMCU wirelessly, due its Wi-Fi module. The database gets the count value for eggs, drinks, fruits, and vegetables and is updated. The code that allows for the information to be uploaded to the database configures the NodeMCU to send the information to the database.

	#	Name	Type	Collation	Attributes	Null	Default	Comments	Extra	Action
	1	**eggs**	int(11)			No	*None*			Change Drop More
	2	**drinks**	int(11)			No	*None*			Change Drop More
	3	**fruits**	int(11)			No	*None*			Change Drop More
	4	**vegetables**	int(11)			No	*None*			Change Drop More

Fig. 18: Database in which sensor values are stored

```
Serial.print("[HTTP] GET...\n");
// start connection and send HTTP header
int httpCode = http.GET();

// httpCode will be negative on error
if (httpCode > 0) {
  // HTTP header has been send and Server response header has been handled
  Serial.printf("[HTTP] GET... code: %d\n", httpCode);
```

Fig. 19: Code snippet that configures NodeMCU to update the database

```php
$con = openConnection();

$stmt = $con->prepare("select eggs, drinks, fruits, vegetables from fridgetable
    order by time desc limit 1");
$stmt->setFetchMode(PDO::FETCH_ASSOC);
$stmt->execute();
$result = $stmt->fetchAll()[0];
$eggs = $result["eggs"];
$drinks = $result["drinks"];
$fruits = $result["fruits"];
$vegetables = $result["vegetables"];
```

Fig. 20: Code snippet of php file that uploads the data directly to the database

4.3 Accessing database values from the web application and mobile application

The purpose of the website is to have a user-friendly interface the user can interact with, and the mobile application makes it easier for the user to have the information at hand, and to get notifications. HTML and CSS were used to create the website, and the mobile application was built with Flutter. Flutter is a cross-platform framework that allows for the same user interface across all platforms [29].

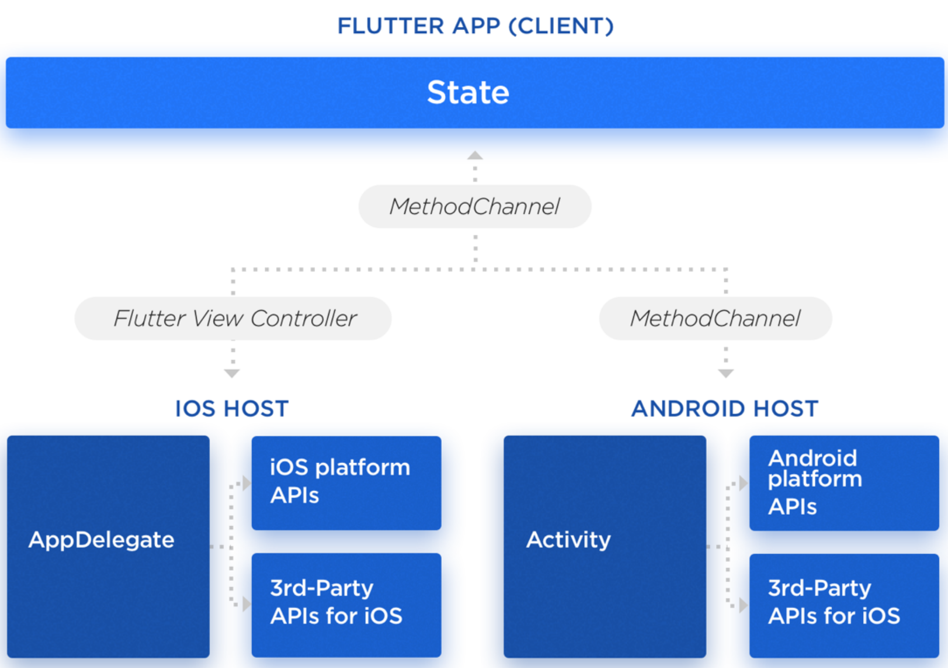


Fig. 21: Diagram of Flutter platform channels

Source: Adapted from [29]

The mobile application has two pages, which are the launch page, and the web application page.

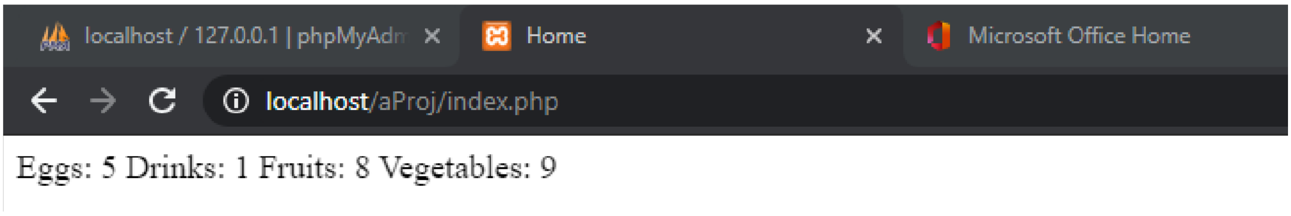


Fig. 22: Hosting of the database on web application

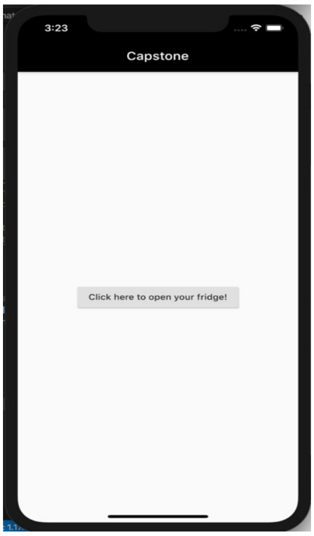


Fig. 23: Mobile application functioning in iOS

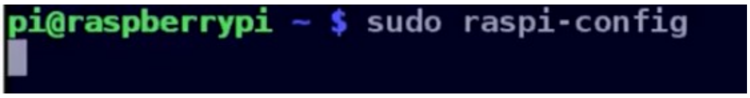
```
class _MonitorPageState extends State<MonitorPage> {
  @override
  Widget build(BuildContext context) {
return Scaffold(
  appBar: AppBar(
    title: Text('Capstone'),
    backgroundColor: Colors.black,

  ), // AppBar
    body: Center(
      child: RaisedButton(
        onPressed: _launchURL,
        child: Text('Click here to open your fridge!'),
      ), // RaisedButton
    ), // Center
  ); // Scaffold
}
```

Fig. 24: Code snippet of mobile application

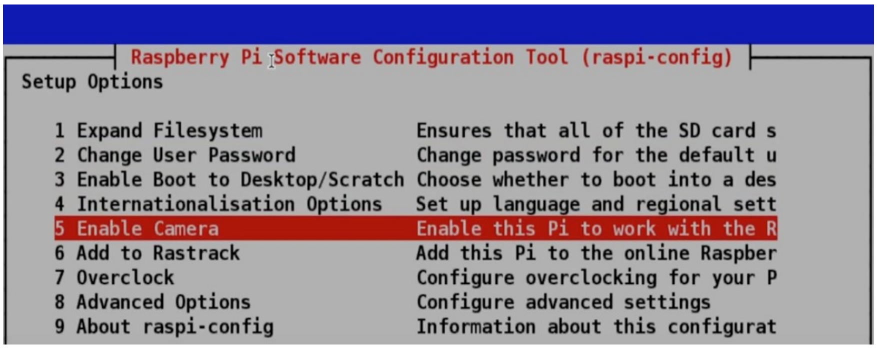
Upon clicking the launch button, the user is taken to the page which displays the current information on the fridge's status.

4.4 Raspberry Pi camera configuration

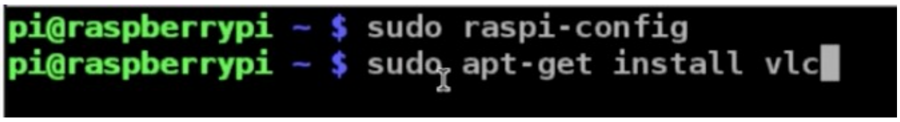
After setting up the connection between the Raspberry Pi camera and the Raspberry Pi, the following commands will be run in the terminal of the Raspberry Pi, using keyboard, mouse, and monitor peripherals.



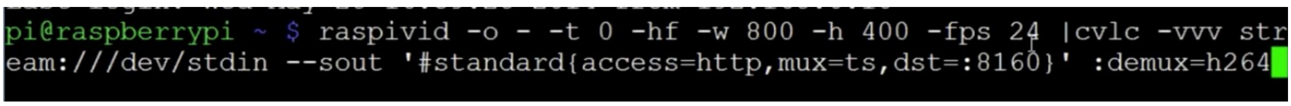
Running this command will bring up the following page:



After enabling the camera, the following command is run to install VLC on the Raspberry Pi:



After installing VLC, the following command is run to start the stream from the camera using HTTP:



The stream can then be accessed by opening VLC Media Player from the user's device, and going to the Network Stream feature and inputting the IP address of the Raspberry Pi.

4.5 An analysis of the system

The test system has a total of five photodiodes to represent eggs, five photodiodes to represent drinks, five pushbuttons to represent fruits, and five pushbuttons to represent vegetables. It also has the MQ-3 gas sensor to detect any odors that emanate from rotting food. The system also has a Raspberry Pi camera provides live video feed to the user through the VLC application. The different parts of the systems could not be simulated together, but the individual parts function as they should.

Chapter 5: Future Improvements and Limitations

5.1 Limitations

Due to the COVID19 pandemic, physical implementation had to be modified into simulations, and compromises had to be made in terms of the components that were being used to simulate. In Proteus, which was used to test and run code, the NodeMCU could not be programmed, so an Arduino had to be used. Also, the parts of the system could not be run as a whole. All the parts had to be tested separately of each other.

5.2 Future Improvements

This project could be expanded to incorporate the live video feed into the mobile application so that all the system parts can be accessible from one place, for more convenience to the user. The user interface could also be made more user-friendly. Also, in addressing the darkness that would evident in the refrigerator, an infrared camera could be used to combat that.

5.3 Conclusion

This project incorporated knowledge from the Internet of Things, Circuits and Electronics, and Foundations of Design and Entrepreneurship. I believe the system would be fully functional if built physically and implemented. The end goal was also achieved, in that a more cost-effective system was designed that meet the objectives of the project.

References

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