Secure Mailbox with Mobile Connectivity

ECE 445 Final Report - Spring 2023

Team 26

Neehar Sawant, Avadh Patel, Roshun Navin

TA: Vishal Dayalan

Contents

1. Introduction **3**

1.1 Problem **3**

1.2 Solution **3**

1.3 Visual Aid **4**

1.4 High-level Requirements List **5**

2. Design **6**

2.1 Block Diagram **6**

2.2 Physical Design **7**

2.3 Subsystems, Requirements, and Verification **9**

2.4 Quantitative Analysis **17**

3. Costs **18**

4. Conclusion **19**

4.1 Accomplishments **19**

4.2 Future Work **19**

4.3 Ethics and Safety **20**

5. Citations **21**

1. Introduction

1.1 Problem:

Mail is a prevalent form of communication in today's world, transmitting sensitive information like bank statements and checks to countless households nationwide. Although keys to apartment building mailboxes are typically only held by the mailman and tenant, conventional mailboxes in single-family homes and townhomes can be easily accessed by anyone. As a result, millions of Americans lack secure means of mail storage, leaving mail vulnerable to theft for extended periods if not retrieved promptly. According to a local news article, checks sent via mail are often stolen, prompting authorities to advise citizens against leaving sensitive materials in mailboxes overnight and instead handing them directly to the mail carrier. Although electronically locking boxes are available for secure package delivery outside the front door, a similar solution for mail that is both secure and can replace traditional mailboxes is currently unavailable.

1.2 Solution:

Our proposed mailbox has two primary features. The first is an automatic locking mechanism that engages when mail is deposited inside. The second allows the user to schedule a time period for the mailbox to remain unlocked, useful for multiple deliveries during the day. Real-time notifications are sent to the user via a mobile application when the mailbox is opened, closed, or when new mail is deposited. The app also allows the user to manually lock and unlock the mailbox and set a schedule for it to remain unlocked. If no schedule is set, the mailbox assumes that only one delivery is expected per day, and will lock automatically after the first deposit and closing of the mailbox door.

The mailbox's implementation involves the use of a magnetic contact sensor that signals the PCB when the mailbox is opened, putting it in a ready state and waiting for the close signal. When the mailbox door is closed, the sensor sends another signal to the PCB, which triggers the locking mechanism to engage. The PCB also connects to the mobile application through the ESP32, which has built-in wireless capabilities, to send lock and unlock signals for controlling the mechanism's actions. The app will also allow users to schedule windows for unlocking the

mailbox. The system uses multiple ultrasonic sensors to detect mail covering them, which is relayed back to the PCB and sent to the mobile application to alert the user of mail. The locking mechanism is driven by a small, low-power motor attached to a metal extension to secure the lock.

1.3 Visual Aid:

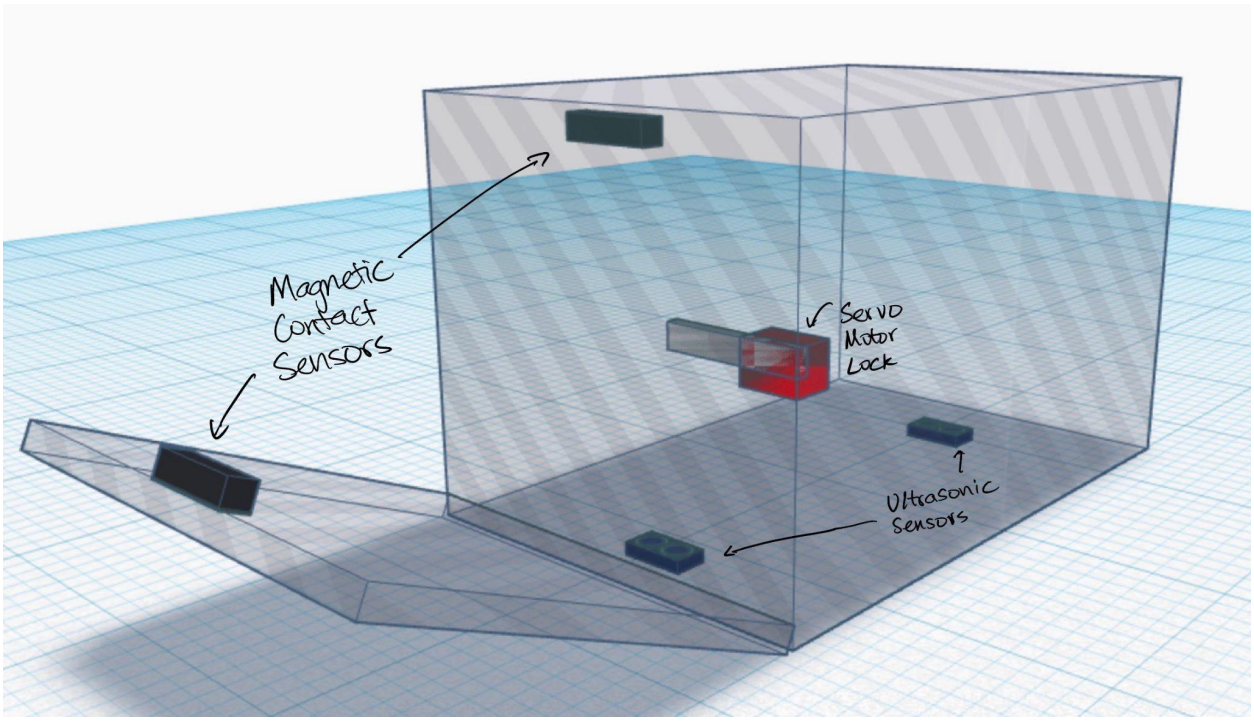


Figure 1: Full Mailbox with Labeled Sensors

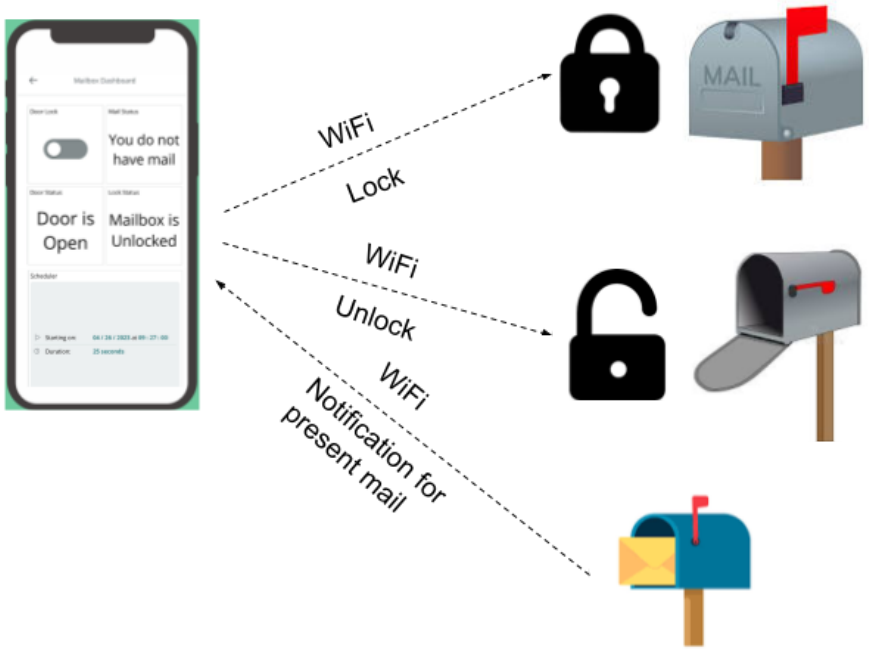


Figure 2: High Level Diagram

1.4 High-level Requirements List:

For our project to be successful, we will implement these requirements:

1. The mailbox must automatically lock within 10 seconds of the door being closed if mail is placed inside and there is no schedule set to leave it unlocked.
2. The mailbox must lock and unlock within 5 seconds of pressing the corresponding button on the application.
3. The mailbox must send a notification within 30 seconds of an action being made on the mailbox. This includes opening and closing the mailbox as well as whether mail is present.

2. Design

2.1 Block Diagram:

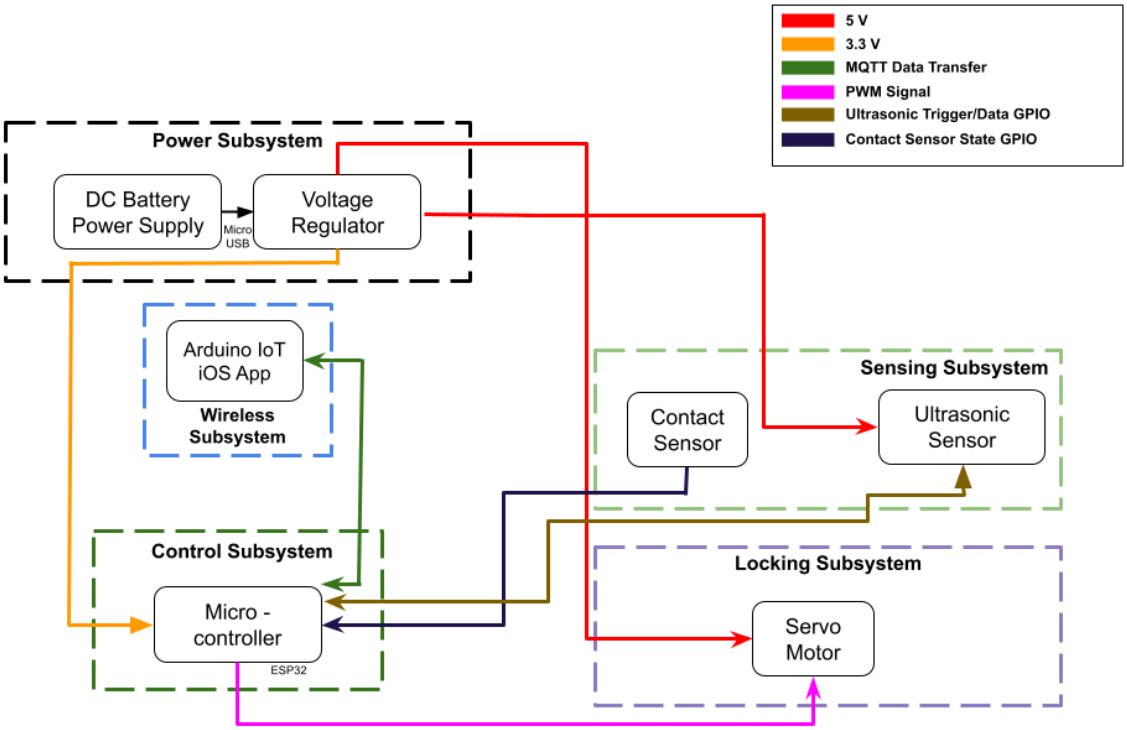


Figure 3: Block Diagram

2.2 Physical Design:

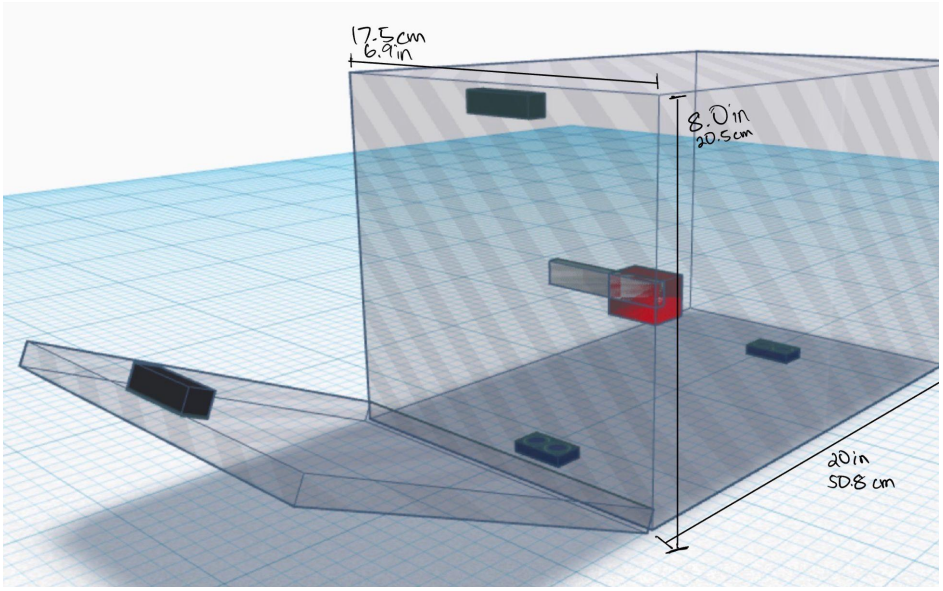


Figure 4: Original Design Sketch (Meets Federal Requirements)

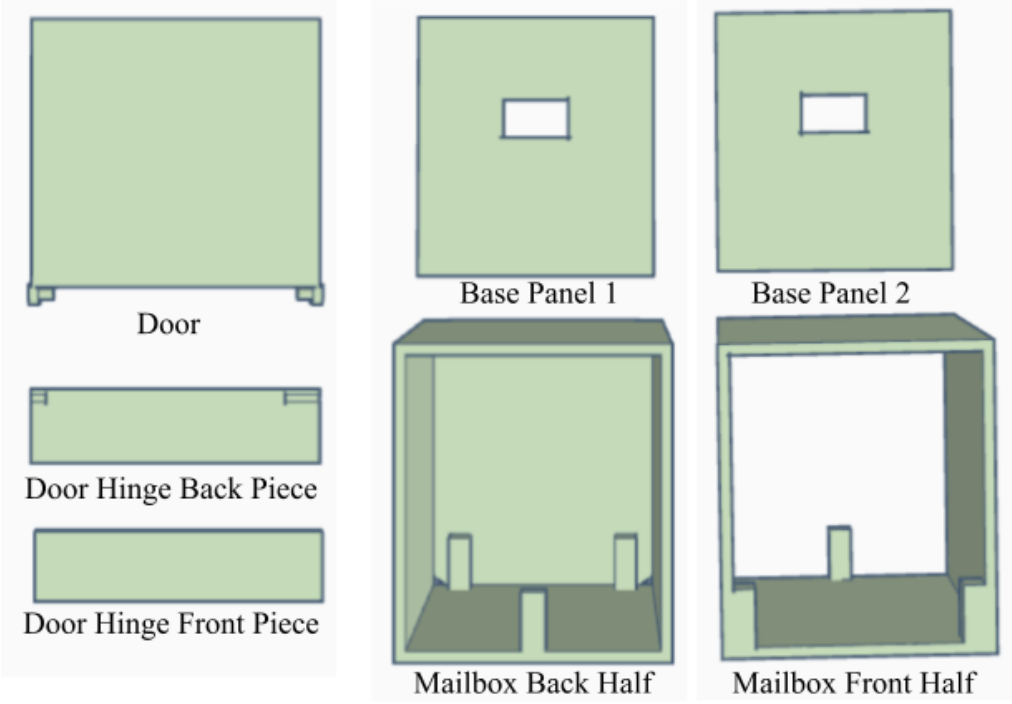


Figure 5: 3D Printed Design Components

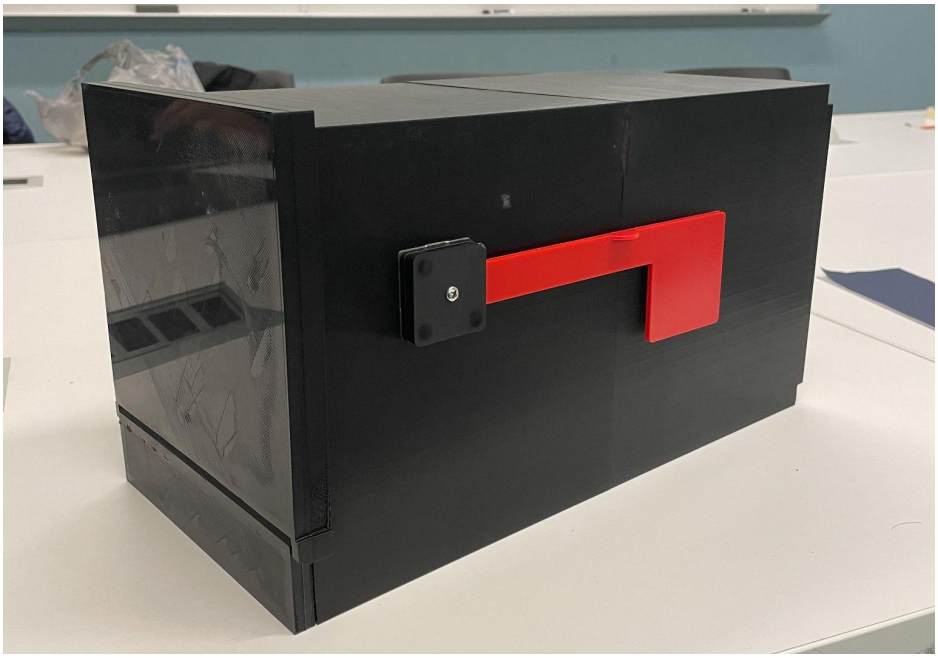


Figure 6: Final Design

Figure 7: Interior View

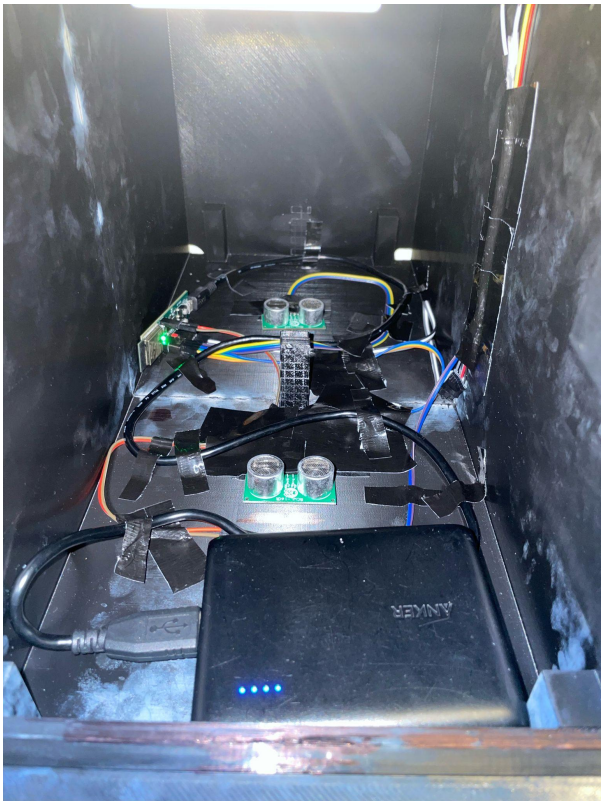


Figure 8: Sensor Storage View

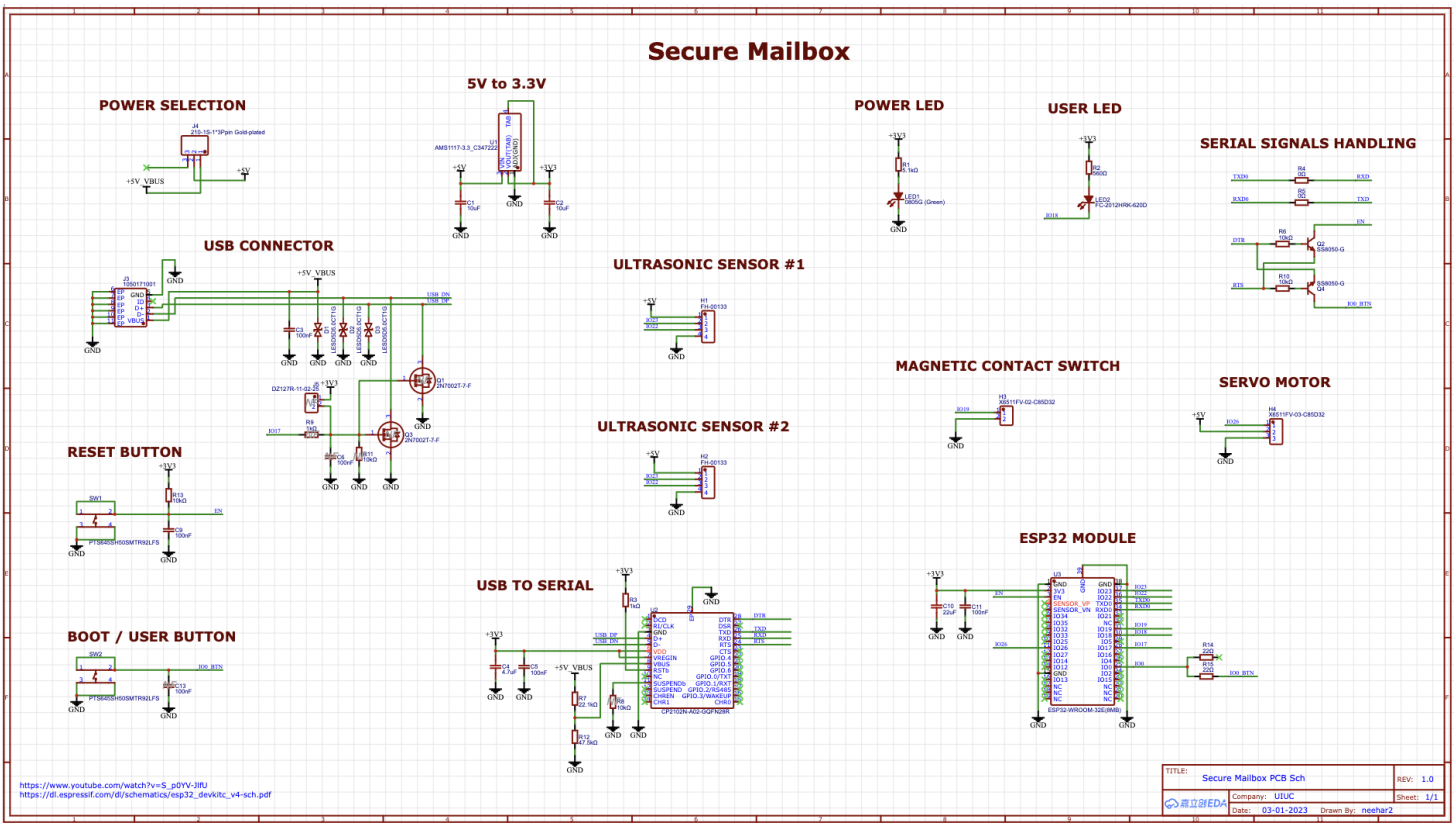


Figure 9: Complete Circuit Schematic

2.3 Subsystems, Requirements, and Verification:

2.3.1 Power

This subsystem provides the needed power to each component of the circuit using a standard 5V micro-USB connection from a portable battery bank. There will need to be voltage and current regulation to prevent damage to components on the PCB. The initial voltage of 5V is decreased to 3.3V for the ESP32 microcontroller. The 5V is used for the ultrasonic sensors and the servo motor. Voltage regulators create a distinct voltage across them making it easy to have an accurate measurement of the output voltage.

Requirements	Verification

• The voltage to the Motor and Wireless subsystem is 5 V ∓ 0.25 V • The voltage for the digital components is 3.3 V ∓ 0.165 V measured	• Use a 100 ohm resistor and using a breadboard place it in series with the 5V output and using a multimeter verify the voltage across the resistor is 5V. • Use a 100 ohm resistor and using a breadboard place it in series with the 3.3V output and using a multimeter verify the voltage across the resistor is 3.3V.

2.3.2 Control

The control subsystem receives and processes data from the wireless and sensing subsystems, then communicates with the wireless and locking subsystems to ensure the mailbox is appropriately locked or unlocked. The control subsystem uses a microcontroller, specifically the ESP-WROOM-32, to facilitate communication with the other subsystems. The microcontroller has built-in Wi-Fi connectivity, enabling it to connect to a server to communicate with the mobile application. When the sensing subsystem sends signals to the microcontroller, it relays the information to the mobile application to alert the user and the locking subsystem if necessary. Additionally, the microcontroller receives data from the mobile application for manual lock/unlock commands or scheduled deliveries, and sends the appropriate signals to the locking subsystem.

Requirements	Verification
• Mailbox locks 9 seconds after mail is placed inside	• Observe mail being placed inside and door closing and then the locking

• Send and receive data from ultrasonic sensors, receive state information from magnetic contact sensor, send state to servo motor	mechanism closing. • Print incoming data from ultrasonic and magnetic contact sensors in serial monitor and ensure they are correct.

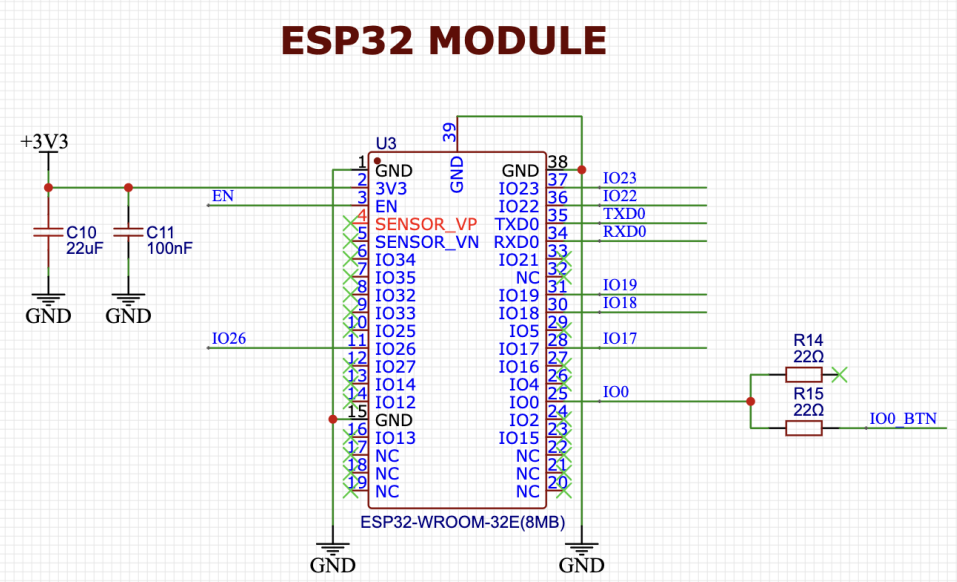


Figure 10:

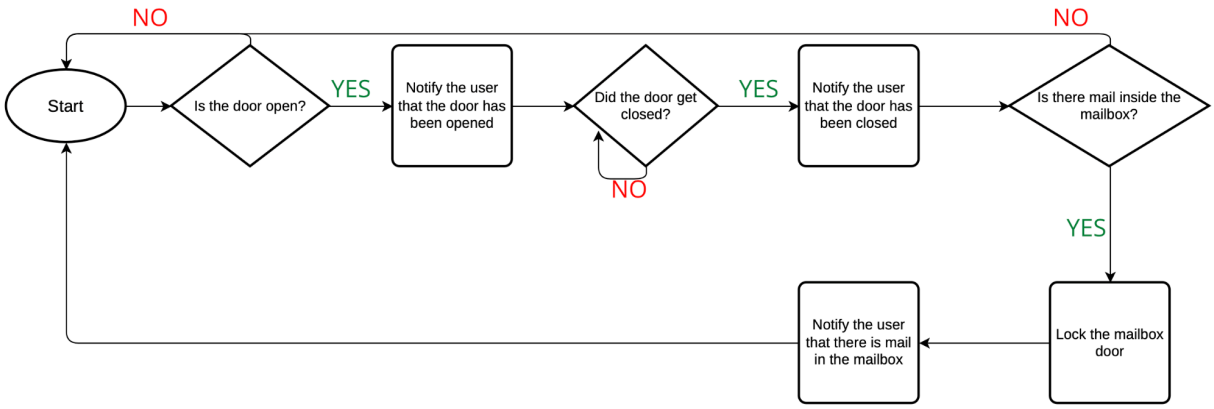
ESP32 Microcontroller Circuit Schematic

2.3.3 Wireless

To enable users to interact with the mailbox, we have leveraged the Arduino IoT Cloud and their iOS application to control its behavior. WiFi is used for communication between the mailbox and the application, maximizing range and usability. The door automatically locks after being opened and closed for the first time, triggering a notification to be sent to the user informing them that the mailbox has been opened, closed, and locked. Another notification will also be sent if mail is present inside the mailbox. The user can manually lock and unlock the mailbox via the application. When the user manually unlocks the mailbox to retrieve their mail and closes the door, it reverts back to its default state where the door is unlocked and waiting for mail. Users can also schedule when the mailbox will be unlocked, providing greater flexibility and security for when they are expecting multiple packages. The mailbox uses the user-set

interval as the default behavior on scheduled days and defaults back to the original functionality on non-scheduled days. Figure 11 shows the logic.

Figure 11: Software Flowchart



Requirements	Verification
• Mailbox locks or unlocks within 5 seconds of hitting the corresponding button on the application • Application sends notification to user within 30 seconds of action on mailbox (Open, Closed, Mail Present) • Mailbox unlocks and locks as given by a user inputted schedule	• Observe servo motor and verify that it moves to 90° when lock is pressed and near 160° when unlock is pressed on the IOT application • Verify that a notification is delivered from the IFTTT application on any mailbox action through the notification center • Observe the lock status on the IOT App and mailbox to ensure that the mailbox is unlocked when the schedule starts and that it is locked when the schedule ends

Mobile Application Sketch:

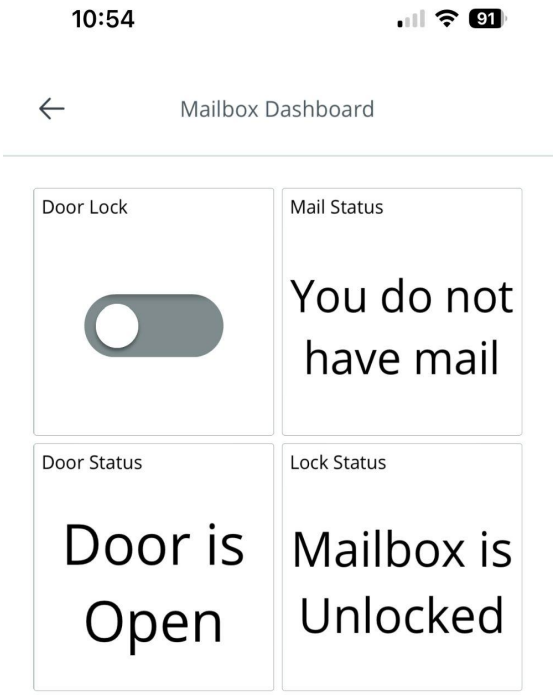


Figure 12: Door Lock/Statuses

This screen is from the Arduino IOT iOS app. It has the door lock button which allows the user to manually lock and unlock the mailbox. Additionally, it also has status boxes for the mail, door, and lock. If mail is put into or taken out of the mailbox the mail status will change. If the door is closed the door status will change. If the mailbox is locked, the lock status changes to say that the mailbox is locked.

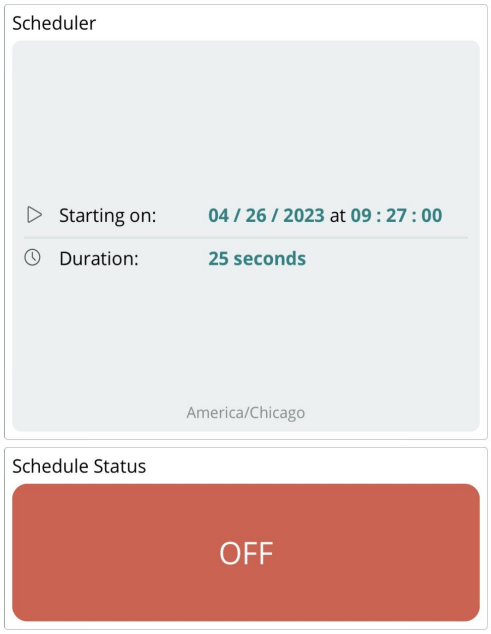


Figure 13: Scheduling

This part of the application allows the user to schedule the mailbox to be unlocked for as long as the user wants. This screen allows you to enter the date and time range the user wants the mailbox in the unlocked state. The user is also able to see whether or not their schedule is on with the schedule status display.

2.3.4 Sensing

The sensors from our system have two main components: a magnetic contact sensor (COM-13247) and two ultrasonic sensors (HC-SR04). The magnetic contact sensor is placed on the door and on the roof of the mailbox to determine whether the door is closed. The ultrasonic sensors are placed at the bottom of the mailbox to determine if there is mail in the mailbox.

The magnetic contact sensor and the ultrasonic sensor have been set up to send data to the control system for managing both the locking mechanism and wireless subsystem for notifications. Whenever the magnetic contact sensor's two contact parts go from being together to separated or vice versa, it sends a signal to the microcontroller notifying that the mailbox has been either opened or closed. Based on the signal received, the control subsystem can determine

whether the door has been opened or closed, enabling it to communicate with the wireless subsystem to send a notification to the user. The ultrasonic sensors have been configured to detect whether there is mail inside the mailbox. Whenever the door is closed, the ultrasonic sensors will send a signal to the control system. If the signal indicates that there is something placed over either of the ultrasonic sensors, the control system can infer that there is mail inside the mailbox. The control subsystem will communicate with the wireless subsystem to notify the user if there is mail present in the mailbox.

Requirements	Verification
• Magnetic contact sensor sends the correct signal when it is either separated or brought back together when the mailbox door is opened and closed respectively • Ultrasonic Sensor sends a signal to the control subsystem if an object is 2-17 cm from the sensor	• Connect one wire of the contact sensor to ground and probe the other wire with a multimeter. Bring the two sensors nearby and view the change in voltage/resistance on the multimeter and ensure there is no change when the two parts are not in contact. • Connect the ground and power pins of the ultrasonic sensor. Connect the trigger to a signal generator and a microcontroller will be required to connect to the echo. Send the trigger signal to the sensor and place objects such as mail at various distances away from the sensor and ensure they are correct distances

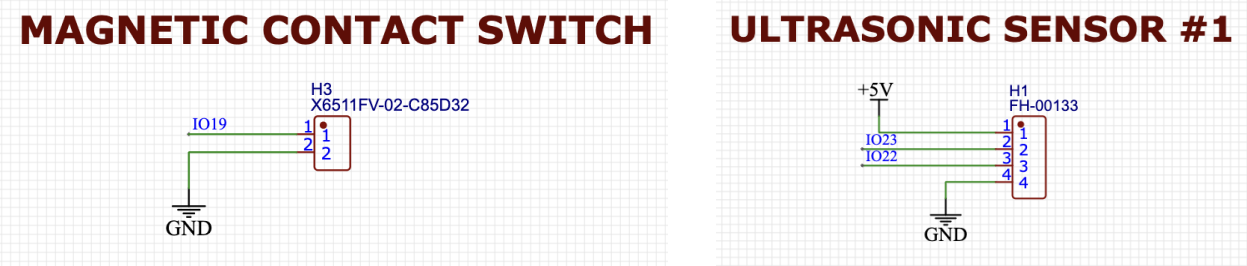


Figure 14: Sensor Schematics

2.3.5 Locking

A servo with a connector (HS-311 Standard Economy Servo) is mounted inside the mailbox which works in conjunction with a piece mounted to the mailbox door. The locking subsystem receives its information from the microcontroller after taking into account the status of the magnetic contact and ultrasonic sensors from the sensor subsystem as well as the manual unlock and lock of the mobile app from the wireless subsystem**.**

To control the servo motor's location, a Pulse-Width Modulated signal is used. This signal changes the servo's position by adjusting the pulse width over a repetitive period. The HS-311 servo motor can receive a pulse width between 0.9 ms and 2.1 ms and operates at a frequency of 50 Hz, which means that the period is 20 ms. A pulse width of 0.9 ms moves the servo location to 0 degrees, while a pulse width of 2.1 ms moves it to 180 degrees. A pulse width of 1.5 ms moves it to 90 degrees, which is the range we want the servo to always stay in. An angle of 0 degrees indicates that the mailbox is unlocked, and 90 degrees indicates that it is locked. Once the microcontroller receives the notification to lock or unlock the mailbox, it sends a continuous pulse width of 1.5 ms or 0.9 ms to move the servo to the correct position.

Requirements	Verification
• Servo Motor is able to move into the correct locking, 90°, and unlocking, 160°, positions in the mailbox	• Connect a signal generator to the servo motor using appropriate wiring, set the signal generator to output a PWM signal at 50 Hz, connect the servo

	motor to a power source of 5 V, and connect it to ground. Send a PWM signal with a width of 1.5 ms to ensure that the servo moves to 90 degrees. Repeat the process and send a PWM signal with a width of 1.88 ms to ensure that the servo moves to 160 degrees

Figure 15:
Servo Motor PWM Diagram

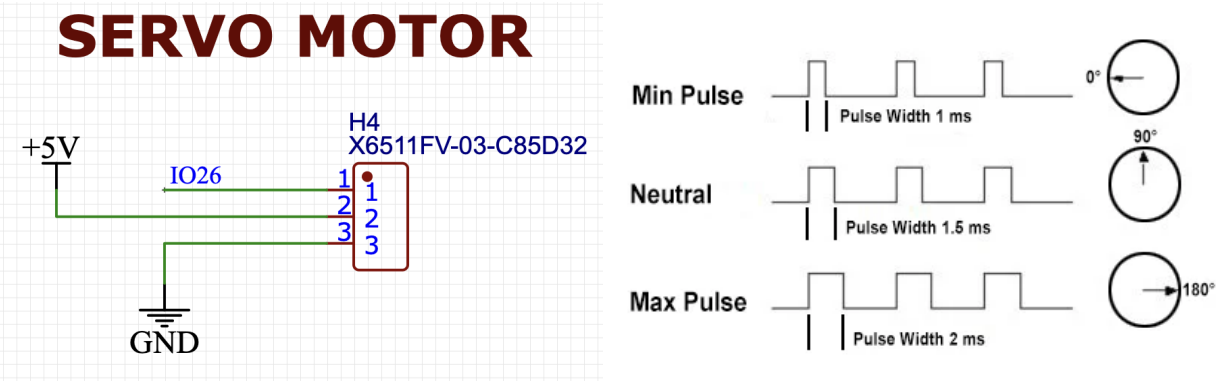


Figure 16:
Servo Motor Circuit Schematic

2.4 Quantitative Analysis

Action	Time (s)*
Automatically locking mailbox when mail is present	0.35
Locking/unlocking mailbox from mobile app	0.48
Updating mobile app dashboard	0.86

Receiving push notification for mailbox updates	2.21
Locking/unlocking mailbox from schedule	0.74

**average of 15 attempts*

Ultrasonic	Distance (cm)
Lower bound	2.35
Upper bound	18.93

3. Costs

Labor:

The average starting salary for ECE graduates is about $92,000/year or $46/hour. Using the estimate that we will each work 100 hours on this project each during this semester, we can estimate the total cost for our labor.

$$\frac{\$46}{hour} \times 100\,hours = \frac{\$4{,}600}{person} \times 2.5 \times 3\,people = \$34{,}500\,total\,labor\,costs$$

Parts:

Description	Manufacturer	Part Number	Quantity	Price	Total
Ultrasonic Distance Sensor	Digi-Key	HC-SR04	3	$4.38	$13.14
Magnetic Contact Sensor	Digi-Key	COM-13247	2	$3.95	$7.90
Servo Motor	HiTec	HS-311 (31311S)	1	$13.54	$13.54
Power Supply	ALITOVE	5050 3528	1	$11.99	$11.99
Microcontroller	HiLetgo	ESP-WROOM-32	1	$10.99	$10.99

3D Printed Mailbox	Illinois Maker Lab	NA	1	$164.80	$164.80
					PARTS TOTAL: $222.36

Grand Total:

$$\$34,500\ total\ labor\ costs\ +\ \$222.36\ total\ parts\ costs\ =\ \$34,722.36\ total\ costs$$

4. Conclusion

4.1 Accomplishments

We were able to create a fully functional mailbox and meet all of our high level requirements. For the high level requirement of automatically locking the door within 10 seconds, we purposefully added a 9 second delay to allow the mailman to add additional mail. After these 9 seconds were over, the mailbox was automatically locked in 0.35 seconds on an average of 15 attempts. On average, the mailbox would lock and unlock in 0.48 seconds after pressing the corresponding button on the mobile application. This is 10.41 times faster than our high level requirement of 5 seconds. On average, notifications were received in 2.21 seconds after any action on the mailbox was made. This is 13.57 times faster than our high level requirement of 30 seconds. We were also able to add a scheduling feature which allows users to schedule their mailbox to stay unlocked for a specified duration in the case of multiple deliveries. When the schedule was active the mailbox was locked/unlocked by it in 0.74 seconds, on average. All of these times show how responsive our mailbox is, and how seamless it would be for a user to interact with it.

4.2 Future Work

There are many improvements that can be made upon the mailbox. Instead of using 3D printed plastic, a metal structure can be used. This would ensure that the mailbox would be durable under high amounts of stress. Additionally this ensures waterproofing/weatherproofing on the mailbox as 3D printed plastic can warp under certain weather conditions. Another

improvement that can be made is to use a camera to give the user access to live feeds on actions being done on their mailbox. A camera would also add an increased range of detecting mail. A more robust locking system can also be added to the mailbox to ensure that it can withstand high amounts of force. This can be done by using a bigger locking piece or multiple servos to lock the mailbox. Another addition that can be made is to use solar power to power the mailbox so that the mailbox does not have to rely on a manual rechargeable battery. This would make the mailbox self-sufficient.

4.3 Ethics and Safety

An ethics issue may arise if an individual were to gain access to the user's phone and use the application to get access to their mail. This can become a risk to the user as someone who gets ahold of their phone will potentially be able to get access to the sensitive documents in their mail as well. In the IEEE Code of Ethics Section 1.1, it is noted that our product must "protect the privacy of others". An individual would be able to compromise the privacy of the user if they were intentionally misusing the product and deceiving the user. A solution to this potential privacy issue would be authenticating the user before being allowed to use the application.

The reliability of our product could result in violations of the ACM Code of Ethics Section 2.9 which states that you must "design and implement systems that are robustly and usably secure". A safety issue that may arise is if one of the components in our product malfunctions. This has the potential of either locking the door permanently or always leaving it unlocked. If it is locked permanently, the user will not be able to safely access their mail. If it is always unlocked, the user will have a false sense of security that their mailbox is locked when it is not. To ensure that this does not occur, we will be testing our product under a plethora of different scenarios to make sure that it does not malfunction.

Another important pillar of the IEEE Code of Ethics is Section 1.5 which partly states that we must be "honest and realistic in stating claims". In order to be transparent with the user regarding the functionality of our product and the possible privacy implications regarding misuse and component failure, our product will not guarantee safety of mail or items placed in the mailbox.

5. Citations

"Magnetic Door Switch Set." *COM*, https://www.sparkfun.com/products/13247.

"Ultrasonic Distance Sensor - HC-SR04." *SEN-15569 - SparkFun Electronics*, https://www.sparkfun.com/products/15569.

Grainger Engineering Office of Marketing and Communications. "Salary Averages." *Electrical & Computer Engineering | UIUC*, https://ece.illinois.edu/admissions/why-ece/salary-averages.

Rivera, Tanya. "Rash of Mailbox Thefts: Stop Putting Checks in Your Mailbox." *wfmynews2.Com*, 17 Feb. 2022, https://www.wfmynews2.com/article/news/local/2-wants-to-know/stop-putting-checks-in-your-mailbox-thieves-steal-checks-wash-change-amount-cash-dont-put-mail-in-blue-usps-mailboxes-overnight-post-office/83-fc6b3146-5565-4a32-8a58-e22b2bab835d.

"HS-311 Standard Economy Servo." *HiTec*, https://hitecrcd.com/products/servos/analog/sport-2/hs-311/product.

Conn, Marla. "Build an IOS Application." *Amazon*, 2021, https://aws.amazon.com/getting-started/hands-on/build-ios-app-amplify/.

"IEEE Code of Ethics." *IEEE*, https://www.ieee.org/about/corporate/governance/p7-8.html.

"ACM Code of Ethics." *ACM*, https://www.acm.org/code-of-ethics.