**MAKERERE UNIVERSITY**

# DESIGN OF MULTIPLE PACKAGE DELIVERY SYSTEM FOR UAV

**OJARA GODWIN**

**17/U/998**

A Project Report submitted to

Makerere University in partial fulfilment of the requirements for the award of

BSc in

Electrical Engineering

**Department of Electrical & Computer Engineering**

**College of Engineering, Design, Art and Technology**

**February, 2022**

## Declaration

I, **Ojara Godwin** hereby declare that I am the original author of this re-port. No portion of the work in this document has been submitted in support of an application for any other degree or qualification of this or any other university or institution of learning. Except where specifically acknowledged, it is our work.

It contains details of the activities that were undertaken in the completion of the project, "Design of multiple package delivery system for A UAV".

*I have abided by the Makerere University academic integrity policy on this report.*

Signed: ........................................................ Date: **13/02/2022**

## Approval

This report has been submitted with the approval of my supervisors.

**Main supervisor**: Dr. Nabuuma Hanifa

Lecturer, Department of Electrical and Computer Engineering,

Makerere University.

SIGNATURE: ……………………………………….... DATE: …08/02/2022……….

**Co-supervisor**: Ms. Tizikara Dativa

Lecturer, Department of Electrical and Computer Engineering,

SIGNATURE: …………………………………........... DATE: …10/02/2022……….

## Acknowledgements

I would like to gratefully acknowledge Dr. Jeremy Ntambi, our field supervisor, Dr. Nabuuma Hanifa (main supervisor) and Ms. Tizikara Dativa (co-supervisor) for their guidance and support in coming up with this project proposal idea. Much gratitude and credit are awarded to Dr. Jeremy Ntambi for his relentless and continued effort to enlighten us and introduce us to the sphere of innovations and inventions with regards to robotics and automations.

## Abstract

Unmanned Aerial Vehicles (UAVs), commonly referred to as drones, have recently seen an increased level of interest as their potential use in same-day home delivery has been promoted and advocated by large retailers and courier delivery companies. The challenge is the deployment of a large fleet of unmanned aerial vehicles (UAVs) or drones currently to perform deliveries of multiple packages within a given area of delivery, with each drone carrying a single package. Moreover, for deliveries within a small neighborhood, a single delivery drone makes multiple flights to and fro the distribution center e.g., a truck or van, warehouse, depot et al, each time carrying and delivering a single package. Such methods of deployment incur high costs of last-mile deliveries, longer time of deliveries and lead to an increase in the traffic density of a given airspace. These tradeoffs must be minimized to promote the feasibility of package/parcel deliveries by drones.

We introduce a novel way to exploit drones in same-day home delivery designs: multiple package deliveries. We explore a technique that can be used to support multiple package/parcel deliveries by a single multirotor (rotary wing) drone on a single flight from the distribution center/depot/warehouse to different delivery locations within a given area or radius.

We introduce the last-mile delivery problem in Section 1 and present the background of the project, the problem statement, its objectives, scope and significance/justification. In Section 2, we give a detailed literature review exploring the work that has already been done in relation to multiple package deliveries by drones, a detailed review of the best contributions to multiple package deliveries and a synthesis of new knowledge from them. Finally, in Chapter 3, we present the project plan comprising the requirements specification (containing detailed description of the proposed design), technical specification (containing flowcharts for the control sequences and a schematic block diagram for the proposed design) and results/outcomes of the project.

## Table of Contents

## List of Abbreviations and Acronyms

| | |
|---|---|
| CAGR | Compound Annual Growth Rate |
| D2C | Direct-to-Consumer |
| DC | Direct Current |
| e.g. | for example |
| FSTSP | Flying Sidekick Traveling Salesman Problem |
| GDP | Gross Domestic Product |
| i.e. | that is |
| PC | Personal Computer |
| TSP | Traveling Salesman Problem |
| TSP-D | Traveling Salesman Problem with Drone |
| UAVs | Unmanned Aerial Vehicles |
| UK | United Kingdom |
| UPS | United States Post Service |
| US | United States |
| VRPD | Vehicle Routing Problem with Drones |
| VRPs | Vehicle Routing Problems |

## List of symbols and S.I. units

| | |
|---|---|
| $ | United States Dollars |
| kg | kilogram |
| km | kilometer |

# 1 Introduction

The markets for both durable and perishable goods have shifted in focus over the past decade to direct-to-consumer (D2C) deliveries (Iman Dayarian, 2018). This shift has been driven by the rapid and significant growth in e-commerce, specifically online shopping followed by home delivery which has grown by between 7 and 10 percent in mature markets, e.g., the US and Germany, and close to 300 percent in developing markets, e.g., India (M. Joerss, 2016), (Iman Dayarian, 2018). Market share in the e-commerce space is primarily a function of the following per-purchase considerations of online shoppers, i.e., speed, flexibility, security and the cost of delivery (Iman Dayarian, 2018). That said, even though a growing number of online shoppers are placing greater importance on the speed of delivery, they are also highly price sensitive and often unwilling to pay more for faster delivery (Iman Dayarian, 2018). Thus, retailers will have to absorb most of the cost of more speedy delivery services, and in a highly competitive market where many retailers are struggling to stay ahead of the competition, all retailers are looking for innovative and cost-effective ways to provide faster D2C deliveries (Iman Dayarian, 2018).

To date, much of the activity with respect to rapid delivery has been in relation to urban and suburban environments. This focus on the urban environment is no surprise given demographic trends which indicate that, by 2050, 70% of the world's population, approximately 6.3 billion people, will live in major cities, with "megacities" being at the forefront of the trend (megacities refers to cities with a population exceeding 10 million inhabitants) (Bretzke, 2013). The high population densities in urban environments, in particular megacities, results in higher and geographically concentrated demand, which in turn results in greater economies of scale, especially within the context of the traditional terrestrial delivery network (Iman Dayarian, 2018).

## 1.1 Project Background

There are significant challenges to a purely terrestrial rapid delivery network in urban environments. Specifically, traffic congestion is frequently reported to be the most pressing infrastructure problem in cities, with freight traffic being simultaneously one of the causes of the infrastructure overload and one of its victims (Iman Dayarian, 2018). Moreover, a common reaction from the city administrations has been imposing restrictive access regulations to city centers for larger vehicles, either permanently or during certain time periods. These challenges drive retailers and carriers to seek new technologies and new concepts to provide cost-effective, flexible, and fast D2C delivery services. Examples of new concepts being pursued are crowd-shipping (M. Savelsbergh, 2017), trunk delivery (G. Gozbayin, 2017), side-walk robots (Wong, 2017), and drone delivery. The use of drones, especially, has obvious advantages in home delivery systems because they do not require a driver and, thus may result in cost savings, and they do not get stuck in traffic and, thus may result in time savings (Iman Dayarian, 2018).

Large retailers such as Amazon and Alibaba as well as courier delivery companies such as UPS and DHL are already considering home deliveries partially or fully performed by drones (Iman Dayarian, 2018). In fact, several drone-based package delivery companies, such as Matternet, and Amazon Prime Air, Flirtey and Flytrex have concentrated their efforts in designing a drone to carry a payload of 2.27kg for a distance of 10km. For Amazon, parcels below this weight limit make up 86 percent of their total number of deliveries (Malik Doole, 2018).

In the last few years, several papers on models and algorithms to support this operational use of drones have appeared. Two designs have been investigated: The first design involves drones delivering a single package on an out-and-back trip from a fulfillment center and supplementing the delivery capacity provided by a regular fleet of delivery vehicles. And the second design involves a drone delivering a single package on an out-and-back trip launched from a delivery vehicle, where the delivery vehicle carries one or more drones, also supplementing the delivery capacity provided by a regular fleet of vehicles, but, of course, also reducing that capacity since drones have to be carried (Iman Dayarian, 2018). The prevailing assumption in existing concepts of operation for drone-based delivery is that each package will be delivered via a single drone, and that package recipients will be adjacent to a location where the drone can land or in a location where the package can be lowered to them via a rope or similar mechanism.

## 1.2 Problem Statement

To meet the goal of faster deliveries, the vast majority of the concepts of operation for drone-based delivery require deployment of a large fleet of drones to make multiple same day deliveries in a given service zone. This concept of operation is inefficient in minimizing the cost of last-mile drone-based delivery.

*Figure 1-1: Multiple package delivery using single package delivery drones causing congestion*

Some of the concepts of operation require the reuse of a single-package delivery drone making multiple out-and-back trips from the fulfillment center or delivery vehicle to the different delivery locations within the service zone. In the long run, this concept of operation is inefficient in minimizing the time of delivery of packages.

The overarching technical challenge therefore; is to develop a concept of operation where the drones' compartments are sufficiently enhanced to autonomously deliver multiple packages at different locations in the same day on a single out-and-back trip launched from a fulfillment center or a delivery vehicle.

## 1.3 Project Scope

This project will focus on design and implementation of the multiple payload delivery system for the drone. The system will consist of a storage compartment with multiple chambers for the different packages of combined total weight 300g and each chamber automated to open only when the drone has reached a delivery point and its only that package to be delivered at that location.

## 1.4 Objectives of the Project

The aims/objectives of this proposed design project are briefly discussed below as the general objective and more insight is given in the specific objectives.

### 1.4.1 General Objective

- To design and implement an automated delivery mechanism for multiple packages for a delivery UAV

### 1.4.2 Specific Objectives

- To establish communication between the microcontroller and user using a WiFi access point
- To implement an actuation mechanism for dispensing the package using a servomotor and helical spring.
- To design and build the storage compartments for carrying three packages of maximum weight 300g.
- To test the performance of the system ensuring package delivery of maximum weight 300g

## 1.5 Justification/Significance of the Project

Approximately 2-5 percent of a country's GDP is lost to traffic congestion every year (Asian Development Bank, 2018). Between the US, UK and Germany alone, the cost of traffic congestion was estimated at $461 billion in 2017 (PWC, 2018) (Economist, 2018). This problem is caused by the perennial population growth in urban cities, which is currently growing at 1.5 million inhabitants per week (PWC, 2018). The envisioned drone-based delivery system could potentially reduce road congestions in cities, and subsequently reduce the associated greenhouse gas emissions.

A recent study estimated that the last-mile delivery expends the global parcel delivery industry nearly $85 billion per year (McKinsey & Company, 2016). This is why E-commerce giants such as Amazon and Uber, but also start-up companies such as Matternet and Flytrex are investigating drone deliveries as a solution to this problem (Malik Doole, 2018). The proposed system offers advantages over other drone-based delivery systems in that it supports faster last-mile deliveries at lower costs. Choi and Schonfeld (Y. Choi, 2017) show that the operating cost, related to battery charging and handling proportionally reduces as the number of flights decreases. They also show that the costs for system operation, which directly relate to the number of drones and their trips made in a day, reduce with multiple package delivery.

# 2 Literature Review

UAVs are a compelling alternative to other modes of transport, especially in time-sensitive environments, because they are less sensitive to ground conditions and congestion (S. J. Kim, 2017). This realization has accelerated the maturation of the technology and has expanded the set of domains in which the use of UAVs is contemplated, e.g., medicine and vaccine delivery (Markoff, 2016), (C. A. Thiels, 2015), organ transport (Francisco, 2016), defense, search and rescue, aerial imaging, environmental surveillance (S. C. Avellar, 2015), and agriculture (A. Barrientos, 2011).

Our research focuses on the use of UAVs in home delivery systems, and consequently, our literature review focuses on last-mile delivery. In the last-mile delivery literature, drones are being employed in different ways, either independently or in conjunction with delivery vehicles, and are launched from and recovered from different locations, either a central facility, a mobile facility, or even a (specially designed and equipped) delivery vehicle.

## 2.1 Related Work

Murray and Chu (Murray C, 2015) introduced the flying sidekick traveling salesman problem (FSTSP), in which a set of customers must be served exactly once by either a delivery vehicle or a drone operating in conjunction with the delivery vehicle. The delivery vehicle and the drone must depart from and return to a single depot exactly once. Over the course of a delivery cycle, the drone may make multiple out-and-back trips, each time making a single delivery, starting and ending at either the depot or the delivery vehicle when it is parked at a customer location. While the trip of the delivery vehicle has multiple stops at customer locations (where deliveries are made), a trip of the drone has a single stop at a customer location (making a single delivery) (Murray C, 2015). The objective of the FSTSP is to minimize the time required to serve all customers, i.e., the difference between the time of departure and time of return of the delivery vehicle and the drone from the depot, and accounts for vehicle travel time, launch and recover time of the drone, and any waiting time of the delivery vehicle for the return of the drone.

Ponza (Ponza, 2016) proposes an improved mathematical formulation for the FSTSP and develops a simulated annealing solution approach. Agatz et al. (N. Agatz, 2016) also consider a last-mile delivery design involving a combination of a delivery vehicle and a drone, which they refer to as the traveling salesman problem with drone (TSP-D). They present solutions obtained by a route first-cluster second heuristic and show that the vehicle-drone delivery system can be more effective than the vehicle-only delivery system. Ha et al (Q. M. Ha, 2015) consider a TSP-D in which once the drone is launched from either the depot or the vehicle, it either returns to the vehicle at the vehicle's next stop or it returns to the depot. The main difference with the version considered by Agatz et al. (N. Agatz, 2016) is that the drone is not launched and recovered at the same stop. Ha et al. (Q. M. Ha, 2016) consider a TSP-D in which the objective is to minimize the total transport cost, comprising of vehicle and drone costs. They present heuristic solution methods based on GRASP and modifying an optimal TSP tour. Ferrandez et al (S. M. Ferrandez, 2016) introduced a vehicle-drone in tandem delivery system and analyze the system in terms of time and energy. In their model, all demands are known in advance and the drone is launched from the vehicle, which follows a TSP tour, i.e., the vehicle acts as a moving hub. Each drone can carry at most one package and therefore must traverse a star distance of ingress and egress from vehicle to delivery location and back to vehicle. The solution approach uses K-means clustering to find the vehicle stops, and a genetic algorithm for finding the vehicle route. Their analysis indicates that the energy efficiencies achieved when employing a drone are significant, but that time improvements only occur when the speed of the drone is at least twice the speed of the vehicle (Iman Dayarian, 2018).

Wang et al. (X. Wang, 2017) address a design similar to the FSTSP, which they refer to as the vehicle routing problem with drones (VRPD). Specifically, they incorporate multiple vehicles, assume that each vehicle can launch two drones, that drones can only fly along the same routes as the vehicles, and at the return of a drone to a vehicle, both the drone and the vehicle can wait for each other.

Mathew et al. (Mathew N, 2015) set two scenarios for drone delivery. A distribution depot dispatched drones supported by a truck from a single depot (heterogeneous delivery problem), and the delivery service was solely operated by drones departing from multiple depots (multiple warehouse delivery problem). Each case was analyzed using the Traveling Salesman Problem (TSP) algorithm. In particular, the first result suggested that the delivery supported by trucks reduced delivery time by percent compared to a truck-only system.

Campbell et al. (J. Campbell, 2017) examine drone deliveries, using small payload capacity drones (e.g., 2.27kg), from fixed depots in conjunction with hybrid vehicle-drone routes and vehicle-only delivery. In contrast to the discrete TSP-based optimization models, they develop strategic models for the design of vehicle-drone delivery systems using continuous spatial density over a service region.

Dorling et al. (K. Dorling, 2017) focus on developing vehicle routing problems (VRPs) specifically for drone delivery scenarios, considering the effect of battery and payload weight on energy consumption. They propose two multi-trip VRPs for drone delivery, one minimizing cost subject to a delivery time limit, and one minimizing the delivery time subject to a budget constraint. An energy consumption model for multi-rotor drones is derived and experimentally validated demonstrating that energy consumption varies approximately linearly with payload and battery weight.

Dayarian et al (Iman Dayarian, 2018) considered a drone-assisted delivery design in which drones resupply delivery vehicles. This design can be viewed as a two-echelon VRP, in which the location of the intermediate facilities (satellites) is not fixed. The delivery vehicle performs the actual delivery of orders at online buyers' home locations, while the drone resupplies the delivery vehicle from the fulfillment center with recently placed orders. They consider two strategies, which differ in the options considered for the location and time of drone resupply. The first option is restricted resupply; where a drone resupply can only take place after all orders on-board a delivery vehicle have been delivered. The second option is flexible resupply; where a drone resupply can take place at any time, even before all orders on-board a delivery vehicle have been delivered. After a delivery vehicle is resupplied, its delivery route will be optimized.

Choi and Schonfeld (Y. Choi, 2017) in their paper analyze fully autonomous drones delivering multiple packages while considering battery capacity. The paper seeks to optimize delivery of multiple packages within the predefined shipment weight over a radius of a service area, considering battery energy storage: the primary source of drone flight. For analytic purposes, characteristics of drones and the baseline for service area are preset. All demands are served from a single distribution depot. They assumed that only one item is delivered per destination. After delivery is completed, the vehicle must return to the depot and go through a series of processes such as battery recharge or replacement, inspection, and parcel replenishment for the next trip. They found out that; the number of packages varies inversely with drone speed and the flight distance varies inversely with the number of packages. They also concluded that it is safe to operate a delivery vehicle until its battery only retains 20% of the full charge. This is generally known as the 80% flight rule, which is commonly used with lithium-ion polymer batteries for the safety, maintenance and protection of drones.

To the best of our knowledge, no previous work has considered a drone-based delivery system in which a drone employs an automated multiple-package storage compartment to facilitate the autonomous delivery of multiple packages on a single out-and-back trip from fulfillment center and delivery locations within a given service zone in the same day. Our intent is to demonstrate that such a design offers many practical advantages over the designs studied in the literature so far.

# 3 Project Methodology

We present the detailed description of the design and its operation under the specific requirements and the sequences of control by the software and hardware are clearly explained with the aid of flow charts under the technical requirements of this section. A schematic block diagram for the hardware design presented in this section.

## 3.1 Requirements Specification and concept of Operation

Each chamber of the carrier will be assigned an identifier such as a serial number or some kind of code and the microcontroller will be configured to store these identifiers. When a client places an order of a specific package, this package will be placed in a specific chamber. Control of the opening and closing of the chambers at the distribution center during loading can be done using a local webpage created using a microcontroller on a smartphone, tablet or PC.

Upon receiving confirmation that the drone has attained stable hovering (or aerial anchoring) at the delivery location; the UAV operator using the webpage can instruct the DC servomotor to start and rotate a helical spring (attached to the chamber's tray) in the right direction such that it gently dispenses or pushes the package from the chamber to the ground. Upon dispensing the package and emptying the chamber, the Node MCU microcontroller should instruct the dc servomotor to stop.

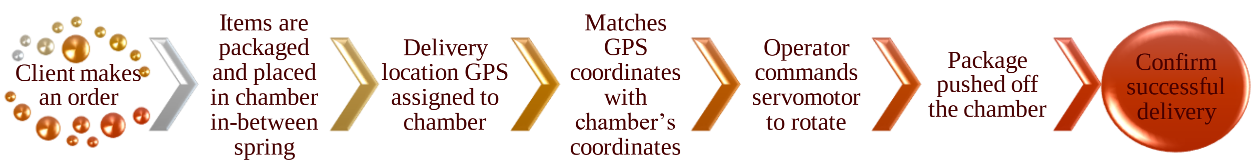


*Figure 3-2 Showing summary of concept of operation*

This process should be repetitive for each chamber when the drone attains stable hovering at the exact delivery location of the package. The chambers should only automatically open while making deliveries of packages at their exact locations. All empty chambers and chambers whose identifiers do not match the delivery location should be put to sleep during delivery.

## 3.2 Functional and performance analysis

### 3.2.1 Functional breakdown structure

Functional analysis was done to break down the different functions that were to be performed by the system in order to get the particular devices that could perform that function and also identify which devices would be shared by the different parts of the system to reduce cost as indicated in the figure below

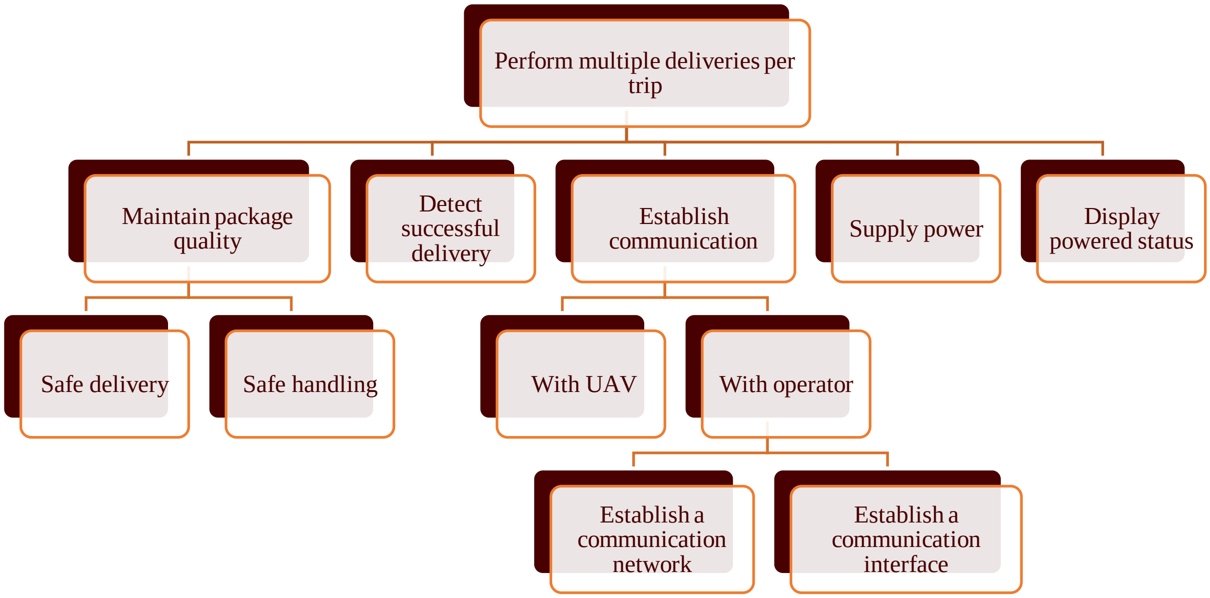


*Figure 3-3: Showing the breakdown of the functions adopted from ISO 15288*

### 3.2.2 Product Function matrix

After the functional analysis, the particular devices for performing the different functions were identified and matched to each other as shown in the product function matrix below

| | FUNCTION \ DEVICE | Microcontroller | Servo motors | LEDs | Helical spring | Plastic boards | Webpage | IR Proximity Sensor | Battery |
|---|---|---|---|---|---|---|---|---|---|
| 1.1 | Safe delivery | | ● | | | ● | | | |
| 1.2 | Safe handling | | ● | | ● | ● | | | |
| 2 | Detect successful delivery | | | | | | | ● | |
| 3.1 | Establish communication with UAV | ● | | | | | | | |
| 3.2 | Establish communication network | ● | | | | | | | |
| 3.3 | Establish user communication interface | ● | | | | | ● | | |
| 4 | Display powered status | | | ● | | | | | |
| 5 | To supply power | | | | | | | | ● |

*Figure 3-4:Showing Product Function Matrix adopted from ISO 15288*

### 3.2.3 Schematic System Block Diagram

A schematic block diagram of the design is shown in **Error! Reference source not found.** below.

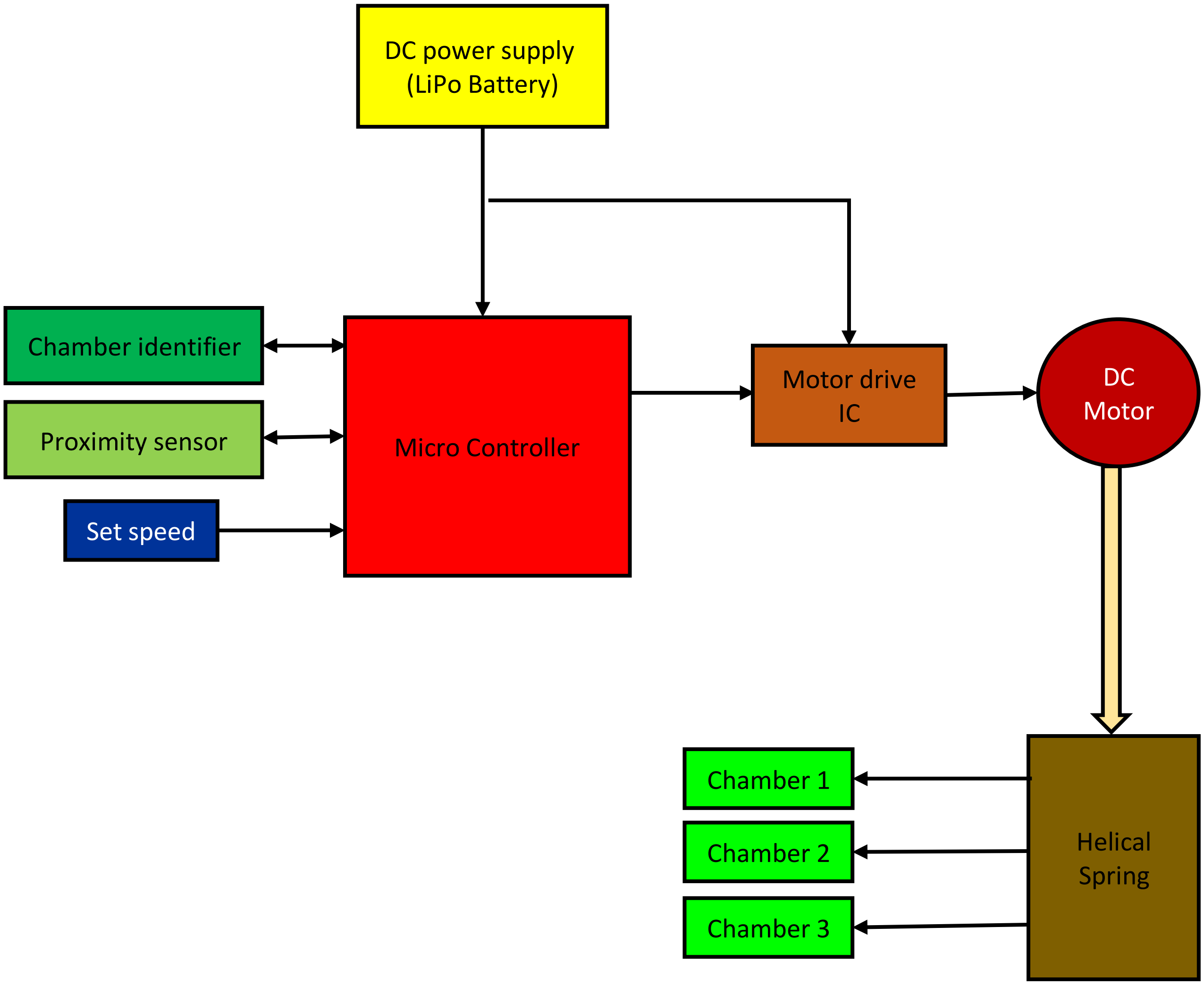


*Figure 3-5: Showing Schematic block diagram for the proposed design*

## 3.3 Technical Specifications

The flowchart of the proposed design process is illustrated in **Error! Reference source not found.** below.

### 3.3.1 Control sequence of the delivery process

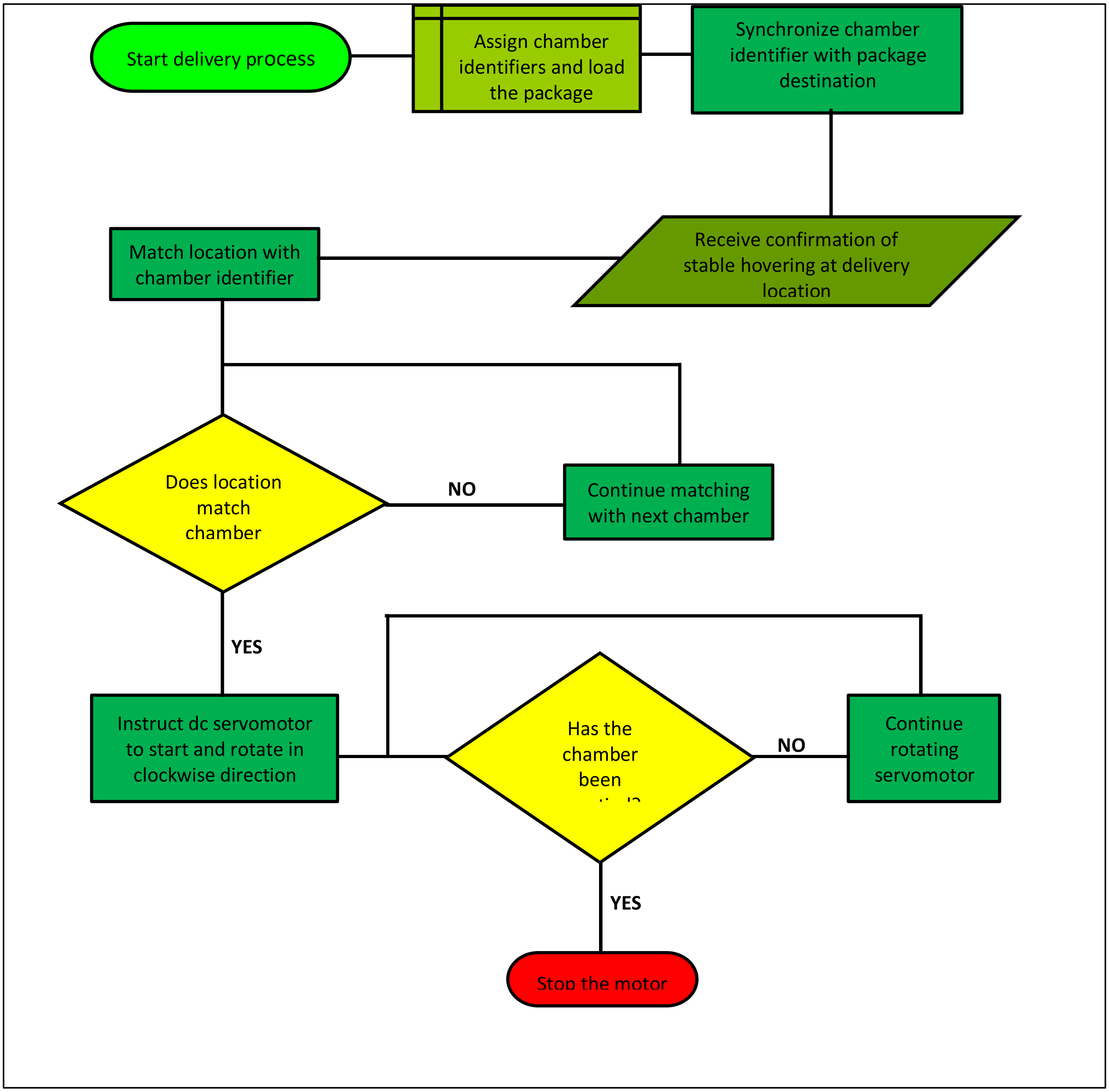


*Figure 3-6: Flowchart showing control sequence for initiating delivery process*

## 3.4 Device Selection

There are a variety of devices that perform the functions we mention in the functional analysis, therefore choice needed to be made depending on the ease of use, cost and performance of the devices and software.

### 3.4.1 Microcontroller

The micro controller chosen for this project amidst other microcontrollers such as Arduino is Node MCU. The **NodeMCU ESP8266 development board** comes with the ESP-12E module containing the ESP8266 chip having Tensilica Xtensa 32-bit LX106 RISC microprocessor. This microprocessor supports RTOS and operates at 80MHz to 160 MHz adjustable clock frequency. NodeMCU has 128 KB RAM and 4MB of Flash memory to store data and programs. Its high processing power with in-built Wi-Fi / Bluetooth and Deep Sleep Operating features make it ideal for IoT projects.

NodeMCU can be powered using a Micro USB jack and VIN pin (External Supply Pin). It supports UART, SPI, and I2C interface (Anon., 2021). It's because of these cheap and extra ordinary features that we chose it over other development boards like Arduino.

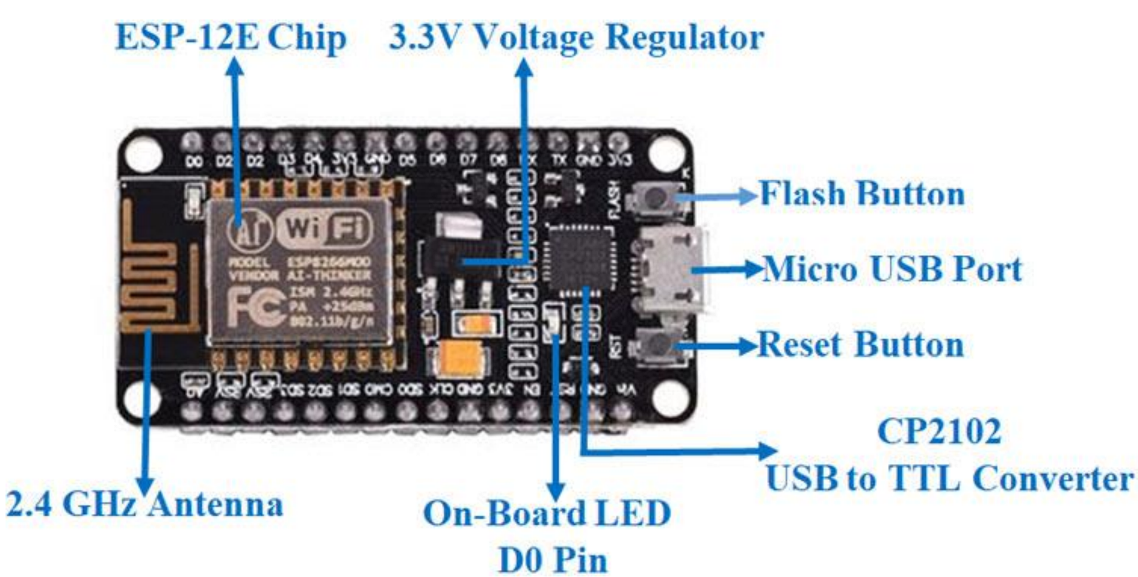


*Figure 3-7: Showing Node MCU and its peripherals.*

The general features of this board are as follows:

- Easy to use
- Programmability with Arduino IDE or IUA languages
- Available as an access point or station
- practicable in Event-driven API applications
- Having an internal antenna
- Containing 13 GPIO pins, 10 PWM channels, I2C, SPI, ADC, UART, and 1-Wire

#### 3.4.1.1 Programming NodeMCU ESP8266 with Arduino IDE

The NodeMCU Development Board can be easily programmed with Arduino IDE since it is easy to use.

Programming NodeMCU with the Arduino IDE will hardly take 5-10 minutes. All we needed was the Arduino IDE, a USB cable and the NodeMCU board itself.

#### 3.4.1.2 Uploading first program.

Once Arduino IDE is installed on the computer, we connected the board with the computer using the USB cable. We opened the Arduino IDE and chose the correct board by selecting **Tools>Boards>NodeMCU1.0** (ESP-12E Module), and choose the correct Port by selecting **Tools>Port**. To get it started with the NodeMCU board and we wrote the code. Once the code is loaded into our IDE, we clicked on the 'upload' button given on the top bar. Once the upload is finished, the board was ready for deployment.

In this project we programmed the node MCU development board to create a local webpage that would be used to control the hardware parts of the device.

### 3.4.2 Servomotor

The servo motor is a closed-loop mechanism that incorporates positional feedback in order to control the rotational or linear speed and position. The motor is controlled with an electric signal, either analog or digital, which determines the amount of movement which represents the final command position for the shaft.

*Figure 3-8: Showing Continuous rotation Servo Motors*

In this project, the servomotor we used for this was the 13kg.cm 360 Degree Continuous Rotation Servo (FS5113R). This motor has the following specifications;

- Model No.: FS5113R
- Dimensions: 40.8 × 20.1 × 38 mm
- Weight: 56 g
- Operating Speed: 0.18 sec/60degree (4.8V) | 0.16 sec/60degree (6V)
- Stall Torque: 12.5 kg.cm (4.8V) | 14kg.cm (6V)
- Operating Voltage: 4.8V~6V
- Operating Angle: 360degree

The low power requirement, light weight and high stall torque is ideal for our system requirements.

### 3.4.3 Proximity sensor

This IR Proximity Sensor is a multipurpose infrared sensor which can be used for obstacle sensing, color detection, fire detection, line sensing, etc and also as an encoder sensor. The sensor provides a digital output.

The sensor outputs a logic one(+5V) at the digital output when an object is placed in front of the sensor and a logic zero(0V), when there is no object in front of the sensor. An onboard LED is used to indicate the presence of an object. This digital output can be directly connected to an Arduino, Raspberry Pi, AVR, PIC, 8051 or any other microcontroller to read the sensor output.

*Figure 3-9: Showing IR sensor*

IR sensors are highly susceptible to ambient light and the IR sensor on this sensor is suitably covered to reduce effect of ambient light on the sensor. The sensor has a maximum range of around 40-50 cm indoors and around 15-20 cm outdoors.

For this case we used it for detecting object fall from each of these chambers. We chose the Venel infrared proximity sensor which can be used as robot path tracking, obstacle-avoiding car and pipeline counter. This IR proximity sensor has the following specifications;

- Power: 3.3V to 5V
- Dimension: 39mm x 15.5mm (include the IR LED)
- Detection range: 2cm to 30cm (depending on the obstacle's color, farthest for white)
- Detection angle: 35 degree
- Recommended environment: in door, to avoid the sunshine effect

### 3.4.4 Software

The programming language used was the Arduino programming language that is based on C/C++ and program to control the hardware was written in Arduino Integrated Development Environment

#### 3.4.4.1 Arduino programming Language and Arduino IDE

Arduino programs are written in the Arduino Integrated Development Environment (IDE). Arduino IDE is a special software running on your system that allows you to write sketches (synonym for program in Arduino language) for different Arduino boards. The Arduino programming language is based on a very simple hardware programming language called processing, which is similar to the C language. After the sketch is written in the Arduino IDE, it should be uploaded on the Arduino board for execution. (Badami, n.d.)

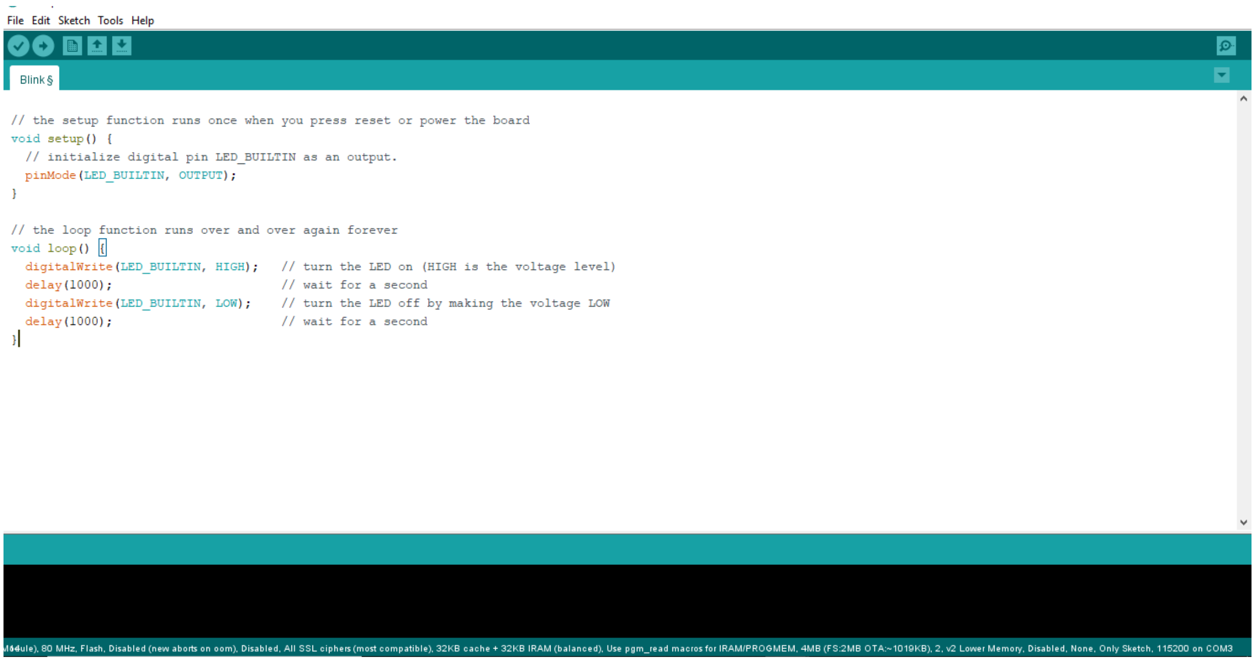

*Figure 3-10: Showing Arduino IDE with Arduino code*

The first step in programming the Arduino board is downloading and installing the Arduino IDE. The open source Arduino IDE runs on Windows, Mac OS X, and Linux. Download the Arduino software (depending on your OS) from the official website and follow the instructions to install. The structure of Arduino program is pretty simple. Arduino programs have a minimum of 2 blocks,

**Preparation & Execution**

Each block has a set of statements enclosed in curly braces:

void setup( )

{

statements-1; …….. statement-n;

}

void loop ( )

{

statement-1;….. statement-n;

}

Here, setup ( ) is the preparation block and loop ( ) is an execution block.

The setup function is the first to execute when the program is executed, and this function is called only once. The setup function is used to initialize the pin modes and start serial communication. This function has to be included even if there are no statements to execute.

Arduino IDE also has library support for programming other Microcontrollers such as Node MCU as used in this project. This will need a few setups before the code is written and deployed to the microcontroller. These settings include importing the specific microcontroller libraries.

## 3.5 Circuit Design

The **Error! Reference source not found.** below illustrates the breadboard connection of the components that comprise the system. We used three continuous rotation servos for the three storage/delivery chambers.

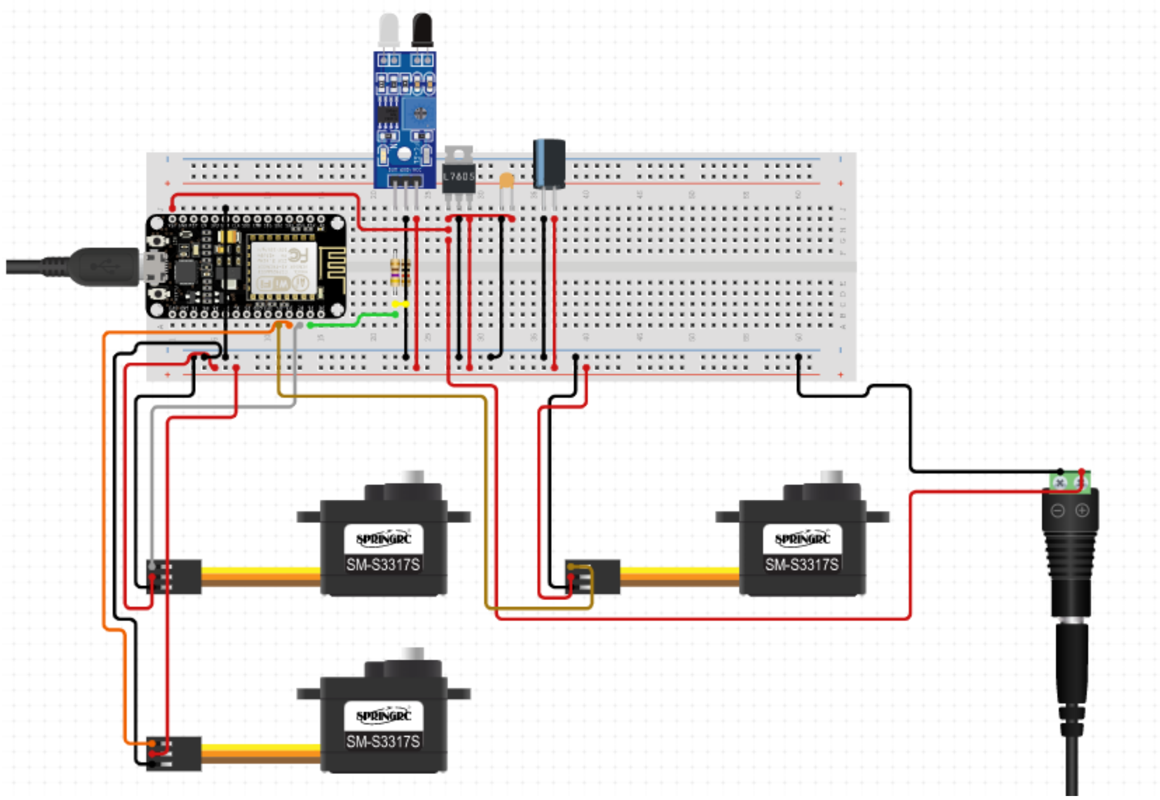


*Figure 3-11: Showing Breadboard Circuit design*

## 3.6 Architectural overview of the box

### 3.6.1 Box design

The architectural design of the delivery box enabled us to develop a plastic box that was mechanically strong enough to hold our package of 300g together with the system components.

The **Error! Reference source not found.** below shows the different faces of the box. We used the ANSYS software to design the box and we assigned to it polyethylene as the construction material.

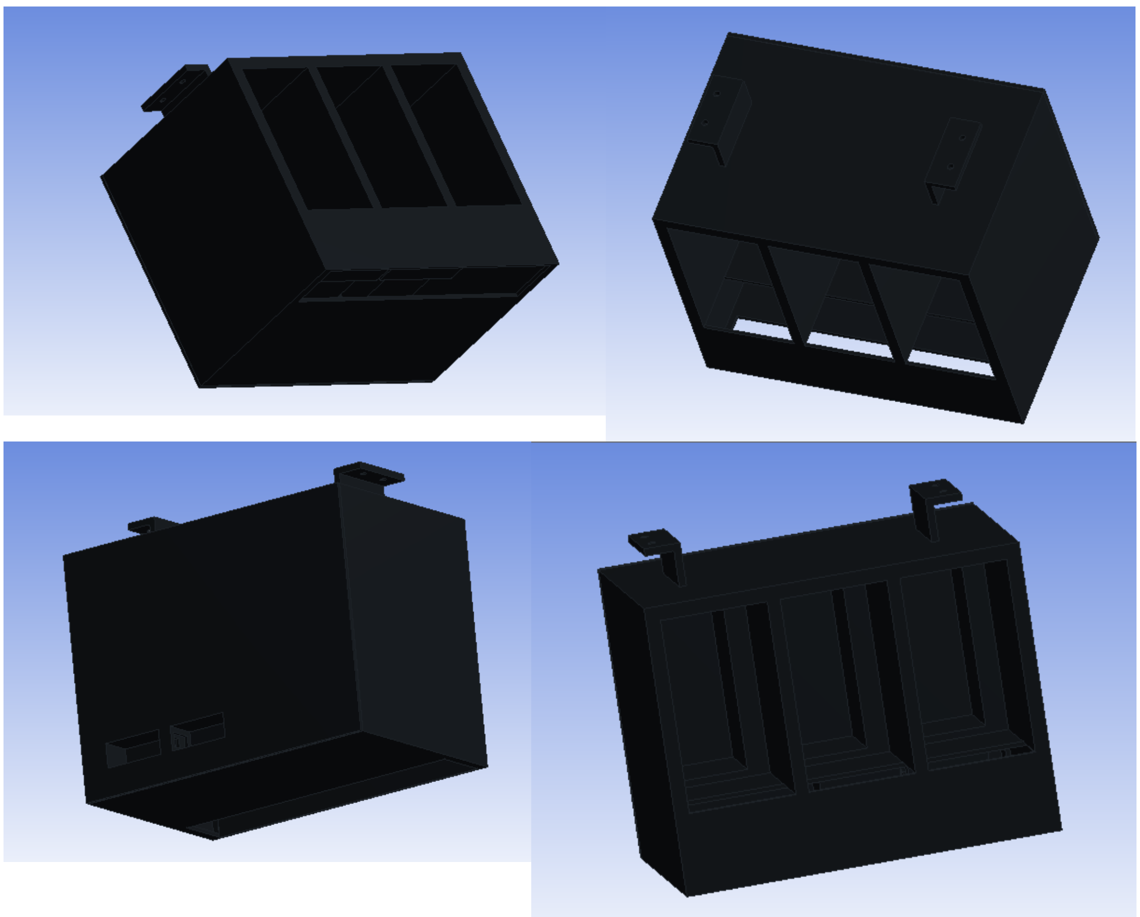

*Figure 3-12: Showing  Architectural Overview of the delivery box*

### 3.6.2 Delivery unit design

In order to incorporate the electrical and electronic components into our design, we used the TinkerCAD platform to design the entire delivery unit as shown in figure 3.12 below;

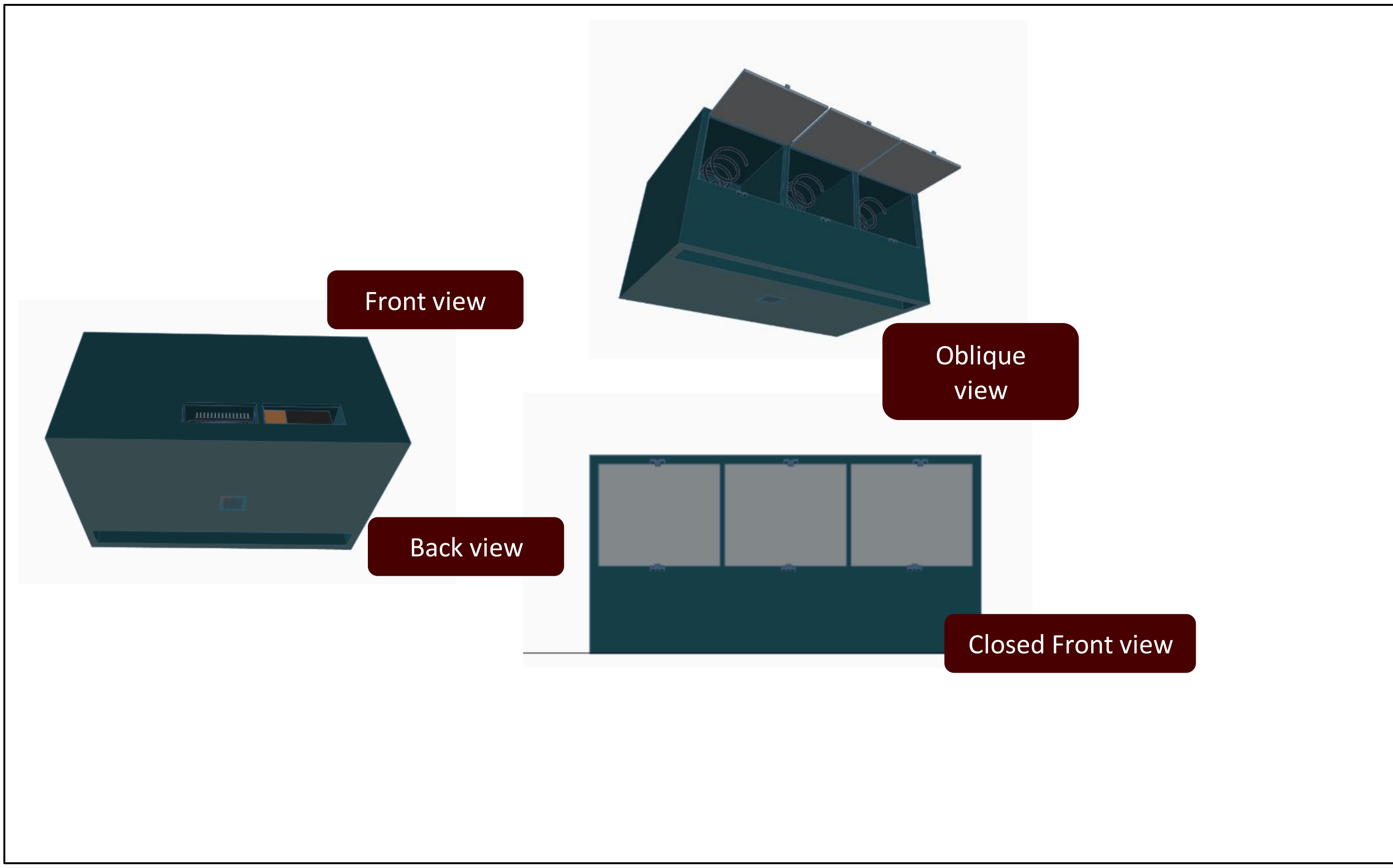


*Figure 3-13: Showing Delivery unit architectural overview*

## 3.7 Prototype Design

The figure 3.13 below shows the working prototype with the full set up of the components.The device was powered from a 240V ac power source that was rectified to a 5V dc power supply by a 5V dc adapter. The electrical/electronic circuitry design followed those discussed in section 3.5 above.

*Figure 3-14: Showing Actual working prototype*

### 3.7.1 Mechanism of operation

When the device is powered by a 5V dc power supply, the NodeMCU ESP8266 is turned on and the WiFi access point is established by the press of a push button on the NodeMCU. This establishes a WiFi network that can be accessed by a mobile phone or Computer as shown in **Error! Reference source not found.** below;

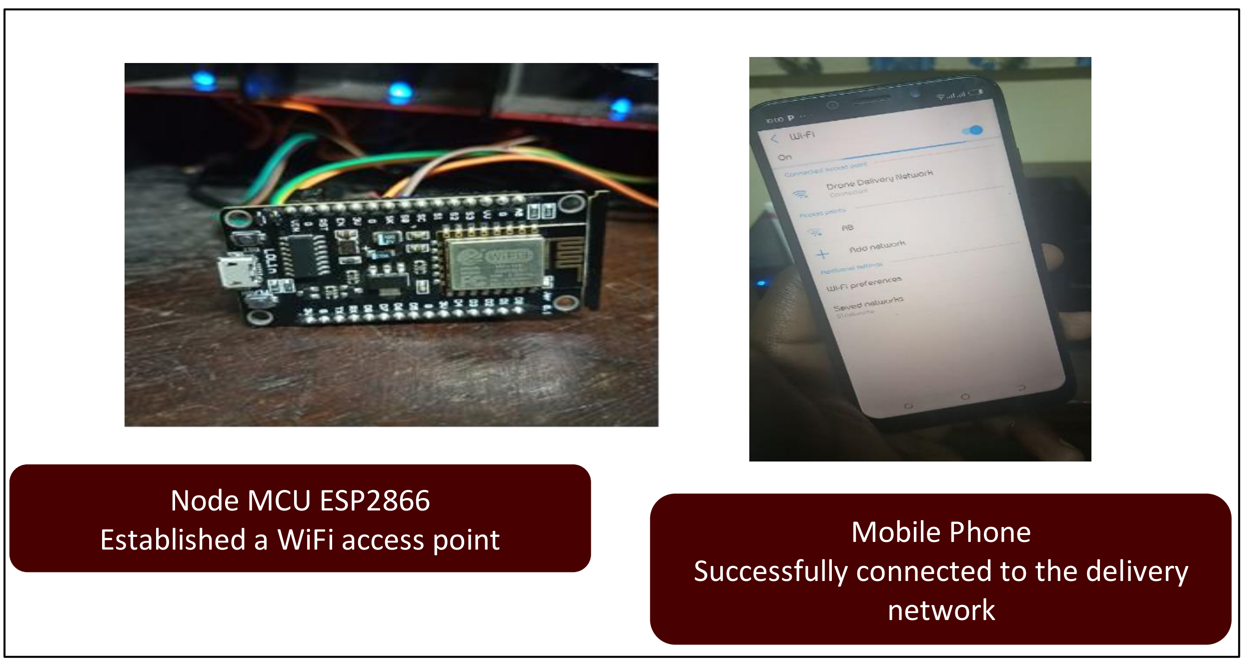


*Figure 3-15: Showing Initialization stage*

The Node MCU then establishes a webpage that is accessible to any mobile device or computer connected on its WiFi network. While on the webpage, the operator is able control delivery by instructing the servos to rotate and dispense packages stored in specific chambers just by the touch/tap of an icon for delivery. The IR proximity sensor then detects the fall of a package and sends a signal that deactivates the servos thus confirming a successful delivery, and the webpage is updated to the new status of the chamber from which the package has been dispensed. The process is repetitive for all chambers at their time of delivery.

# 4 Results/Outcomes of the Project

This section contains the prototype model, test results and limitations

To watch a demo of the prototype follow the link below:
[https://drive.google.com/file/d/1ajYffl14KUIR4F2uGLt8PWhaC3n7k5-d/view?usp=sharing](https://drive.google.com/file/d/1ajYffl14KUIR4F2uGLt8PWhaC3n7k5-d/view?usp=sharing)

## 4.1 Communication between an mobile device and microcontroller

We successfully established communication between the delivery box and the operator using the NodeMCU ESP8266 whereby; the interface was a webpage established on a mobile phone or computer by the WiFi access point launched by the NodeMCU itself.

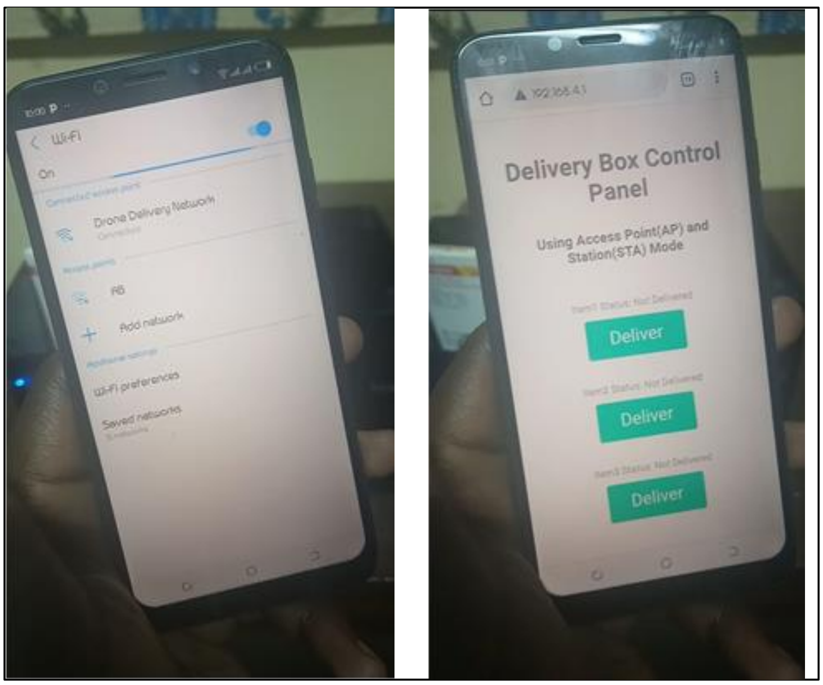


*Figure 4-16: Showing Communication interface*

## 4.2 Delivery operations

We performed delivery tests on the three chambers of the system using a 10g packet of tablets.

- The servomotors operated at a speed of 38rpm, obtained by counting the number of revolutions per minute.

- The average time of delivery by the three motors was 4 seconds, beyond which all the packages were already dispensed.
- There was a time delay of about 2 seconds before the servomotors could respond to instructions. Therefore, they had a response time of 2 seconds.
- The servomotors did not stop instantly upon the fall of a package. It took an average of 1-2 seconds for the Infrared Proximity sensor to detect the fall of the package and send the deactivation signal to the servomotors.

## 4.3 Webpage updates

Upon successful delivery, the webpage successfully updated the status of the delivery chambers to reflect the state of delivery as shown in below;

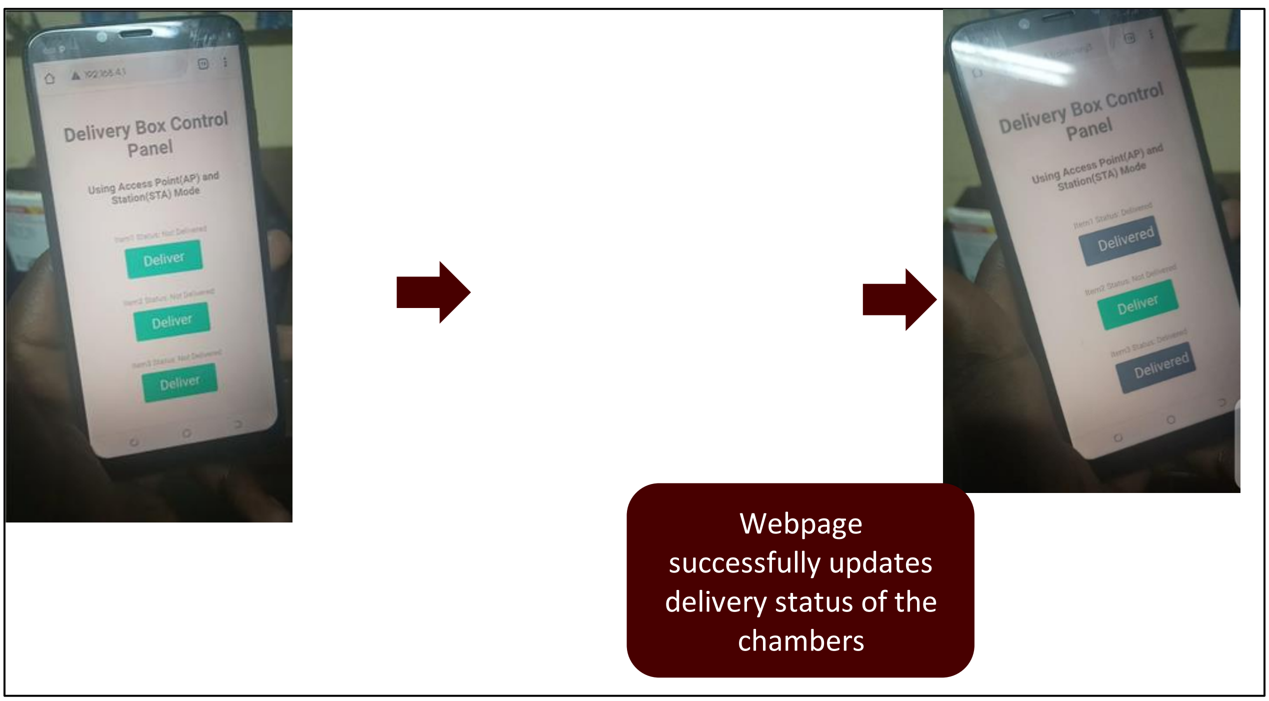


*Figure 4-17: Showing Successful webpage update.*

## 4.4 Prototype Performance.

The operating speed of the motors was around 38rpm.

Power consumption of the entire system was about 4.8V at 380mA

The average response time from the time when an order is made on the web page was 2s.

The average delivery time was 4s

The average stoppage time for chambers varied depending the position of the chambers from the IR sensor, the furthest having stoppage time of 6s the next 5s and the nearest 4s .

The prototype design limited the package dimensions to about 40x10x80mm

## 4.5 Prototype Benefits

The prototype reduces the delivery time of the drones by up to 60% since three packages can be delivered at once instead of one at a time.

The prototype reduces the drone deployment by a factor of three since one drone is deployed to deliver three packages instead of three drones.

## 4.6 Prototype Limitations

The prototype design was limited to packages of dimension 40x10x80mm.

The prototype weighs about 900g. On average a drone carries about 2.3 kg, therefore the 39.13% drone carriage capacity is wasted on carrying the delivery box.

The power consumption on the drone increases and this reduces the range of flight of drones.

These are also the trades off made when we increased the number of packages from one to three.

# 5 Conclusion, Recommendations and Future Work.

The prototype was found to be a viable product that would greatly decongest drone deliveries in cities, reduce drone delivery costs and save time on delivery.

The prototype can also be integrated with vehicle deliveries for long distance deliveries to cover more distances.

The porotype would preferably be used for drones that carry relatively greater weight compared to the ones that carry lighter weight.

## 5.1 Future Works

To reduce the package limitation caused by the size of space between the spiral of the helical spring, a better actuation mechanism which uses the same principle as the DVD drive will be implemented to increase space for package carriage.

The prototype can be made fully autonomous by integrating it with the drones gps system and deliver on arrival at destination without the control of operator.

## 5.2 Feedback from the panelists

The panelists raised the following comments;

- The need to find out what the client wants delivered
- Benefits /costs of using a 3 chamber box vs a single chamber box
- What tradeoffs did you make as the number of packages increased?
- Need to include a brief analysis of these tradeoffs in report
- Good work presented
- Consider the impact of the designed chamber on the range of the drone.
- I have analyzed the feedbacks in sections **Error! Reference source not found.** to 4.6 above and their effects on our prototype.

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