BIG BOX, small PACKAGE - SECURE DRONE DELIVERY

DESIGN DOCUMENT:

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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 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 system must communicate with the drone to know when to open the dropoff door.
- The receptacle must open up for the drone's arrival, such that the delivery can be dropped off. Once the package has been deposited and the drone departs, the receptacle must close.

- The wireless system and the control unit must notify the user when the package has arrived using the web page or mobile application.

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 page and mobile application designed to inform the user of any packages that have arrived.

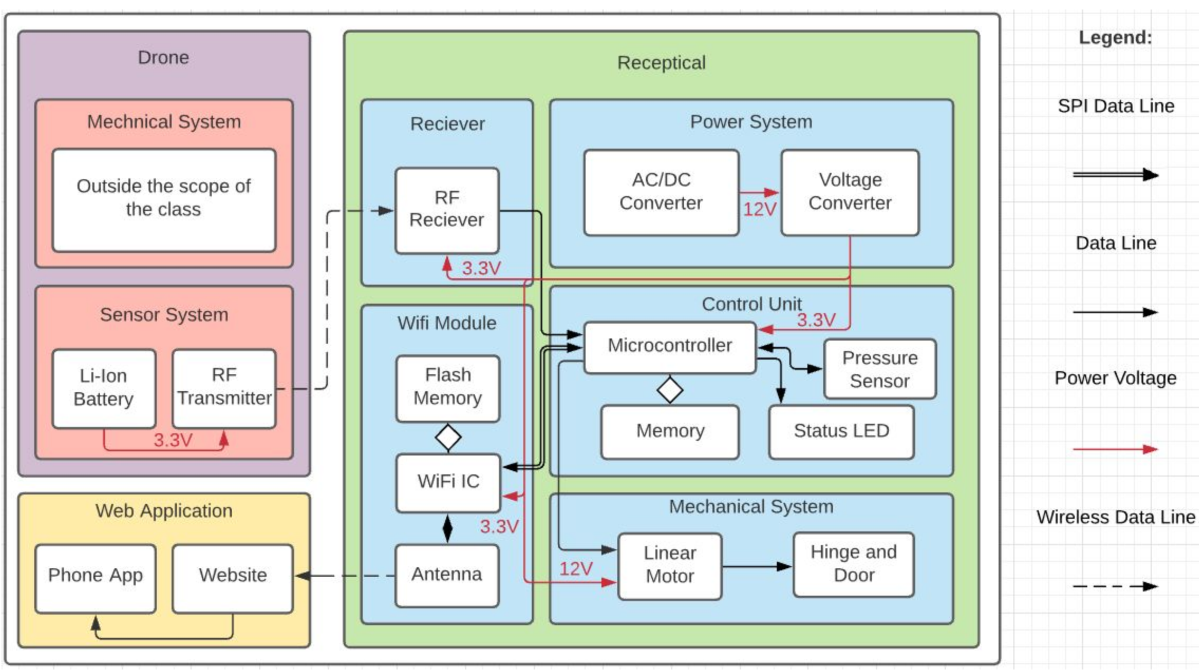


Figure 2: Block Diagram

2.1 Power Supply

A power supply is necessary to keep the receptacle operational at all times. With the use of an internal battery pack, managing different subsystem voltages consistently is possible, safely and securely. With a secure power supply, the receptacle can operate without the threat of power loss due to environmental disasters and inclement weather.

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. The 12V is then delivered into a voltage controller with an output voltage of 3.3V.

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 wifi module, control unit, and receiver module all require this lower input voltage in order to properly function.

Requirements	Verification
The voltage converter must continuously deliver 3.3V DC from a 12V DC source. The subsystems that require 3.3V are the wifi, control, and receiver modules.	A. Using a voltage meter, probe the end and determine if the component 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.

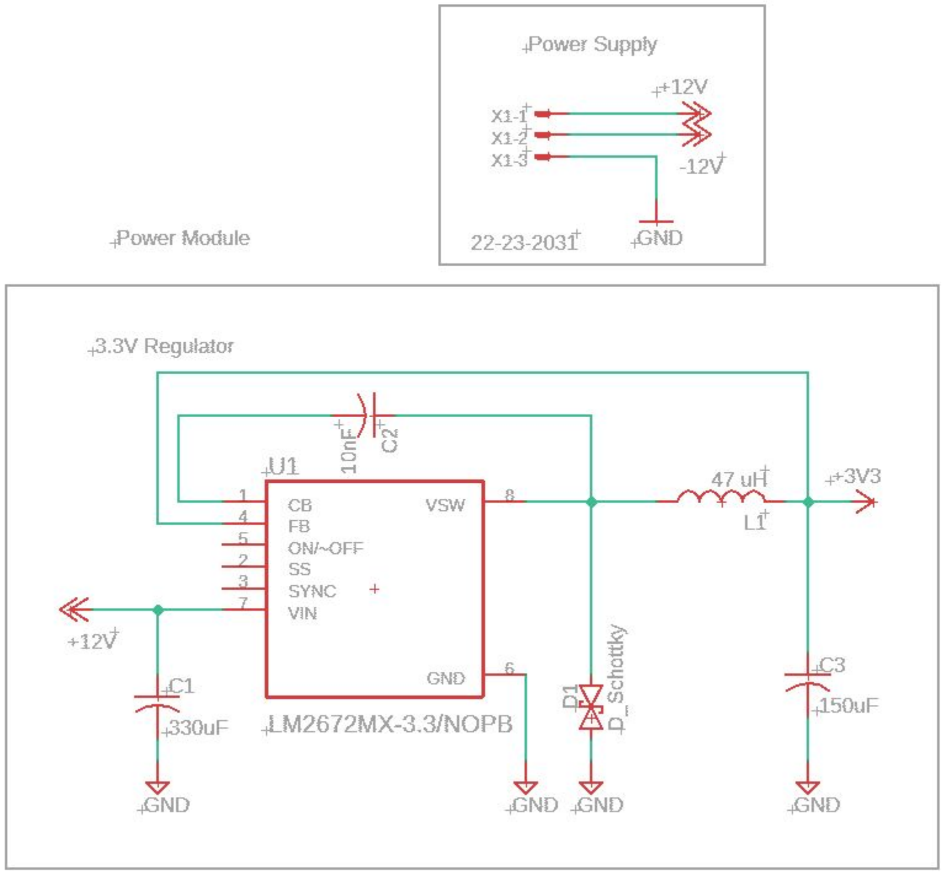


Figure 3: Power Module Schematics

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
A. Powered at a constant 5V. B. Able to communicate with the wifi module, allowing it to poll the appropriate signals. C. Sends control signals to the linear motor circuit to open/close it. The microcontroller must be	A. Flip the power switch and probe the input voltage is a steady 5V. B. C. Write a program that sends a signal to the linear actuators to make it move linearly. D.

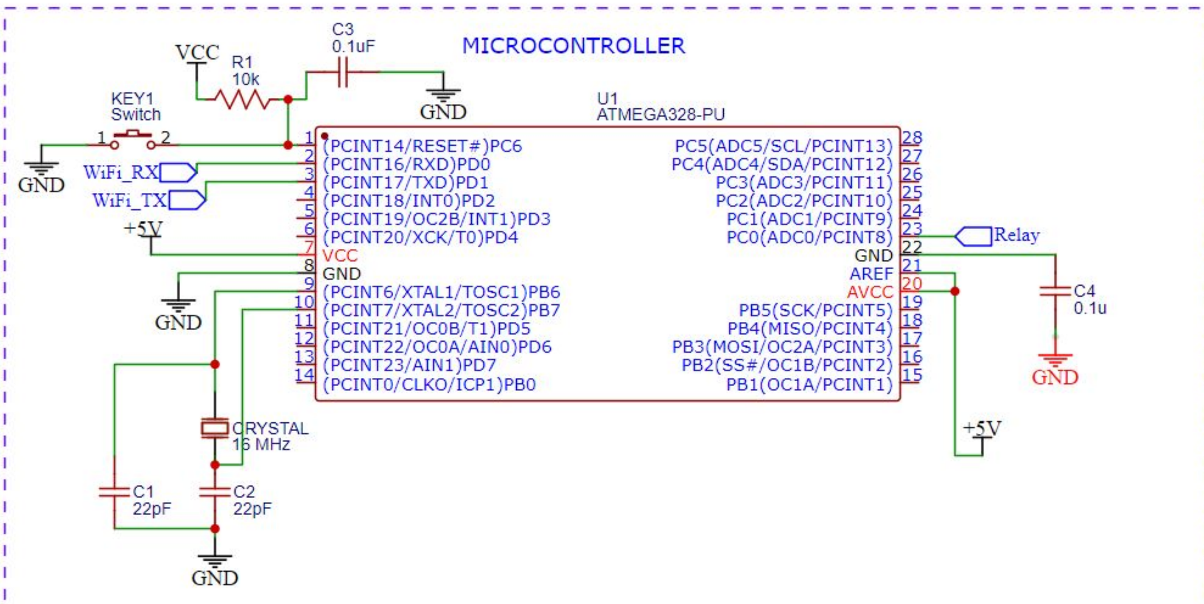


Figure 4: Microcontroller Schematic

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	A. Attach the LED in series with the

display the correct lights when the box is powered, the box is empty, and when then there is a package inside.	correct resistor such that the LED is 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. They 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 ground and flip the bias ensuring the actuator extends and reduces correctly.

2.3.4 Pressure Sensor

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

Requirement	Verification
Must send a signal to the microcontroller that a package of less than 1 kg.	A. Set a small mass of 5 kg on the sensor of various proportions to determine if the sensor picks up the existence of the package. B. Repeat using packages of 1kg less until the sensor can sense a package of 0.5 kg can be detected.

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

We chose the ESP32 Microcontroller to serve as our wireless access point, as it has integrated WiFi and Bluetooth capabilities. The ESP32 also supports common communication protocols such as SPI and UART, allowing for exchange of data across the ESP32 and the microcontroller responsible for the data collection and control of the main receptacle.

Requirement	Verification
A. Supports both SPI and UART communication	

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. For our purposes the wireless communication requires a low bandwidth of less than 1Mbps which is within the bounds of the WiFi IC capabilities.

Requirement	Verification

2.3.3 Flash Memory

The flash memory module contains the program memory for the WiFi IC, connected synchronously through SPI. Our estimates of initial program size are well under 1MB so choosing an appropriate module can help save costs in the future.

Requirement	Verification
A. Supports SPI communication B. Have approximately 1MB or less amount of storage	A. Perform read and write operations through the microcontroller over the SPI interfaces B. Write the supported size of known data to memory, 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

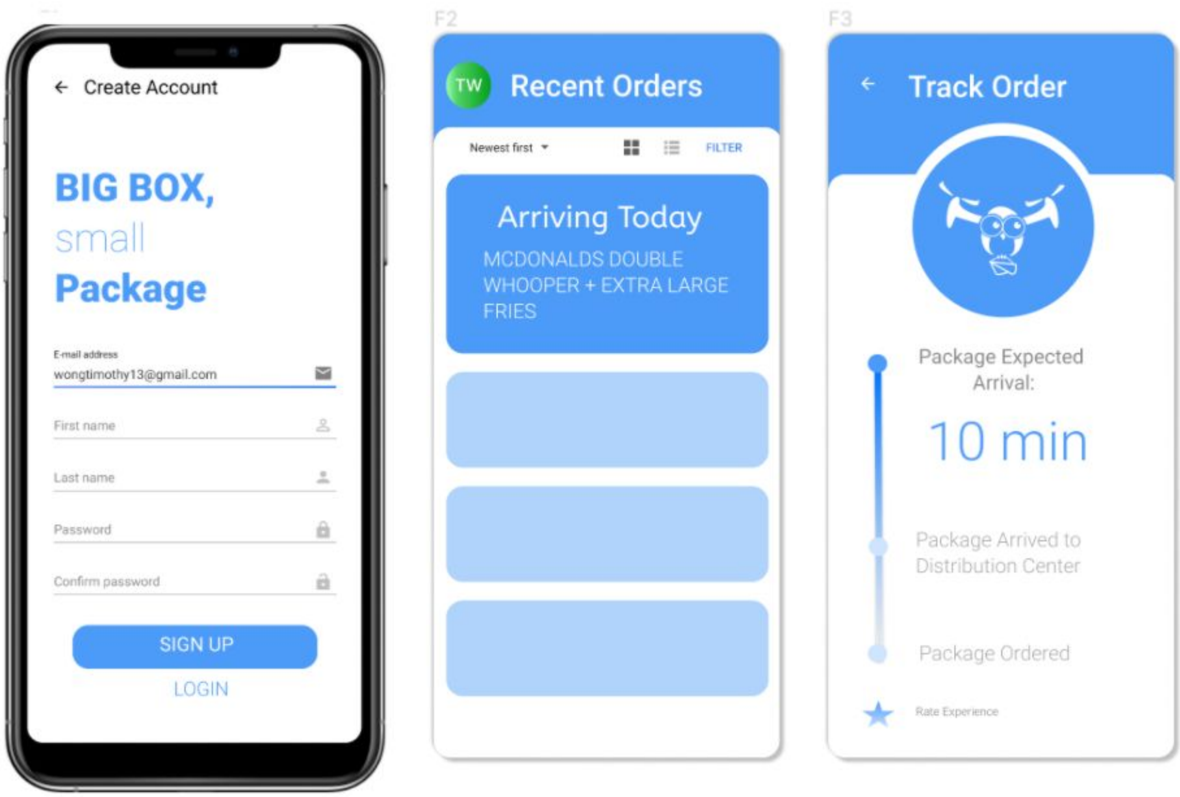
- A database is used to manage data of the status and locations of the drone/drones and receptacles. The database will be hosted through AWS DynamoDB coupled with AWS Lambda. One of the major advantages here is that they offer a free tier and that we would not have to maintain any hardware ourselves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

Requirement	Verification
A. Database tables can be updated. B. Database data is persistent. C. Database data can be read. D. Database data can be deleted.	A. For verification, we will 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 over is able to connect with WiFi to access the server that the receptacle publishes to.



Draft of the Prototyped UI

Requirement	Verification
A. Is able to interface with the microcontroller through WiFi. B. Login for users to create/access accounts and register their box. C. The app correctly displays status signals	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.

for deliveries whether it has or has not arrived, on its way, and time for expected delivery.	

2.4.2.2 Smartphone App Algorithm

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 Li-Ion Battery

Requirement	Verification

2.5.2 RF Transmitter and Receiver

Requirement	Verification

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 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.

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

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

From the data sheet of the WiFi IC we find that it is sensitive at -98 dBm at 1Mbps operating in 802.11b mode and sensitive at -88 dBm at 11Mbps in 802.11b mode.

[max range calculation using these values here]

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 Cost	$54,000

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	5	5 x $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			
Control Unit			
ATmega328P	Microcontroller	1	$2.52
WiFi IC(ESP32)	Microcontroller with integrated WiFi	1	$7.50
PCB	PCB	1	$50

4. Schedule

Week	Timothy Wong	Phillip Jedralski	Christian Fernandez
March 1	1. Design Document 2. Order Parts	1. Design Document 2. Finish ordering Power Module parts	1. Design Document 2. Finish ordering Wireless Module parts
March 8	1. PCB design 2. Programming microcontroller	1. Test linear actuator 2. Submit design to Machine Shop	1. Begin working on PCB layout 2. Start testing of ESP32 wireless communication
March 15	1. Work on an Android app	1. Solder and test components on PCB 2. Test RF signals	1. Implement AWS backend endpoints
March 22	1. Synthesize everything	1. Resubmit PCB design	1. Finalize wireless software components
March 29	1. Debugging/Testing	1. Debugging/Testin g	1. Debugging/Testing
April 5	1. Full system testing	1. Debugging/Testin g	1. Full system testing
April 12	1. Prepare for Mock Demo	1. Prepare for Mock Demo	1. 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].