BIG BOX, small PACKAGE - SECURE DRONE DELIVERY

DESIGN DOCUMENT:

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Table of Contents

1. Introduction **2**
1.1 Objective 2
1.2 Background 2
1.3 High-Level Requirement List 4
2. Design **4**
2.1 Power Supply 5
2.2 Control Module 7
2.2.1 Microcontroller 7
2.2.3 Status LED 8
2.2.4 Linear Actuator 9
2.3.4 Pressure Sensor 10
2.3 WiFi Module 10
2.3.1 WiFi IC 10
2.3.2 Antenna 11
2.3.3 Flash Memory 11
2.4 Software 12
2.4.1 Database 12
2.4.2 Smartphone App 13
2.4.2.2 Smartphone App Algorithm 14
2.5 RF Sensor System 14
2.5.1 Sensor Voltage Converter 14
2.5.2 RF Transmitter and Receiver 14
2.6 Tolerance Analysis 15
3. Cost Analysis **15**
4. Schedule **17**
5. Ethics and Safety **18**
6. References **19**

1. Introduction

1.1 Objective

We introduce an innovative Internet of Things (IoT) receptacle where a mobile delivery drone can dock on and securely deposit small packages. The basic function of the receptacle is such that it can receive a drone delivery package and hold it safely until the consumer comes to retrieve it. With drones becoming an increasingly more popular consumer and commercial venture, the need for drone accessories is in high demand. With the advent of delivery services like Uber Eats and Grubhub, alternative services are becoming increasingly more competitive. Combining the accessibility and novelty of drones with the boom of delivery service of small items such as food and packages, drone delivery practically creates itself. However, even with a demand for such a service, investment in drone infrastructure is needed. Giving drones a location to land and deliver packages will make it simpler and more convenient to operate drone delivery at a mass scale, even at a more primitive level. With our project, we aim to create the prototype for a delivery receptacle designed with the ability to stand up to the rigors of drone package delivery.

1.2 Background

On December 28, 2020, the Federal Aviation (FAA) announced a major update to the rules of unmanned recreational and commercial drones. The major change was that all drones that weigh more than 0.55 pounds must be identifiable through a registered "Remote ID" (enforced starting September 2023) [1]. The second and arguably more groundbreaking change was the relaxation of restrictions of drones flying over people and property at night, for commercial pilots. Previously, this activity required waivers from the FAA. This change is likely to expedite the commercialization and integration of drones into the airspace. There is great market potential for Unmanned Aerial Vehicles (UAVs) in many big industries ranging from security and inspection to agriculture [2]. One high potential area that we focus on in the project is the delivery industry. Major e-commerce organizations including Amazon, UPS, Walmart have all heavily invested in the research and development of drones and drone infrastructure for commercialization.

According to Amazon, 75 to 90 percent of purchased items weigh under 5 pounds [3]. Drone delivery opens the avenue toward < 1 hours delivery, night delivery, and reduces the need for human middlemen between warehouse to consumer.

Much of the research done on drone delivery has been focused towards the drone such as obstacle avoidance, noise reduction, battery technology, etc. There is less being done to interface a dropped off package to the hands of the consumer. Delivered packages are prone to theft. This is a particular problem with drones since it is difficult for drones to drop off a package securely without dangerous contact with people or tricky obstacle avoidance. Risk of theft also increases with night delivery as there is increased duration to steal a package since the consumer is asleep. We propose a receptacle that drones can land atop and deposit a package for the consumer.

Figure 1: Physical Design

1.3 High-Level Requirement List

- The receptacle must use RF to communicate with the drone and WiFi to communicate with the web-server.
- Once the drone is 2 feet above the receptacle, the door must open within 30 seconds using a single door and linear actuator. Once the delivery has been completed and the drone has departed, the receptacle must close, and remain closed, within 30 seconds.
- The wireless system must notify the user that their package has arrived using the mobile application, website, and through the LEDs present on the receptacle.

2. Design

In this design, we break the project up into three main blocks, the drone, the receptacle, and finally the web applications. The drone component will consist of a drone with the necessary RF transmitter, allowing communication between the drone and the receptacle. The receptacle will contain the majority of the hardware components, including the receiver, power system, WiFi module, control unit, and the mechanical sub-system. The WiFi module and the control unit will then interface with a web server and mobile application designed to inform the user of any packages that have arrived.

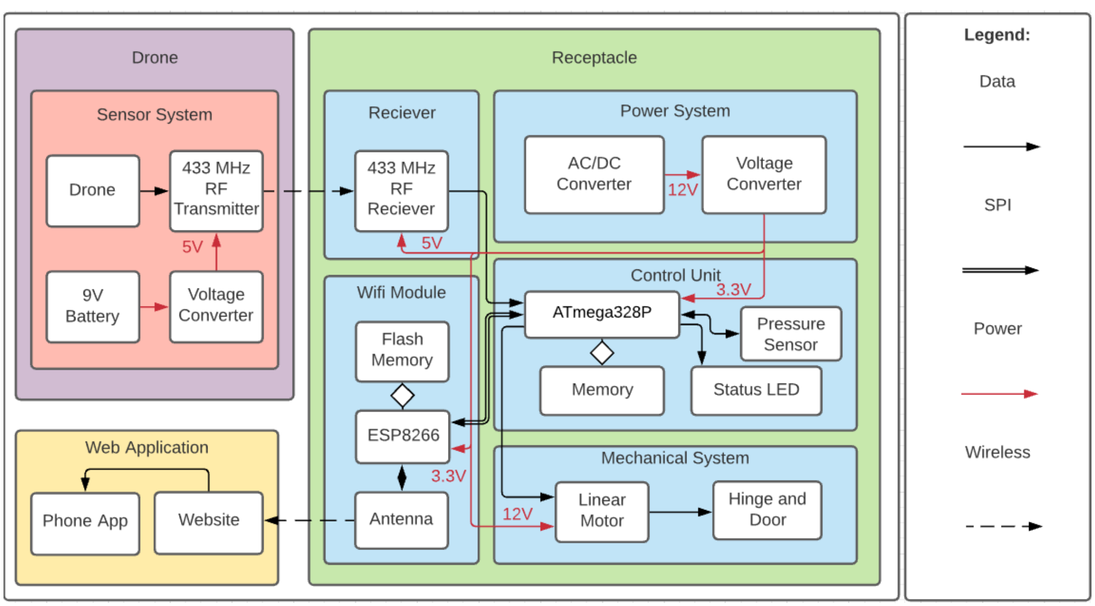

Figure 2: Block Diagram

2.1 Power Supply

A power supply is necessary to keep the receptacle operational at all times. Using a 120V AC wall source to power the receptacle, the incoming voltage is converted to ±12V to be used to eject and draw in the linear actuator's arm. From there, the 12V signal is converted to 3.3V necessary to power the microcontroller and other necessary subsystems critical to the receptacle's functionality.

2.1.1 AC/DC Converter

- The drone receptacle will be powered using a single wall 120V AC supply. This supply will be then converted to ±12V DC, which is necessary for the linear motor.

Requirements	Verification
➢ The power supply must continuously deliver ± 12V DC from a 120V AC wall supply. The positive 12V will be used to eject the linear motor arm, while the negative 12V will be used to draw the arm back in.	A. With a voltage meter, probe the end and determine if the component measures up to the ± 12V requirement. B. Set a timer for 5 minutes. C. Continuously check, as the timer runs, to ensure it is within the necessary range.

2.1.2 Voltage Converter

- Once the ±12V DC supply has been established for the linear motor, it is key to power up the remainder of the subsystems. The 12V node will be dropped down to a more workable 3.3V to sustain power to the WiFi module, control unit, and receiver module.

Requirements	Verification
➢ The voltage converter must continuously deliver 3.3V DC from a	A. Using a voltage meter, probe the end and determine if the component

12V DC source. The subsystems that require 3.3V are the WiFi, control, and receiver modules.	measures up to the 3.3V requirement. B. Set a timer for 5 minutes. C. Continuously check, as the timer runs, to ensure it is within the necessary 1% range.

2.2 Control Module

The control unit is a key feature of any design, where many features need to be controlled. In this design, the microcontroller, memory card, and LEDs will work together to control all the internal signals used within the receptacle box.

2.2.1 Microcontroller

- The ATmega328P microcontroller will be used to interface with the WiFi module where it periodically polls for the signal whether a drone has arrived and should open the top door for the drone. The microcontroller sends the correct input signals to activate the switch to turn on the linear actuator to open/close the door. It also sets the status LED accordingly. It is programmed using an Arduino board as an In-System Programmer.

Requirement	Verification
➢ Able to communicate with the WiFi module over SPI.	A. Connect ATmega328P SPI interface to an ESP8266 dev board connected to a computer over USB. B. Configure the ATmega32P as master and ESP8266 device as slave. C. Send 100 bytes of characters from ATmega328P to the ESP8266 over SPI. D. From ESP8266 echo characters to

	serial monitor, verify characters are the same as those sent.
➢ Sends control signals to the linear motor circuit to open/close it. The microcontroller must be.	A. Write a program that sends a low voltage signal to the linear actuator actuator relay circuit, activating the ±12V to drive or retract the arm.

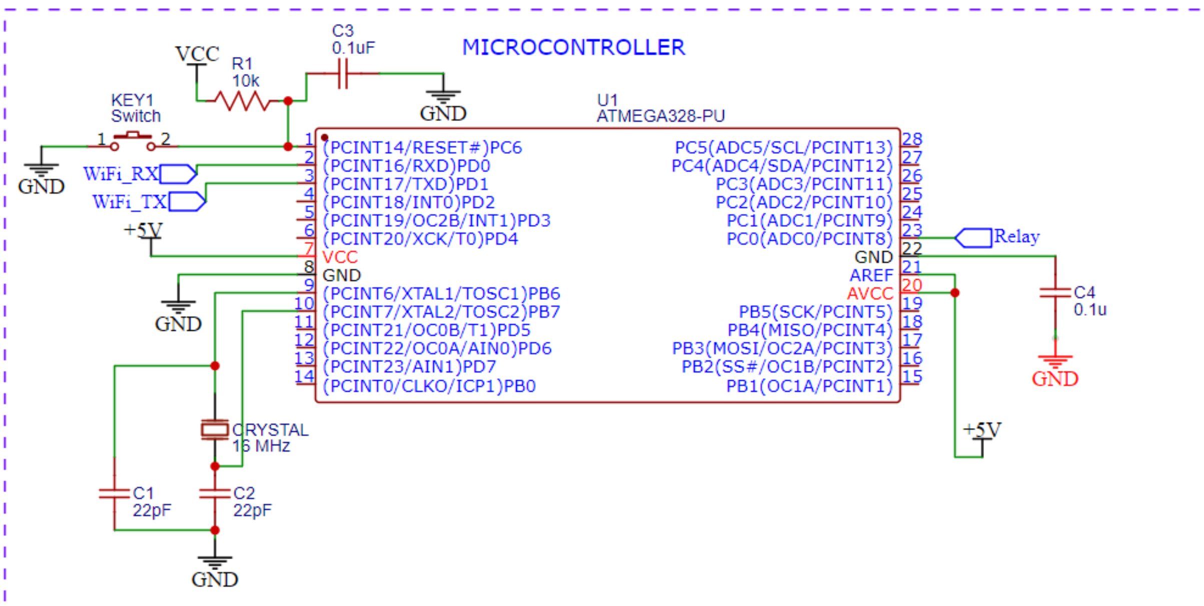

Figure 3: Microcontroller Schematic

2.2.3 Status LED

- The status LED is powered through the microcontroller displays notable signals. It must denote that the box is active, powered on, and functioning correctly, as well as denote that a package has been received in the receptacle or empty.

Requirement	Verification
➢ Must be reasonably visible 1 meter away, and display the correct lights	A. Attach the LED in series with the correct resistor such that the LED is

when the box is powered, the box is empty, and when then there is a package inside.	sufficiently reasonably bright a meter away. B. Test every variation of LED display.

2.2.4 Linear Actuator

- A 12V linear actuator is used to open and close the hinged door on the top. It will be hooked up to a set of relays to ensure that the correct voltage is applied with the appropriate state.

Requirement	Verification
➢ Must be powerful enough and extend enough to open and close the door.	A. Connect terminals to ±12VDC and flip the bias ensuring the actuator extends and reduces correctly.

2.3.4 Pressure Sensor

- The pressure sensor is used in the drone receptacle to determine whether or not the package has been deposited in the receptacle.

Requirement	Verification
➢ The sensor must send a signal to the microcontroller that a package of less than 1 kg is in the receptacle.	A. Place 3 different packages (flat, square, and rectangular) of 0.5 kg and ensure that the sensor has an output signal that correctly recognizes a package is held.

2.3 WiFi Module

The WiFi Module handles the wireless communication of the receptacle with devices such as the user's mobile phone, as well as serving as the access point to the internet. Access to the internet allows the device to utilize services such as cloud data storage and opens the opportunity for cloud data processing as well.

2.3.1 WiFi IC

- The WiFi IC serves as the gateway for the secure delivery box to connect to the greater internet, communicating with the Atmega microcontroller to determine when a package has arrived and forwarding this notification to the user. For this purpose we chose the ESP8266, a low cost wireless solution that contains a 32-bit microcontroller and WiFi transceiver that supports sufficient bandwidth at a medium range.

Requirement	Verification
➢ The WiFi module must support SPI communication.	A. Connect SPI interface to verified device, such as the required flash memory. B. Perform a write of known data over the interface. C. Read the data back over SPI, ensure integrity.
➢ The WiFi module must operate at a minimum bandwidth of 1Mbps in IEEE 802.11b mode.	A. Assemble WiFi IC on PCB according to datasheet B. Supply power to IC. C. On a mobile device, check that WiFi network appears in the list of nearby networks.

2.3.2 Antenna

- To increase the range of the WiFi IC to be able to maintain a consistent connection to the wireless router under the assumption that the receptacle will be placed a sufficient distance from the place of residence, we will use an external antenna that supports access of at least 50 meters.

Requirement	Verification
➢ The antenna must be omnidirectional.	A. Measure signal from 360° of rotation around the antenna. B. Verify that RSSI does not vary by more than +/-6dB.
➢ The antenna must receive signal strength greater than -98dBm at 50m with +20.5dBm power.	A. Measure signal strength with a similar WiFi unit and antenna at 50m. B. Verify received signal is greater than -98dBm.

2.3.3 Flash Memory

- The flash memory module contains the program memory for the WiFi IC, connected synchronously through SPI. Our estimates of our initial program size is under 1MB so choosing an appropriate module can help save costs on the overall design.

Requirement	Verification
➢ Supports SPI communication	A. Connect flash memory to a microcontroller with SPI interface and serial monitor, such as the ESP8266 dev board connected to a computer over USB. B. Write a buffer of text data over SPI to

	flash memory. C. Read data from flash memory and display to serial monitor. D. Verify output from monitor contains entire text.
➢ The flash memory will have at least 1MB of storage.	A. Write 1 MB of known data to flash memory. B. Perform a read of the same amount and verify integrity of data.

2.4 Software

Once the package has arrived it is necessary to take the package arrival into account, and let the user know when it is time to pick up their parcel. With a web application, we will be able to have a web server store information about package information, such as logs and other order history. From there a smartphone application will send user's notifications right to their phone and make it easy to keep track of their deliveries.

2.4.1 Database

- A database is used to manage data of the status and locations of the drone/drones and receptacles. The database will be hosted through AWS DynamoDB coupled with AWS Lambda. One of the major advantages here is that they offer a free tier and that we would not have to maintain any hardware ourselves to operate it. Additionally, AWS services allow for ease of scalability if that is ever desired for actual commercial applications.

Requirement	Verification
➢ The database tables are able to be written to, read from, and be deleted.	A. Write a test script uploaded to Bucket for AWS Lambda that takes a HTTP request to write, read, update, and then

	delete the table.

2.4.2 Smartphone App

- An Android/IOS app provides the customer with a user interface on their smartphones to communicate with the receptacle to tell when their delivery has arrived. The smartphone app interacts with the system OS and is able to connect with WiFi to access the server that the receptacle publishes to. It also receives push notifications informing the user that their package has arrived.

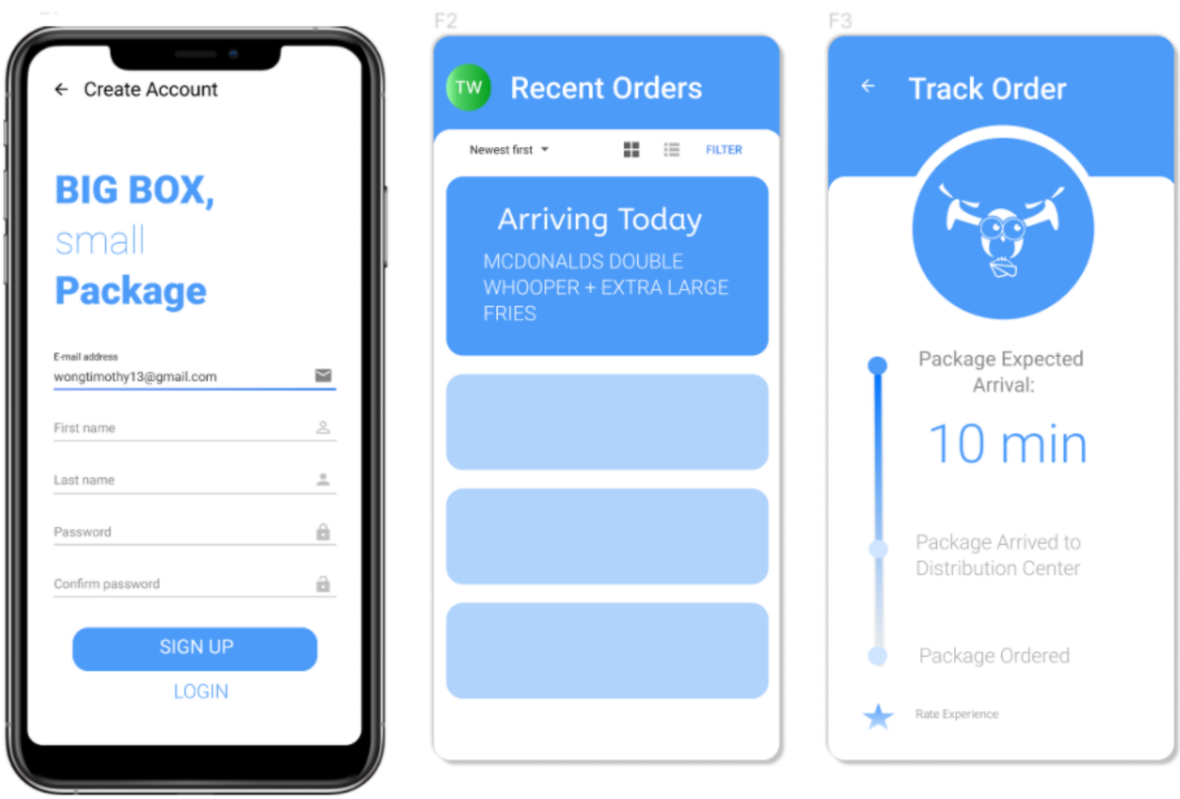

Figure 4: Draft of the Prototyped UI

Requirement	Verification
➢ The app will be able to interface with the microcontroller through WiFi.	A. Login confirmed visually. Receptacle position is manually inputted. B. View the app to see if its displayed

	status matches up to the actual state. Do this for states: Delivered, Not Delivered.
➢ The app has a login for users to create/access accounts and register their box.	A. Confirmed that users can successfully register for an account. B. User signs in and logoff account successfully.
➢ The app correctly displays status signals for deliveries whether it has or has not arrived, on its way, and time for expected delivery.	A. Place the box inside the receptacle and configure it to replicate when a box is delivered and observe to see if App status shows a package is delivered. B. Replicate signal to receptacle that a delivery is on the way and observe to see if the App shows an "On its way" status.
➢ App displays smartphone notification that a package has arrived within 1 minute of arrival.	A. Send a signal through the database that sets the status signal that a package is sent and verify that a notification pops up on the phone within 1 minute.

2.5 RF Sensor System

An important feature of our design is the drone's ability to detect and communicate with the receptacle. This requires the use of sensors in the form of radio frequency transmission from the drone to the receiver on the receptacle box. This gives a way to determine when the drone has reached its destination, thus informing the end user of their package's arrival.

2.5.1 Sensor Voltage Converter

- With a 9V battery, it is necessary to drop the voltage down to a workable 5V, to make sure that the RF transmitter receives the correct input voltage.

Requirement	Verification
➢ The voltage converter must be able to convert the 9V of a battery and convert it to 5V.	A. Using a voltage meter, probe the end and determine if the component measures up to the 5V requirement. B. Set a timer for 5 minutes. C. Continuously check, as the timer runs, to ensure it is within the necessary 1% range.

2.5.2 RF Transmitter and Receiver

- Radio frequency transmitter for communication with the receiver on the receptacle, notifies the receptacle as to when the drone positioning is suitable for the release of the package.

Requirement	Verification
➢ The RF transmitter must send a 5-bit code message to the receiver, with a range of 5 feet.	A. Write a test code to send a 5-but signal in the Arduino IDE. B. Read the message on the receiver. C. Progressively test the transmitter and receiver from a progressively further distance away to bound the limits of the signal detection

2.6 Tolerance Analysis

A core component of our design that is essential to the functionality of our project is its capability to connect to a wireless access point such as a home WiFi router. As the receptacle is designed to be placed outside, it must have a sufficient range to reach the access point and connect at a distance safe enough for drones to locate and land close enough to.

To determine the effective data rate of the wireless transmission at various distances we can apply the Free Space Path Loss formula with the known value for WiFi transmission frequency of 2.4 GHz.

$$FSPL(dB) = 20log_{10}(d) + 20log_{10}(f) + 20log_{10}(\frac{4\pi}{c})$$

Where *d* is the distance in meters, *f* is the frequency of the transmission in Hz, and *c* being the speed of light. Using 2.4 GHz for our value of frequency, we arrive at the following equation:

$$FSPL = 20log_{10}(d) + 20log_{10}(2.4e9) + 20log10(\frac{4\pi}{c})$$

$$= 20log_{10}(d) + 40.04$$

Using the FSPL equation, we can calculate the Received Signal Strength Indicator (RSSI) at various distances with this equation that relates the transmission power and the path loss at a given distance.

$$RSSI = P_t - P_L(d)$$

The WiFi IC we have chosen has a typical transmission power of 19.5 dBm, which we can use with the above equation to arrive at the following table, mapping distances to the expected RSSI.

Distance (m)	10	20	30	40	50	60
RSSI (dBm)	-40.54	-46.56	-50.08	-52.58	-54.52	-56.10

Table 1: Received Signal Strength Indicator at various distances

From the data sheet of the WiFi IC we find support for different versions of the 802.11 wireless specification, each at different bandwidths with specific sensitivity requirements at those bandwidths.

Specification	Sensitivity (dBm)
802.11b, 1 Mbps	-98
802.11b, 11 Mbps	-88
802.11g, 6 Mbps	-93
802.11g, 54 Mbps	-75

Table 2: Receiver sensitivity at supported wireless specifications

We can see from Table 1 and Table 2 that each specification is supported at our required range of 50m. Since our design requires minimum bandwidth, choosing the 1 Mbps bitrate at a sensitivity of -98 dBm allows us to make optimizations such as lowering the transmission power of the WiFi IC's transmitter while still maintaining a stable connection.

3. Cost Analysis

Labor: We assume that all of us get ~$40/hour, working 15hours a week for 12 weeks.

Team Member	Hourly Wage	Weekly Hours	Number of Weeks	Multiplier	Cost Per Member
Timothy Wong	$40	15	12	2.5	$18,000
Phillip Jedralski	$40	15	12	2.5	$18,000
Christian Fernandez	$40	15	12	2.5	$18,000
				Total Labor	$54,000

	Cost	

Parts:

Part Number	Description	Quantity	Unit Cost [USD]
Power Supply			
(Amazon; HKWPS-12V100W)	Power Supply	1	$36.99
(Digikey; 1727-5841-1-ND)	Schottky Diode	1	$0.42
(Digikey; AIAP-03-470K-ND)	47 µH Inductor	1	$1.33
(Digikey; 490-13295-1-ND)	10 nF Capacitor	1	$0.10
(Digikey; LM2672N-3.3/NOPB-ND)	3.3 V Regulator	1	$5.56
(Digikey; PCE3888CT-ND)	330 µF Capacitor	1	$0.59
(Digikey; 493-2204-1-ND)	150 µF Capacitor	1	$0.51
Subtotal:			*$45.50*
Control Unit			
ATmega328P	Microcontroller	1	$2.52
ESP8266 ESP-01	WiFi Module	1	$6.50
(Digikey; 399-1926-ND)	22 pF Capacitor	1	$0.44
(Digikey; 300-6034-ND)	16 MHz Crystal	1	$0.54
(Digikey; ED3050-5-ND)	28 Pin DIP Socket	1	$0.33
Subtotal:			*$10.33*

Linear Actuator			
(Digikey; 255-2080-ND)	Relay	2	2 x $1.63
(Digikey; EG2355-ND)	3-Way Switch	1	$1.92
Subtotal:			*$5.18*
RF Module			
(Amazon; 433 MHz Tx and Rx)	RF Module	1	$1.69
(Digikey; N145-ND)	9V Batteries	2	2 x $4.26
(Digikey; BC9VPC-ND)	Battery Holder	2	2 x $4.16
(Digikey; 2299-TE6-1A-DC-1-PB-ND)	Power Switch	1	$1.15
(Digikey; 490-13295-1-ND)	10 nF Capacitor	1	$0.10
(Digikey; PCE3750CT-ND)	100 µF Capacitor	1	$0.12
(Mouser; ELE-101ELL3R3ME11D)	3.3 µF Capacitor	1	$0.30
(Digikey; PCE4304CT-ND)	4.7 µH Inductor	1	$1.33
(Digikey; 296-43596-1-ND)	5 V Regulator	1	$4.20
Subtotal:			*$25.73*
Total:			*$86.74*

The total cost is the sum of the cost of labor and parts which amounts to $54,086.74.

4. Schedule

Week	Timothy Wong	Phillip Jedralski	Christian Fernandez

March 1	➢ Design Document ➢ Order Parts	➢ Design Document ➢ Finish ordering Power Module parts	➢ Design Document ➢ Finish ordering Wireless Module parts
March 8	➢ PCB design ➢ Programming microcontroller	➢ Test linear actuator ➢ Submit design to Machine Shop	➢ Begin working on PCB layout ➢ Start testing of wireless communication
March 15	➢ Work on an Android app	➢ Solder and test components on PCB ➢ Test RF signals	➢ Implement AWS backend endpoints
March 22	➢ Synthesize everything	➢ Resubmit PCB design	➢ Finalize wireless software components
March 29	➢ Debugging/Testing	➢ Debugging/Testing	➢ Debugging/Testing
April 5	➢ Full system testing	➢ Debugging/Testing	➢ Full system testing
April 12	➢ Prepare for Mock Demo	➢ Prepare for Mock Demo	➢ Prepare for Mock Demo
April 19	MOCK DEMO FOR REAL DEMO NEXT WEEK		

5. Ethics and Safety

Our project raises several issues in regards to the safety and ethical use of our design, not only because of the fact that the drone sector is heavily regulated, but also because of our added constraint of making a secure design.

As the secure dropbox is designed to be placed outside in a similar function to a mailbox, the receptacle will need to follow the latest IP requirements, to prevent not only the inner circuitry from moisture damage, but the package as well. Not ensuring such precautions violates IEEE Code of Ethics, #9, which stresses avoiding the injuring of other persons, including their property [4].

Careful consideration will also have to be put into the operation and modifications of the drone as well. Since we will be attaching a sensor module to the drone containing both a battery and an RF module, accounting of the weight of the drone in accordance with FAA regulations is required. Drones over 250 grams must be registered with the FAA under Part 107, and must have visible markings for identification displayed on the drone at all times [1].

With the main purpose of the receptacle being delivery of packages in a secure manner, access to the inner contents should be restricted to the owner of the dropbox for which packages are delivered, and the drone service that is performing a delivery that is explicitly requested by the owner.

Collection of user data, an issue of increasing relevance in the digital era, raises the question of who should have access to a user's data, in the case of our project a history of the deliveries sent to the owners delivery box, including information about the arrival time as well as the authorized sender of the package. It is our belief that user data belongs first and foremost to the user, and will only make such data available to the respective owner. Regarding the security of the transfer of this data over a wireless network, requires a level of security and encryption to uphold #1 of the IEEE Code of Ethics, to paramount the safety, health, and welfare of the public, which includes protection of users' privacy [4].

6. References

[1] faa.gov. 2021. ‘Certificated Remote Pilots including Commercial Operators’. [Online] Available at: https://www.faa.gov/uas/commercial_operators/ [Accessed 17 February 2021].

[2] Ackerman, R., 2021. ‘Things are Looking Up for the Commercialization of Drones’. [Online] Securitymagazine.com. Available at: https://www.securitymagazine.com/articles/94331-things-are-looking-up-for-the-commercialization-of-drones [Accessed 12 February 2021].

[3] C. Guglielmo, “Turns Out Amazon, Touting Drone Delivery, Does Sell Lots of Products That Weigh Less Than 5 Pounds,” *Forbes*, 03-Dec-2013. [Online]. Available: https://www.forbes.com/sites/connieguglielmo/2013/12/02/turns-out-amazon-touting-drone-delivery-does-sell-lots-of-products-that-weigh-less-than-5-pounds/?sh=2ed6d239455e. [Accessed: 18-Feb-2021].

[4] Ieee.org. 2021. ‘IEEE Code of Ethics’. [Online] Available at: https://www.ieee.org/about/corporate/governance/p7-8.html [Accessed 15 February 2021].