BIG BOX, small PACKAGE - SECURE DRONE DELIVERY

FINAL REPORT:

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Abstract

This report describes in detail our senior design project, the Big Box, small Package - Secure Drone Delivery. This device is a drone delivery receptacle that is capable of automatic, wireless, and secure deliveries. Our design is unique in that it provides vital infrastructure for the developing drone delivery industry. This allows for the user to receive small packages of less than 5 lb securely, and receive notifications automatically over a mobile device or computer. We carefully measured and verified all of our results and are happy to report that each individual component operates to their designed requirements. When fully integrating the project, issues arose, and design flaws became apparent that prevented full functionality. This product was developed and tested in the University of Illinois ECE 445 senior design course with the intention of eventually being used in commercial applications.

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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 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 takeout and packages. 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. 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 Incentive for Project and Proposed Solution

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 less than 1 hour 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 on the drone such as obstacle avoidance, noise reduction, battery technology, etc. [4]. 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.

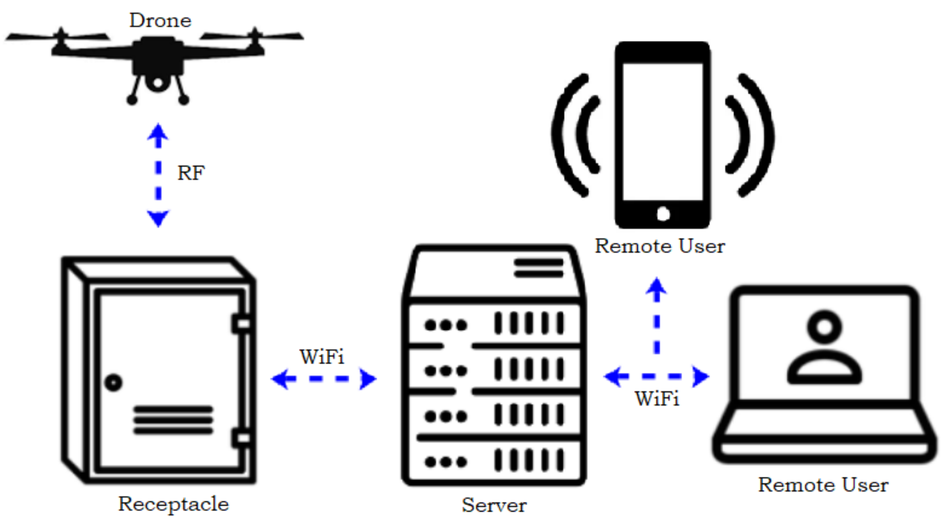

Figure 1: Visualization of receptacle design

1.3 High-Level Requirements

- The receptacle must use RF to communicate with the drone and WiFi to communicate with the webserver.
- Once the drone is 2 feet above the receptacle, the door must open within 30 seconds using a single door and gear motor. 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 broke the project up into three main blocks: the drone, the receptacle, and finally the web applications, shown in Figure 2. The drone module consists of a simulated drone with the necessary RF transmitter, allowing communication between it and the receptacle. To reduce the scope of the project, we did not actually use a drone. Instead, we have a mockup that simulates signals sent by a drone. The receptacle contains the majority of the hardware components, including the receiver, power system, WiFi module, control unit, and the electro-mechanical sub-systems. The WiFi module and the control unit interfaces with a web server and mobile application designed to inform the user of any packages that have arrived.

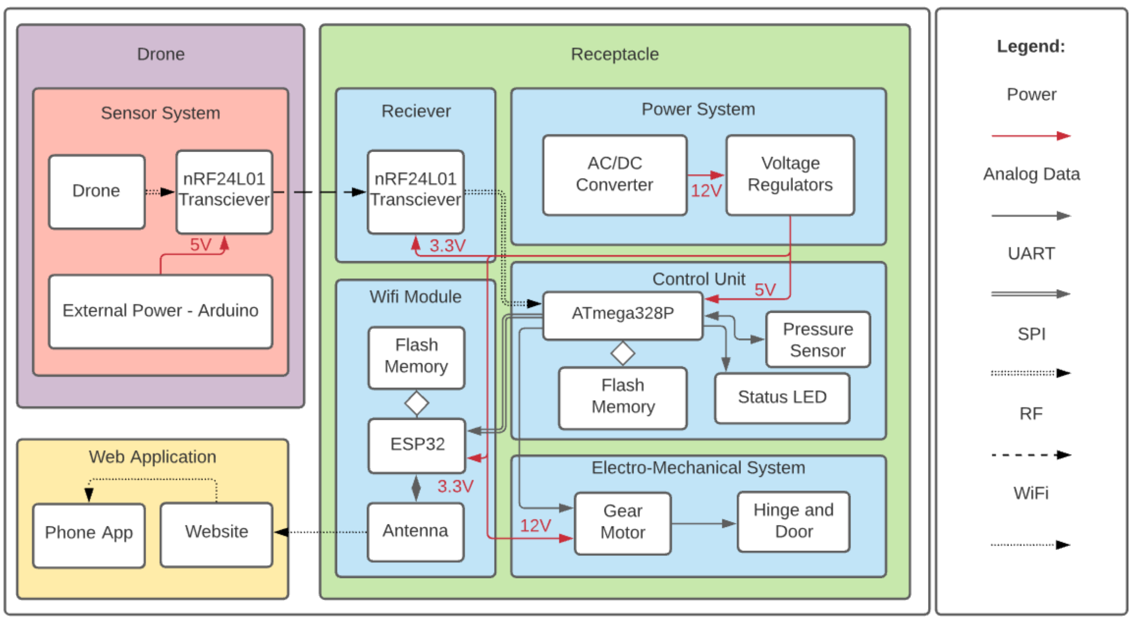

Figure 2: Block diagram

In Figure 3, we have the process flow diagram for the Big Box, small Package - Secure Drone Delivery system. At the top, we start in an idle state. Instead, we have our onboard RF module constantly polling to see if a drone has arrived to deliver a package. Once a signal is received, the control unit sends signals to the relay system to apply the correct bias across the motor to open the door. From there, the RF module continuously polls for an RF signal to close. Within the receptacle, the pressure sensor pad sends an analog signal to the control unit saying a package has been received. From there, the drone sends a close signal to shut the door. Once both the pressure sensor and the door are fully closed, the control unit will send a signal with the package information and time stamp using the WiFi module to a web server. Once the information is on the web server, the user can access it using their mobile device or a computer.

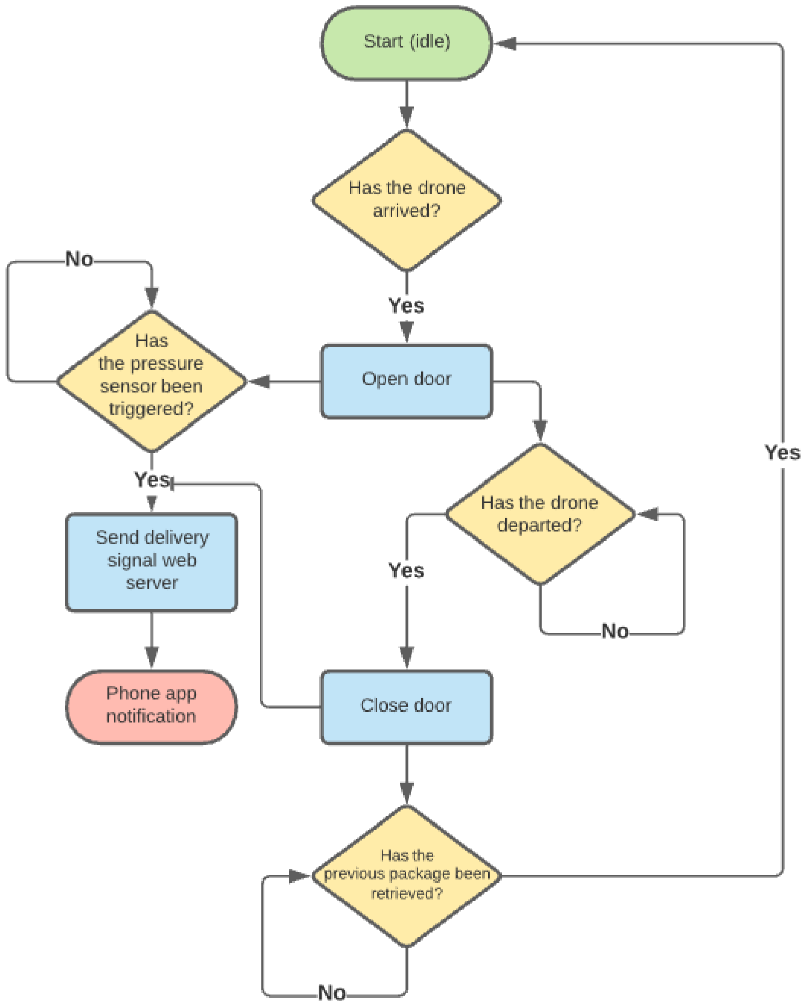

Figure 3: Process flow diagram

2.1 Power Supply

A power supply is necessary to keep the receptacle operational at all times. Using a 120 V AC wall source to power the receptacle, the incoming voltage is converted to 12 V DC, which is used in the electro-mechanical motor relay system. The stable 12 V is further regulated using a 3.3 V and 5 V buck converter, which are used for the receptacle's more sensitive electronic components like the ATmega328P, ESP32, and nRF24L01.

2.1.1 AC/DC Converter

The drone receptacle is powered using a single wall 120V AC supply. This supply is then converted to 12 V DC. We decided upon a wall outlet setup over a battery setup because most houses and buildings have external wall outlets. In the event of a power failure due to theft or natural disaster, the receptacle would not be able to be pried open.

2.1.2 Voltage Converters

The 12 V input for the AC/DC converter is regulated to 3.3 V and 5 V to supply power to the non-motor modules. The 3.3 V supplies the Wifi and RF modules and status LEDs while the 5 V supplies the microcontroller. Capacitive and inductive elements were sized according to the space constraints within the electrical box as well as according to the suggested specifications in the datasheets.

2.2 Control Module

In this control unit, the microcontroller circuit works to control the outgoing signals to the motor relay circuit and ESP32 WiFi module, while also managing the incoming switch, pressure sensor, and RF information. The pressure sensor inside the drone receptacle monitors whether or not there is a package, and the green LED display allows the user to visually see if their package has arrived.

2.2.1 Microcontroller

The ATmega328P microcontroller is used to interface with the RF module where it periodically polls for RF signals. The microcontroller also sends the correct signals to activate the motor relay circuit, which determines whether or not the motor will rotate clockwise or counter-clockwise. The microcontroller also communicates with the WiFi module to send time stamp information about the delivered package. Figure 3 illustrates the pin assignments for individual modules.

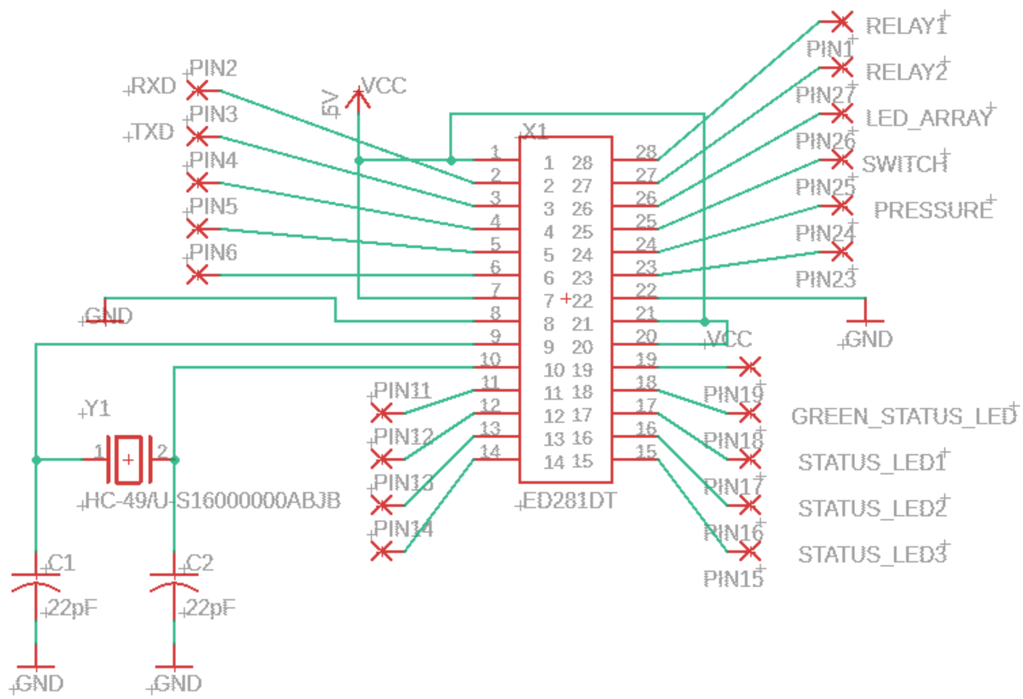

Figure 3: Microcontroller schematic

2.2.3 Status LEDs

There are three status LEDs that denote whether the receptacle is either opening, closing, or at a neutral static state. There is a fourth, green LED that denotes whether the package has been received in the receptacle, or is empty.

2.3.4 Pressure Sensor

The pressure sensor is used to determine whether or not a package is currently inside the drone receptacle, illustrated in Figure 4. The sensor is under a cardboard pad with a stud, such that any weight added to the surface will push the stud into the sensor, and thus detect the package. The green LED lights up once any package is present on the pad.

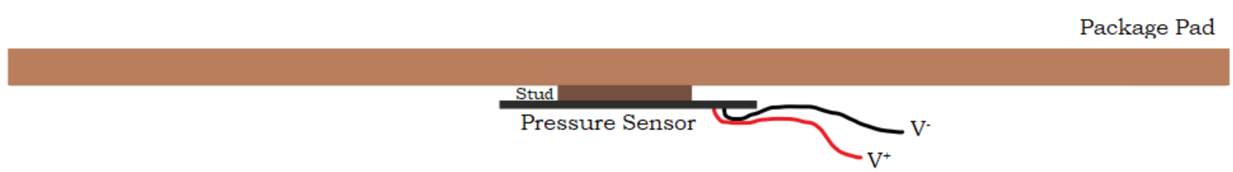

Figure 4: Physical receptacle pressure pad graphic

2.3 WiFi Module

The WiFi module handles the wireless communication between the receptacle and our backend web server, for when a delivery event is triggered by the main control unit. The module consists of a WiFi IC coupled with a transceiver for maintaining a reliable connection to a wireless access point such as a home router, and communicates over the standard HTTP protocol.

2.3.1 WiFi IC

The WiFi IC serves as the gateway for the secure delivery box to connect to the internet, communicating with the Atmega328P microcontroller to determine when a package has arrived and forwarding this notification to the user. For this purpose we chose the ESP32, a low-cost wireless solution that contains a 32-bit microcontroller and WiFi transceiver that supports sufficient bandwidth at a medium range.

2.4 Mechanical System

The mechanical system consists of the gear motor attached to a gear assembly that rotates a belt connected to the door. This swings the door around its hinge to open and close the door. We have it set so that the maximum open distance is 90 degrees pointing upwards.

2.4.1 Gear Motor Relay Circuit

A 12 V gear motor is used to open and close the hinged door on the top. It is connected to a set of relays controlled by the control unit to ensure that the correct voltage is applied to open and close the top door. In order to achieve enough voltage to activate the relays, a BJT circuit is used for each relay to amplify the control unit’s 5 V to 8 V, shown in Figure 5.

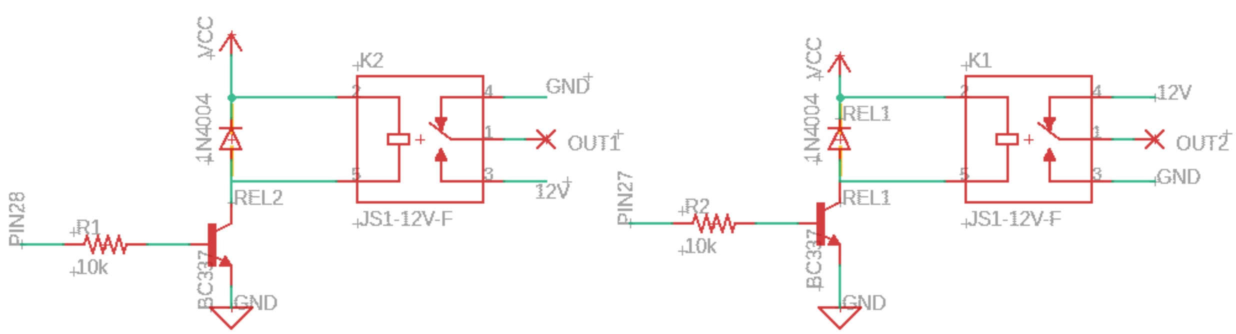

Figure 5: Gear motor relay circuit

2.5 Software

Once the package has arrived it is necessary to account the arrival information, and let the user know when it is time to pick up their delivery. With this web application, we have the web server store information about package information, such as logs and order history. From there a smartphone application will send user notifications right to their phone, and make it easy to keep track of their deliveries. To achieve this, we utilize AWS services that are popular with IoT designs, namely AWS Lambda and DynamoDB. AWS Lambda is Amazon's serverless computing platform, which allows users to upload code that is run when called rather than having a constantly running server. This fits the architecture pattern of our design since deliveries may be far between and would require a running server to remain idle for long periods of time. Figure 6 displays the process flow of the software.

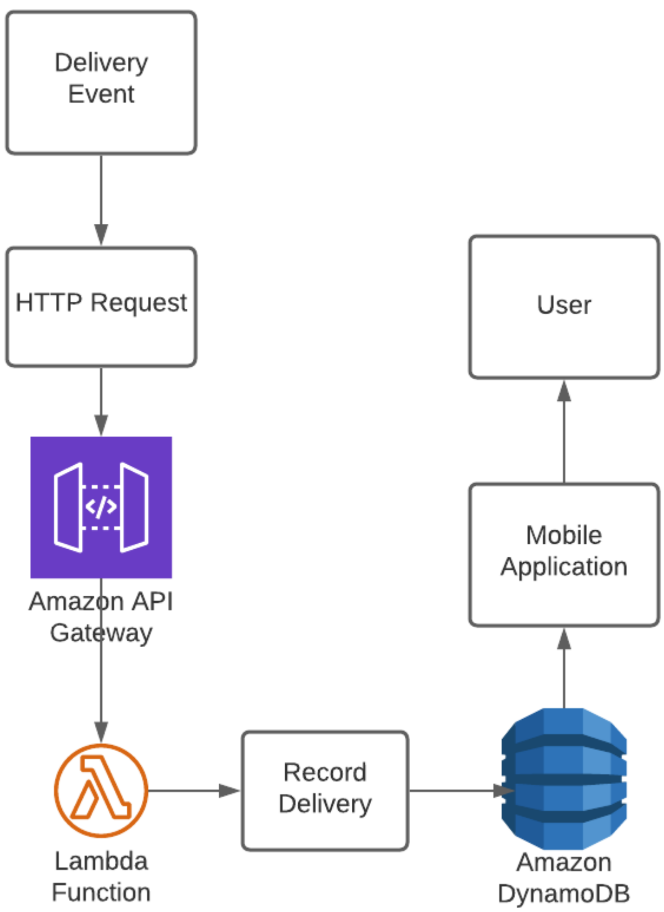

Figure 6: Flow diagram for delivery event

2.5.1 AWS Backend

A database is used to manage the status of the deliveries. The database is hosted through AWS DynamoDB coupled with AWS Lambda for handling requests from our wireless module. One of the major advantages of using AWS 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. An example of the storage of our delivery information in DynamoDB is shown in Figure 7, which assigns a unique ID, timestamp, and status to each delivery.

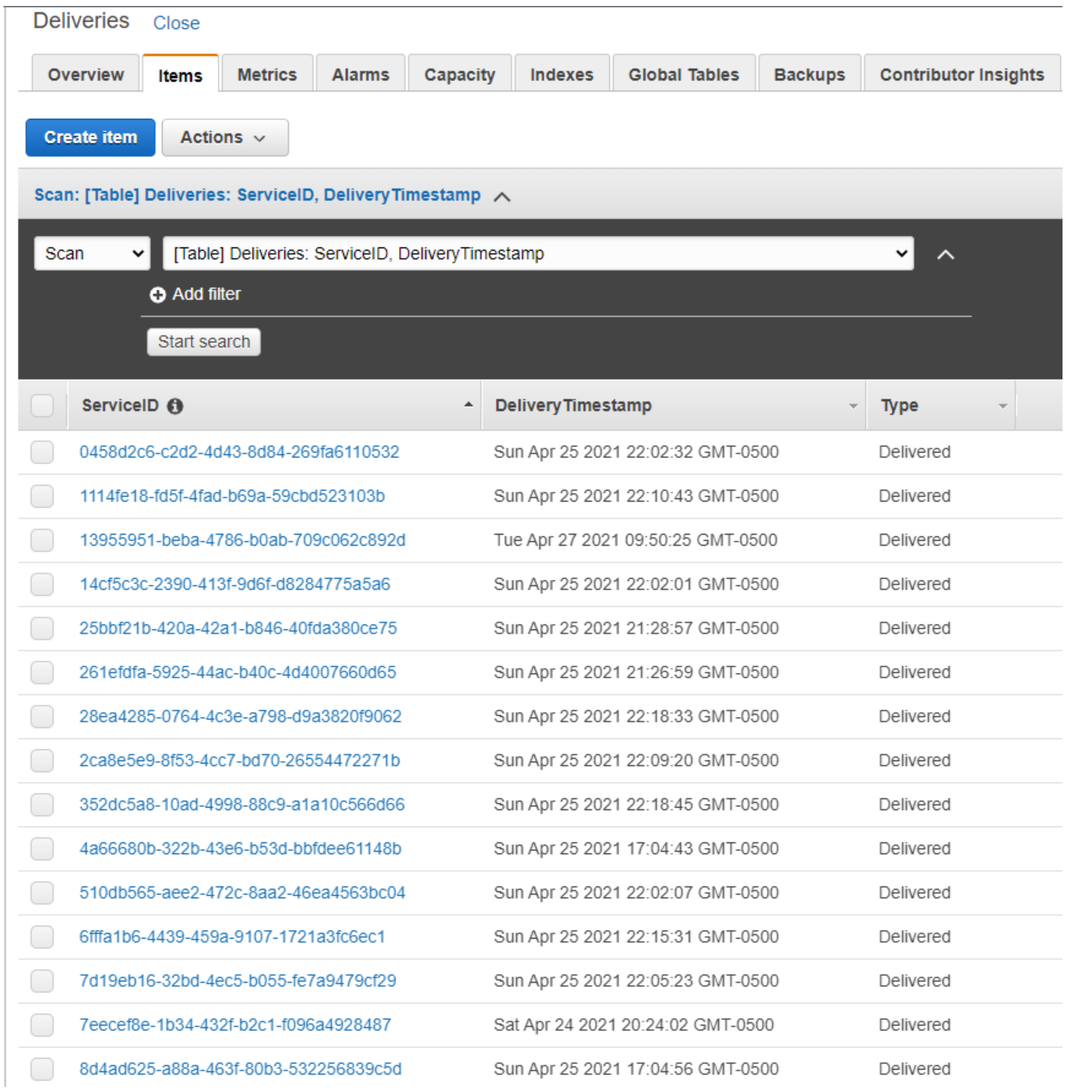

Figure 7: DynamoDB storage of delivery information

2.5.2 Smartphone Application

An Android/IOS app provides the customer with a user interface on their smartphones to communicate with the receptacle to view when their delivery has arrived. The smartphone app interacts with the system OS and is able to connect through WiFi to access the server that the receptacle publishes to. It also receives notifications informing the user that their package has arrived. Figure 8 shows the mobile application, displaying the timestamp of the delivery as well as the status. Delivery history is sorted by most recent arrival for ease of use.

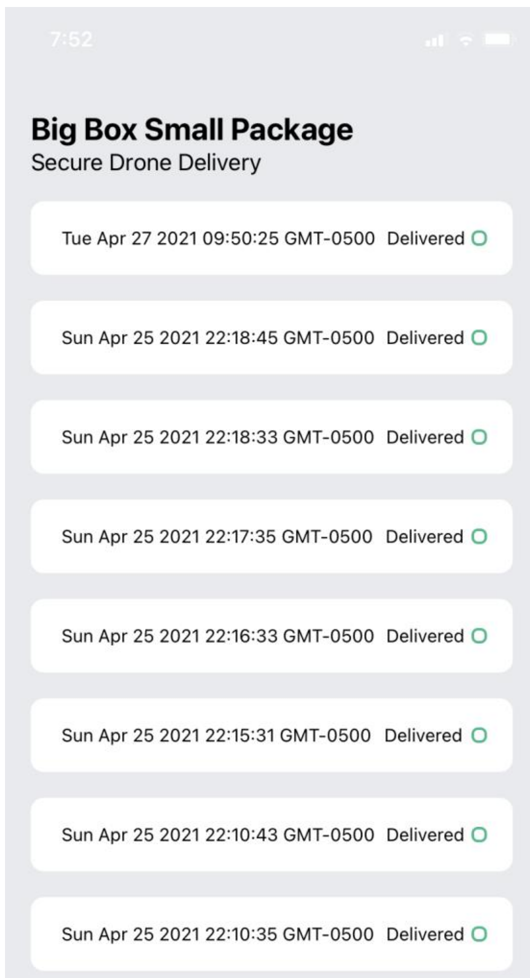

Figure 8: Mobile application and delivery status

2.6 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 provides a way to determine when the drone has reached its destination.

2.6.1 RF Transmitter and Receiver

The nRF24L01 RF transceiver was used to communicate between the drone and the receptacle. This particular transmitter/receiver operates at 2.4 GHz and offers bidirectional communication, opening up easier communication methods and less interference between the transmitter and receiver. We chose this module based on ease of use, affordability, and practicality.

3. Design Verification

3.1 Power Supply

3.1.1 AC/DC Converter

The AC/DC converter successfully powered the board with 12 V continuously for 5 minutes with no visible signs of circuit deterioration. In Table 1, we measured the voltage with respect to time, and over the course of 5 minutes, no significant change was observed. Figure 9 shows the output waveform of the AC/DC converter.

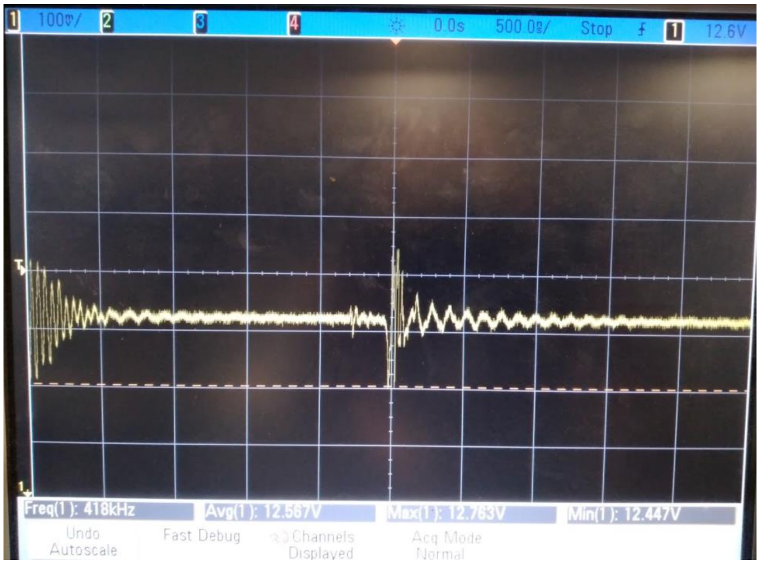

Figure 9: Output mean cycle waveform for the AC/DC converter

Time [s]	60	120	180	240	300
Voltage [V]	11.89	11.92	11.93	11.88	11.91

Table 1: AC/DC converter output voltage compared to time

3.1.2 Voltage Converters

The 3.3 V and 5 V voltage converters successfully converted the input 12 V to their respective output voltages. The waveform for the 3.3 V converter, shown in Figure 10, displays a significant amount of noise that ultimately caused issues with the RF module. The RF module is sensitive to noise, reducing its effectiveness to the point where it would not receive RF signals. To counteract this issue, we used an Arduino Uno to supply power to this module; however, the WiFi module remained powered by the 3.3 V converter. Again in Figure 10, we see the 5 V converter with less noise and an overall lower ripple than the 3.3 V converter.

$$\Delta i_{ripple} = \frac{Vin * D}{L * fsw} \text{ (Equation 1)}$$

$$\Delta V_{ripple} = \frac{\Delta i_{ripple}}{8 * C * fsw} \text{ (Equation 2)}$$

In Table 2, we compare the voltage ripple in the devices and we discover that the ripples are under 5%. Ideally, they should be approximately 1%, and this can be accomplished by using larger inductors and capacitors for each converter. In Equation 1, we see the current ripple is dependent on inductance L, where a larger inductance would result in a smaller current ripple. In Equation 2, we see the voltage ripple is dependent on the current ripple and capacitance C, where a larger capacitance would result in a smaller voltage ripple. If we were to redesign these converters, size would not be as important to us as it was initially, instead selecting the higher valued filtering devices would result in better performance.

	3.3 V Converter	**5 V Converter**
Ripple [mV]	150	200
Ripple [%]	4.54	4

Table 2: 3.3 V and 5 V converter ripple

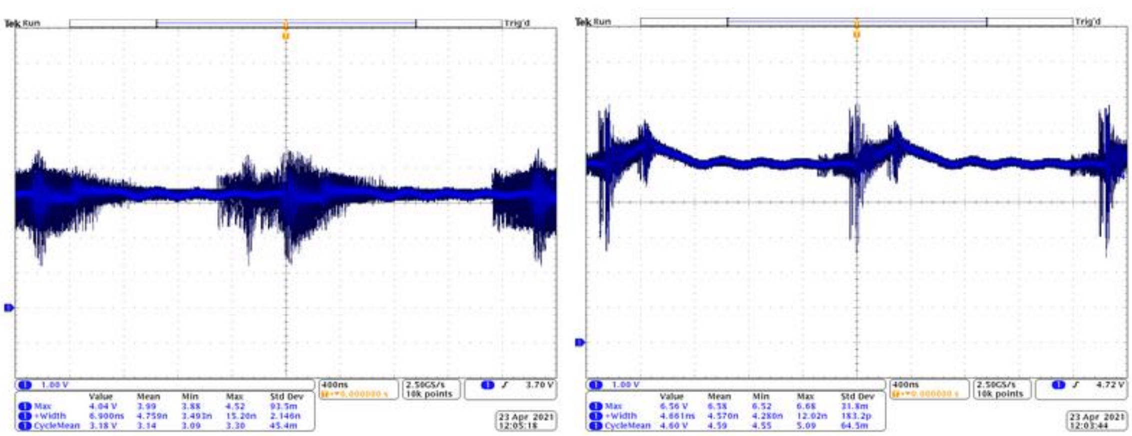

Figure 10: Output mean cycle waveform for the 3.3 V and 5 V converter

3.2 Control Module

3.2.1 Microcontroller

The ATmega328P was successful in receiving data from the ESP32 WiFi chip. This was seen visually from a test LED that lit up when the microcontroller decoded a signal sent from the ESP32 chip. It was also successful in controlling the gear motor relay circuit. A test program that sent signals to the relays that opened and closed the door based on button presses was loaded and visually confirmed to work.

3.2.3 Status LEDs

When the drone receptacle is powered on, an LED is lit, displaying that the motor is idle and in its “Neutral” state. Once the signal from the microcontroller is sent to the motor relay circuit to open the receptacle door, the neutral LED turns off and the open LED turns on signaling the “Open” state. When the door finally stops moving, the neutral LED turns back on, and the open LED turns off. The same occurs with the “Close” state, where the close LED turns on when the receptacle door closes, with the neutral LED lighting up when the door finally closes.

3.3.4 Pressure Sensor

When testing all the package types, listed in Table 3, we concluded that any item less than 10 grams is too small of a package to trigger the pressure pad; however, the padded envelope and all box types successfully triggered the pressure sensor. This makes sense, because these packaging types are commonly used for Amazon delivery, which fits under the design criteria. Anything smaller can be easily substituted for the mail service, and falls outside the scope of the design.

	Postcard	**Envelope**	**Padded Envelope**	**Small Box**	**Medium Box**	**Large Box**
Weight [g]	6.0	10.8	15.3	21.7	39.8	62.4
Triggers Pressure Sensor?	No	No	Yes	Yes	Yes	Yes

Table 3: Package types with the weight and sensor detection status

3.3 WiFi Module

3.3.1 WiFi IC

The ESP32 wireless module communication over UART was able to be verified using the serial interface of an Arduino as well as a USB to serial interface for visual output to the serial monitor of a computer. Successful communication was observed at baud rates up to 500 kbaud. We were also able to verify that the wireless module, when programmed as a wireless access point, appears in the list of available networks when viewed from a mobile device. This satisfied our second block requirement.

3.4 Mechanical System

3.4.1 Gear Motor Relay Circuit

The gear motor relay circuit was able to successfully take control signals from the microcontroller to operate the BJT amplifier circuit, which then would turn on the relay. The BJT circuit, in Figure 5, is necessary for the design because these relays require a voltage of at least 70% of the output voltage to turn on. Since the output voltage is 12 V, we need at least 8 V for these relays. Table 4 shows the truth table for the motor response. When both signals are low, the motor is negatively biased, and results in the closing of the door. When both signals are high, the motor is positively biased, and results in the opening of the door. When there is a mismatch, the door motor is not engaged. This is done to ensure that when the box is first turned on, and both signals are low, they will remain closed.

Signal #1	**Signal #2**	**Motor Response**
Low	Low	Close
Low	High	Neutral
High	Low	Neutral
High	High	Open

Table 4: Relay circuit truth table (Low = 0 V, High = 12 V)

3.5 Software

3.5.1 AWS Backend

Requests sent by the ESP32 module over HTTP were successfully logged through the AWS logs service, and no requests were observed to have been dropped or failed under a stable connection.

3.5.2 Smartphone App

We were able to verify the status of delivery being displayed on the mobile application, which is processed by the backend and written into the database. Afterwhich the mobile and web applications retrieve the data as shown by Figure 8. We also measured the app notification arrival time on the mobile and web interfaces, averaging under two seconds from the delivery event being sent by the microcontroller to the notification appearing to the user.

3.6 RF Sensor System

3.6.1 RF Transmitter and Receiver

The RF transmitter and receiver were able to communicate without any issue up to 10 feet. This was more than enough for the purpose of this project, where two feet of distance between the drone and the receptacle are needed. The three messages “Open”, “Neutral”, and “Close” are transmitted to the receiver effectively, with less than 100 ms of delay. LED indicators on receptacle light up when the microcontroller intercepts the correct data from the receiver.

4. 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
				Labor Cost	$54,000

Detailed Parts List:

Part Number	Description	Quantity	Unit Cost [USD]
Power Supply			
(Amazon; SNT1205BK)	Power Supply	1	$9.99
(Digikey; 1727-5841-1-ND)	Schottky Diode	2	$0.42
(Digikey; AIAP-03-470K-ND)	47 µH Inductor	2	$1.33
(Digikey; 490-13295-1-ND)	10 nF Capacitor	5	$0.10
(Digikey; LM2672N-3.3)	3.3 V Regulator	2	$5.56
(Digikey; PCE3888CT-ND)	330 µF Capacitor	2	$0.59
(Digikey; 493-2204-1-ND)	150 µF Capacitor	2	$0.51

(Digikey; 2299-TE6-1A-DC)	Power Switch	2	$1.15
(Digikey; PCE3750CT-ND)	100 µF Capacitor	2	$0.12
(Digikey; 399-5502-1-ND)	3.3 µF Capacitor	2	$0.30
(Digikey; PCE4304CT-ND)	4.7 µF Capacitor	2	$1.33
(Digikey; AIAP-02-4R7K)	4.7 µH Inductor	2	$0.54
(Digikey; 296-43596-1-ND)	5 V Regulator	2	$4.20
(Digikey; 300-6034-ND)	16 MHz Crystal	2	$0.54
(Digikey; ED3050-5-ND)	28 Pin DIP Socket	2	$0.33
Linear Actuator			
(Digikey; 255-2080-ND)	Relay	2	$3.26
(Digikey; EG1510-ND)	Rocker Switch	2	$2.22
RF Module			
(Amazon; 433 nRF24L01)	RF Module	10	$12.88
Control Unit			
(Digikey; ATmega328P-PU)	Microcontroller	3	$7.56
(Sparkfun; Sparkfun SEN-09376)	Pressure Sensor	1	$11.25
WiFi Module			
(Amazon; ESP32)	WiFi Module	1	$10.98
Total:			$85.55

The total cost is the sum of the cost of labor and parts which amounts to $54,085.55.

5. Conclusion

5.1 Accomplishments

We successfully tested all of our modules independently on the PCB. With the exception of the high noise from the 3.3V regulator output, all of the modules were fully functional. The wireless module was able to successfully read a request for a delivery event from the serial interface, and the mobile application was able to display the notification within seconds of the delivery. Our relay system was able to control the motors to a fully opened and closed position, and the RF signals sent by our drone simulation were able to trigger the state of the receptacle to simulate the open and closed routines.

5.2 Uncertainties

Although our modules functioned independently, we had a problem integrating the motor into the full circuit. When the motor was integrated into the circuit, there was a large current draw with subsequent overheating to the rest of our sensitive circuitry, especially the RF transceiver.

5.3 Ethical Considerations

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

As the secure drone receptacle is designed for outside placement in a similar function to a mailbox, the receptacle needed 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 [5].

Careful consideration is also necessary for operation and modification for the operation and modifications of the drone as well. Since the RF communication module is designed to be installed on the drone, 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 to deliver packages in a secure manner, access to the inner contents should be restricted to the owner of the drone receptacle 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 owner's delivery box, include information about the arrival time. 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].

5.4 Future Work

One area of improvement would be to fix the overheating problem associated when the motor is combined into the circuit. One solution would be to use a current regulator which isolates our current sensitive circuitry on our PCB away from the motor circuit.

Another step forward would be to incorporate a drone to the project and attach our RF module onto it for further testing. Our project made many assumptions and offsetted a lot of responsibility to the drone. These assumptions are equally important for our project in a real commercial application. It is assumed that the drone has the capability of hovering over the receptacle with such accuracy that the delivered object would be able to land perfectly inside each time. This may not necessarily true and may require that the receptacle have additional mechanisms that help the drone lock onto the target. Additionally, the door to the receptacle only opens up a maximum of 90 degrees, standing vertically. This may obstruct the drone's vision and require a higher hovering distance to deliver the package. It would be more practical to have a horizontally sliding door.

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] J.-P. Aurambout, K. Gkoumas, and B. Ciuffo, “Last mile delivery by drones: an estimation of viable market potential and access to citizens across European cities,” European Transport Research Review, vol. 11, no. 1, 2019.

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

7. Appendix A

Requirements	Verification	Results
AC/DC Converter		
➢ The power supply must continuously deliver 12 V DC from a 120 V AC wall supply.	❖ With a voltmeter, probe the outputs to ensure that the voltage is within the necessary 12 V range.	Yes
Voltage Converters		
➢ The voltage converters must continuously deliver 3.3 V and 5 V from a 12 V source with a ripple within ±1%.	❖ Use an oscilloscope to capture an image of the waveform to ensure the ripple is within ±1%.	High ripple, average voltage satisfied
Microcontroller		
➢ The ATmega328P must be able to communicate with the WiFi module over UART.	❖ Connect the ATmega328P serial UART interface to an ESP32 development board connected to a computer over USB. Write a program for ATmega328P that lights an LED when it receives a particular character byte. Send the byte of characters to the ESP32 and verify that the LED lights up.	Yes

➢ Sends control signals to the gear motor relay circuit to open/close it.	❖ Write a program that sends a low voltage signal to the gear motor relay circuit, activating the motor that opens and closes the door based on button presses. Visually verify that the motor actuates correctly.	Yes
Status LEDs		
➢ Must be reasonably visible 1 meter away, and display the correct lights when the box is powered, the box is empty, and when then there is a package inside.	❖ Attach the LED in series with the correct resistor such that the LED is sufficiently reasonably bright a meter away.	Yes
Pressure Sensor		
➢ The sensor must be able to accurately detect that a package of less than 5 lb (2268 g) can be detected on the package pad.	❖ Write a program that prints on the serial monitor if a package is delivered. Using different package sizes (postcard, envelope, padded envelope, small box, medium box, and large box), observe if the package is detected. Calibrate sensor such that packages less than 5 lb can be detected.	Yes

WiFi IC		
➢ The WiFi module must support UART communication.	❖ Connect the UART interface to a verified device, perform a write of known data over the interface; read the data back over UART, ensure integrity.	Yes
➢ The WiFi module must operate at a minimum bandwidth of 1Mbps in IEEE 802.11b mode.	❖ Assemble WiFi IC on PCB according to the datasheet. On a mobile device, check that WiFi network appears in the list of nearby networks.	Yes
Gear Motor Relay Circuit		
➢ The 12V DC input must supply a voltage within ±5% across the relay system.	❖ Relay #1 reads 0 V while Relay #2 reads 12 V. Relay #1 reads 12 V while Relay #2 reads 0 V.	Yes
AWS Backend		
➢ The AWS Lambda instance supports GET and POST requests through HTTP.	❖ Define GET and POST endpoints through the AWS Lambda console. From the ESP32, send a GET method request followed by a POST method request over HTTP. Verify that the GET and POST requests appear in the AWS logs.	Yes

Smartphone App		
➢ The app correctly displays status signals for deliveries whether it has or has not arrived.	❖ Place the box inside the receptacle and configure it to replicate when a box is delivered; record that App status shows a package is delivered.	Yes
➢ App displays smartphone notification that a package has arrived within 1 minute of arrival.	❖ Send a signal through the database that sets the status signal that a package is sent and verify that a notification appears on the phone within 1 minute.	Yes
RF Transmitter and Receiver		
➢ The RF transmitter must send control messages to the RF receiver.	❖ Write test code to send an "Open", "Neutral", and "Close" command; record the message on the receiver.	Yes
➢ The RF transmitter signal must be detected within a 5 ft radius of our receiver.	❖ Test the transmitter and receiver from a progressively further distance away to bound the limits of the signal detection.	Yes