Package Smart-Lock

Finn Bastian, Amari Olivacce, Faiyaz Sajjad, Justin Paige

Engineering Design Report

ECE442: Systems Analysis and Design

Prof. Jonathan Muckell

4/23/2025

Problem Statement

Homeowners need a secure and reliable solution to protect deliveries of all sizes because current options either leave packages vulnerable or are too restrictive.

Problem Description

Porch piracy—the theft of unattended packages from residential doorsteps—has emerged as a significant and costly consequence of the rapid growth in online shopping. As e-commerce continues to expand, an increasing number of deliveries are left exposed on doorsteps, creating easy opportunities for theft. In 2024, *The E-Commerce Times*, a recognized authority in digital retail reporting, estimated that package theft resulted in $12 billion in losses, impacting nearly 58 million Americans (E-Commerce Times, 2024). Further underscoring the prevalence of this issue, consumer research platform *ValuePenguin* reported that 35% of Americans have experienced package theft, with 59% of these incidents occurring within the past year (ValuePenguin, 2024a). With an average loss of $114 per incident, the cumulative financial impact is substantial, elevating porch piracy from a minor inconvenience to a serious consumer security concern.

Notably, the likelihood of package theft is closely tied to the size and perceived value of the delivery. Medium-sized packages—commonly used by major retailers such as Amazon and Walmart—are especially vulnerable. These shipments often contain high-demand items like electronics and apparel, making them prime targets for theft. According to *ValuePenguin's* 2024 report, 63% of thefts involved deliveries from these large-scale retailers (ValuePenguin, 2024b). While some homeowners attempt to deter theft using lockboxes, most existing models are limited in size and incapable of securing multiple or larger packages. This becomes particularly problematic during peak shopping periods when several deliveries may arrive simultaneously. The widespread nature of this issue highlights the need for a more adaptable, scalable solution—one capable of securing multiple packages of various sizes without the limitations of conventional lockbox designs.

Background Work

To comprehensively understand existing strategies for mitigating package theft, we examined a range of solutions currently available. These encompass five commercial products, one patented system, and two do-it-yourself (DIY) methods. Each solution was categorized based on its primary function: surveillance, secure storage, or deterrence.

Commercial Products

1. **Ring Video Doorbell**
   A smart doorbell equipped with a camera and two-way audio, allowing homeowners to monitor and communicate with visitors remotely via a smartphone app. It provides real-time alerts and video footage but does not physically secure packages.
2. **Amazon Hub Locker**
   A self-service kiosk where Amazon customers can retrieve packages using a unique pickup code. While it ensures secure delivery, it requires recipients to travel to the locker location.
3. **Yale Smart Delivery Box**
   A porch-mounted lockable box that automatically secures packages upon delivery. It connects to a smartphone app for remote access and notifications. However, its capacity is limited to certain package sizes.
4. **Landport Lockbox**
   A heavy-duty, weather-resistant lockbox designed for residential use. Delivery personnel can place packages inside and secure the box using a provided code. Its fixed size may not accommodate larger deliveries.
5. **Package Vault**
   A robust smart lockbox designed to prevent package theft. It features Bluetooth connectivity, allowing authorized users to unlock the box via a smartphone app. Its sturdy construction ensures durability and protection against unauthorized access. However, it's unable to provide security for larger or multiple packages.

Patented Solution

- **Secure Locker System and Method (US6862576B1)**
  A patented intelligent locker system designed for home use, integrating information technology to manage secure package deliveries. It allows for controlled access and monitoring of deliveries through an in-residence IT system.

DIY Solutions

1. **Build Your Own Porch Pirate Package Protector**
   A DIY project demonstrating how to construct a secure package box using common materials, aimed at preventing theft by locking away deliveries until retrieval.
2. **Glitter Bomb Trap**
   A decoy package that, when opened by a thief, releases glitter, spray, or emits loud sounds. Often equipped with hidden cameras to record the event, serving both as a deterrent and a means of capturing evidence.

Categorization of Solutions

- **Surveillance-Based Solutions**:
  These focus on monitoring and recording activities around the delivery area.
  - Ring Video Doorbell
  - Glitter Bomb Trap
- **Secure Storage Solutions**:
  These aim to physically protect packages until the homeowner can retrieve them.
  - Amazon Hub Locker
  - Yale Smart Delivery Box
  - Landport Lockbox
  - Package Vault
  - Build Your Own Porch Pirate Package Protector
  - Secure Locker System (US6862576B1)

Conclusion

While existing solutions offer varying degrees of protection against package theft, they often come with limitations. Surveillance devices can deter or document theft but do not physically prevent it.

Secure storage options may be constrained by size or require the recipient to travel to a different location. DIY methods can be cost-effective but may lack advanced features. This analysis highlights the need for an adaptable, scalable solution that combines real-time monitoring with secure, on-site storage to effectively safeguard deliveries of all sizes.

Design Constraints

1. **Budget Limits:** The system's parts must be less than or equal to $200, so that the system is within the budget defined by the stakeholder

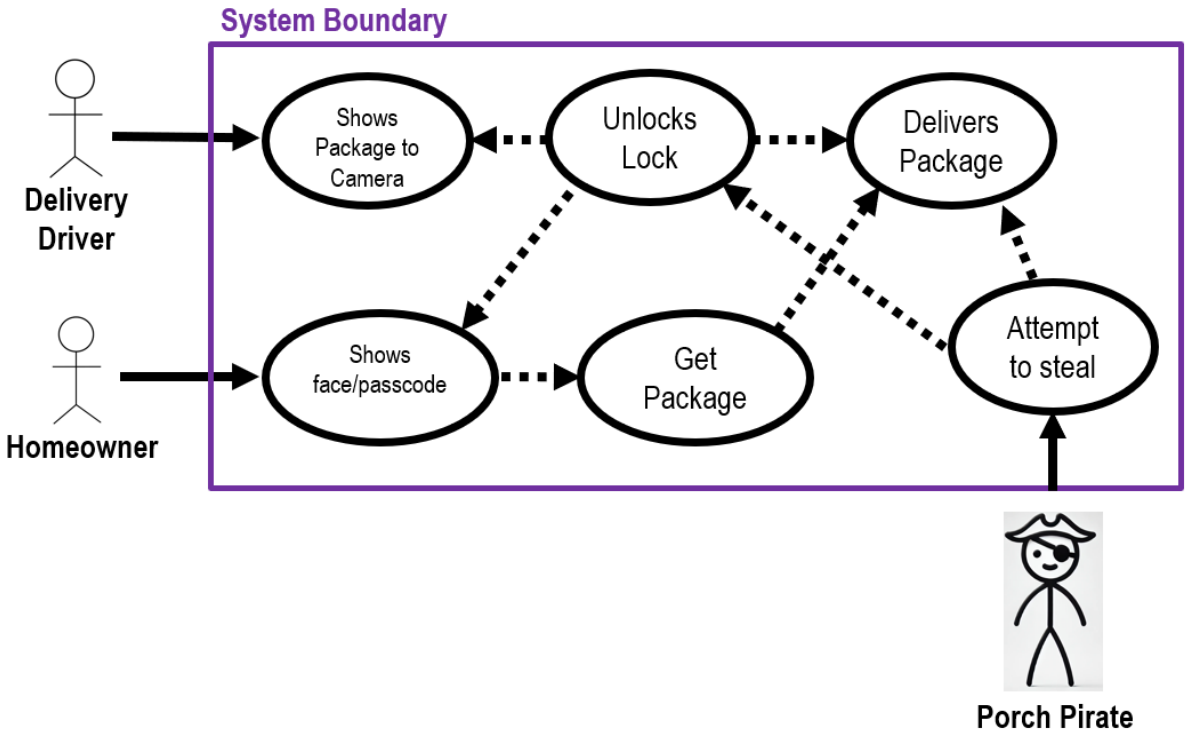
2. **Time Constraint:** The system must be finalized and prototype ready within 2 months to meet the date of 04/23/24 given by the stakeholder

3. **Weather Resistance:** The system must be able to withstand the harsh weather conditions such as raining, snowing, and all different varieties of temperatures and conditions

4. **Ethical Considerations:** The system must be used to only prevent or deter porch piracy, not harm anybody in the process of protecting the package

5. **Installation Flexibility:** Since our system is designed to attach to different kinds of containers (lockers, gates, doors, etc.), the hardware needs to be modular, compact, and easy to install without needing a specific shape or structure.

Use Case Diagram



The use case diagram above shows a lock that is able to be unlocked by only the homeowner and the delivery personnel. This system works by first letting the homeowner create a passcode, then they can enter the passcode and retrieve the package. The delivery personnel must show the passcode on the package (which is placed there by the homeowner), then once the lock is unlocked, the entry point of choice (door, gate, hatch, locker, etc.) could be opened, and the package could be placed. This allows only authorized users to deliver/ retrieve the package, since the lock is only unlocked once it detects the correct passcode.

System Requirements

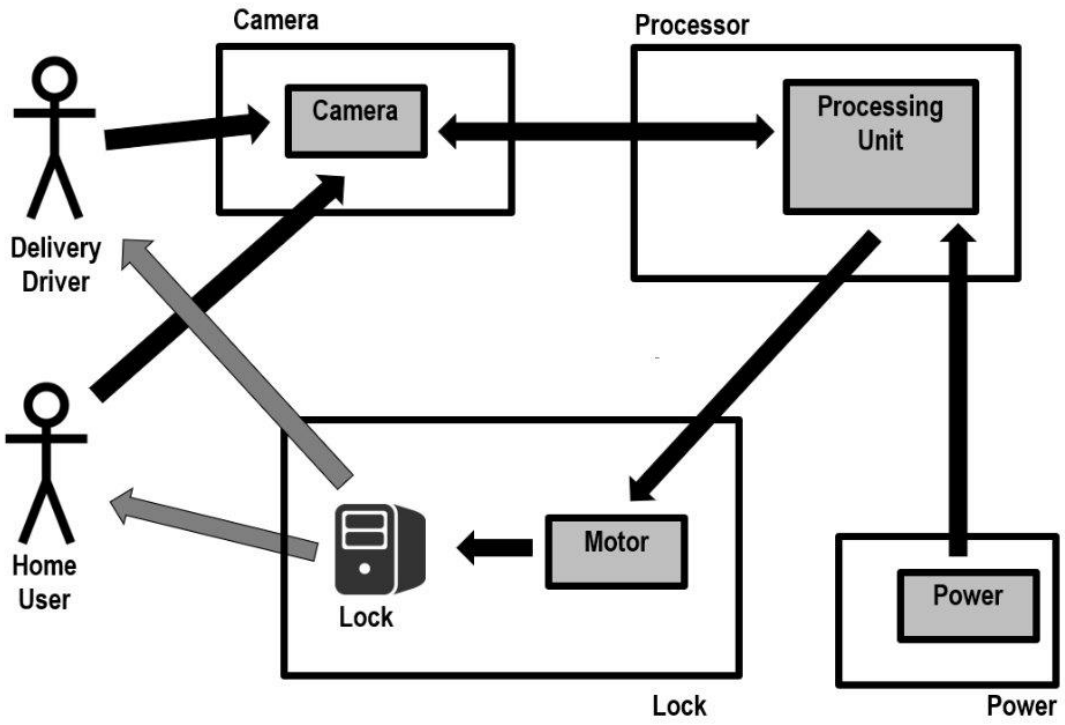
1. **Unlock:** The system must unlock within 2 seconds of detecting the passcode set by the homeowner, to allow the valid users such as the homeowner to retrieve the package, and the delivery person to deliver the package

2. **Relock:** Once the passcode is recognized and the system is unlocked, the system must be able to relock automatically within 10 seconds once the passcode isn't detected. This is to ensure that unauthorized entry to the chosen access point is prevented

3. **Passcode Recognition:** The system must be able to scan and recognize the passcode from any printed or electronic text in real time. This is to make sure that the homeowner and delivery personnel have an easier way of verifying that they're authorized users

4. **Attachable:** The system must be able to be placed on any entry point such as doors, gates, hatches, cabinets, and lockers, in order to allow the user to customize the storage to be able to store any package or packages of any size and shape

High Level System Design



The high-level system design outlines how our smart locking system enables secure and flexible package delivery and retrieval by authorized users, such as the homeowner and the delivery person. The system is designed to be mounted on any common entry point — including doors, gates, hatches, cabinets, and lockers — and is not limited by package size or quantity.

The process begins with the homeowner setting a custom passcode that is recognized by the system. When someone approaches the system — either to deliver or retrieve a package — the built-in camera continuously scans for the passcode. The passcode may be displayed on a printed package label (for delivery), a printed or digital passcode sheet (for the homeowner), or an app that visibly displays the passcode.

When the camera detects any text, it sends the data to a processing unit, which verifies whether the input text matches the stored passcode. This verification occurs within 3 seconds. If the passcode is valid, the system unlocks the entry point within 2 seconds by triggering the locking mechanism through a signal from the processing unit.

Once unlocked, the system continues to scan for the presence of the correct passcode. If the passcode is no longer visible, a 10-second countdown begins. If it is not re-detected within that time, the system automatically relocks to secure the contents and prevent unauthorized access.

This design satisfies all critical system requirements:

- **Unlocks** within 2 seconds after detecting a valid passcode, ensuring quick access for authorized users.
- **Relocks** automatically within 10 seconds after the passcode is no longer detected, preventing unauthorized entry.
- **Passcode Recognition** is performed in real-time, detecting characters from both printed and electronic sources for ease of use by both the homeowner and the delivery personnel.

The system ensures a seamless and secure interaction for both deliveries and retrievals, offering flexibility in how the passcode is presented and minimizing reliance on fixed hardware or package sizes.

Design Justification

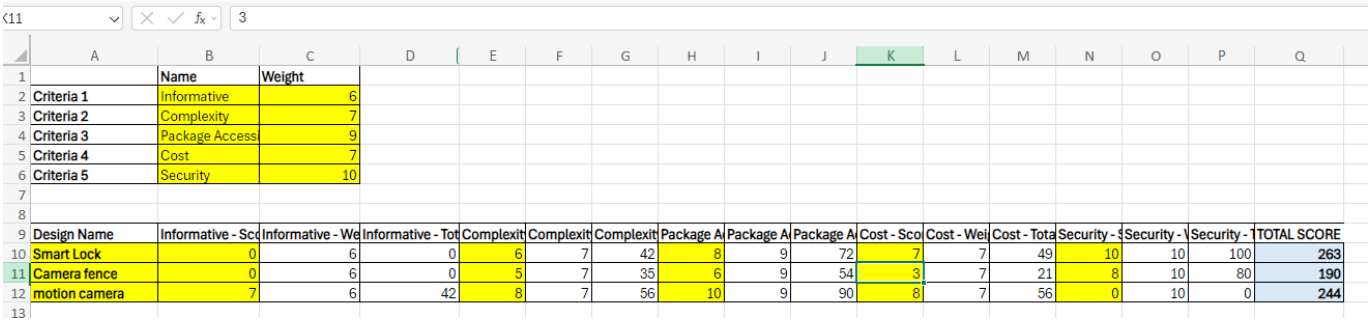
Designs of choice:

Smart Lock – A lock that could be attached to any entry point chosen by the homeowner. Once attached to the chosen entry point, the camera will scan for any text, which if found to have matched the passcode set by the homeowner, will unlock the lock and automatically lock 10 seconds after the passcode isn't detected by the camera, to prevent unauthorized access. The package that the delivery driver will have scanned will have the

passcode on it, since the homeowner will enter it in address line 2 while filling out their address for delivery. If an invalid passcode is found, the system will remain locked and continue to search for any text to compare to the passcode. This product allows any package of any size, and any quantity to be stored in any entry point that is deemed appropriate by the homeowner to store the package(s); it also prevents porch piracy by allowing only authorized users (such as homeowners and delivery personnel) to deliver and retrieve packages from the entry point of choice, and by keeping out unauthorized users (such as porch pirates) from reaching the packages.

Camera Fence – A fence that only unlocks once it detects the face or address set by the homeowner. For the delivery person to unlock the fence, they must show the package label to the camera, which will then compare with the address set by the homeowner, and if there is a match, the fence will unlock and open. For the homeowner to unlock the fence, they will have to show their face to the camera, and once the system confirms that it is the homeowner, it will unlock and open. After 5 seconds of the camera not detecting the homeowner or the correct address, it will once again lock and start detecting faces and any text (for address), in order to prevent unauthorized access. If the correct face or address isn't found, the system will remain locked and will continue to search for faces and text to compare to the address. The idea of this product is to prevent porch piracy by locking out unauthorized users (such as porch pirates) and allowing authorized users (such as homeowners and delivery person) from entering the premises.

Motion Camera – The motion camera is a system that searches for movement, and once it has detected movement, it will start to record the premises, and once it stops detecting movement, it will stop recording and save in the homeowner's device of choice. The point of this product isn't to prevent porch piracy, but to get evidence to find out who took the package and use it against them if the homeowner chooses to in court.

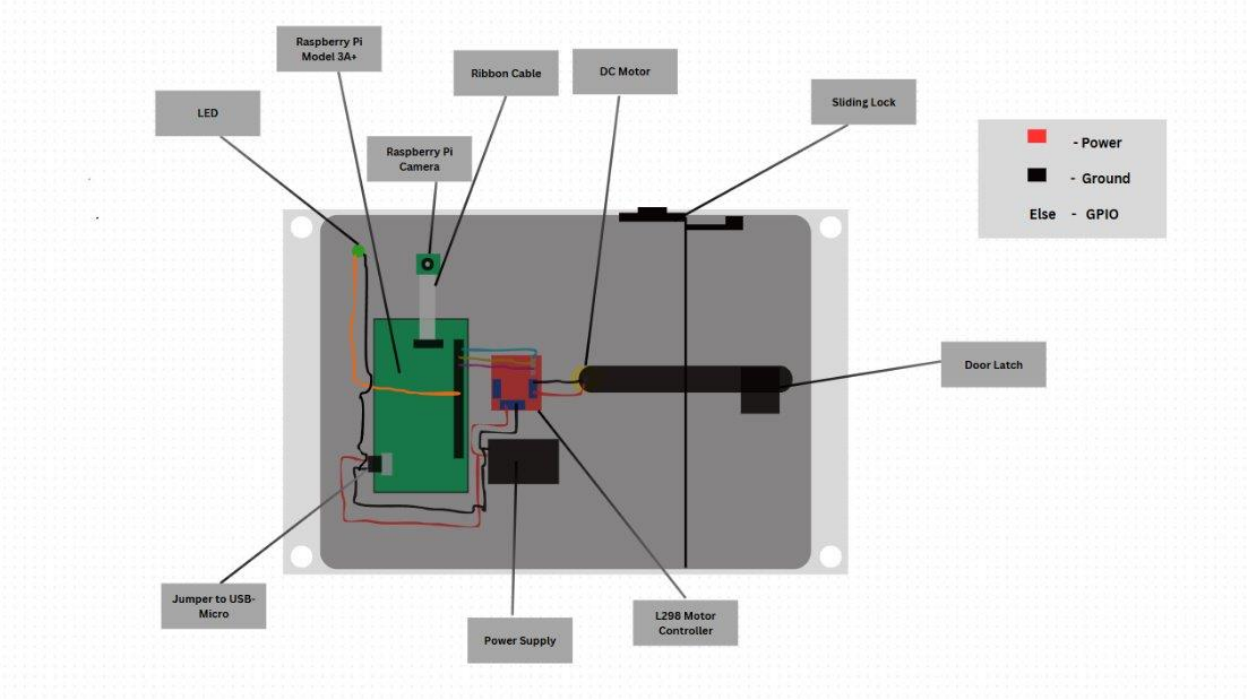


	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
1		Name	Weight														
2	Criteria 1	Informative	6														
3	Criteria 2	Complexity	7														
4	Criteria 3	Package Access	9														
5	Criteria 4	Cost	7														
6	Criteria 5	Security	10														
7																	
8																	
9	Design Name	Informative - Sc	Informative - We	Informative - Tot	Complexit	Complexit	Complexit	Package A	Package A	Package A	Cost - Sco	Cost - Wei	Cost - Tota	Security - S	Security - V	Security - T	TOTAL SCORE
10	Smart Lock	0	6	0	6	7	42	8	9	72	7	7	49	10	10	100	263
11	Camera fence	0	6	0	5	7	35	6	9	54	3	7	21	8	10	80	190
12	motion camera	7	6	42	8	7	56	10	9	90	8	7	56	0	10	0	244
13																	

The decision matrix above was used to decide what the most effective product would be to solve the security of packages of all sizes and quantities. The two most important criteria that would decide the product for our solution were **Security**, and **Package Access**. Out of the three solutions, the Smart Lock scored the highest on Security by a large margin and came second within a small margin for Package Access. This meant that the Smart Lock was our solution of choice.

With its ability to secure packages by locking the access point of choice, only unlocking for either the Homeowner or the Delivery Personnel once the respective user has scanned the correct passcode, and locking 10 seconds after passcode isn't detected, means that the security score of 10 for this product is justified. Once the lock is unlocked, the package could easily be accessed by the homeowner, by just opening the respective access point (doors, hatches, gates, etc.). This justifies the high score of 8 given to the Smart Lock for Package Access. With the Smart Lock scoring high for both security and package access, we are confident that it will be a great porch piracy preventing product that could secure packages of all sizes and quantities.

Physical Design



The Smart Lock is a lock that scans package labels, printed paper, and apps such as Notepad, in order to detect the passcode which is set by the user through an app on their phone. This allows the user to attach the Smart Lock to any entry points such as doors, hatches, gates, and more, giving the user the ability to customize their storage of choice, leaving no limit to what the size and shape of the package is, or how many packages could be delivered.

This is accomplished by a Raspberry Pi 3 Model A+ running Python code that repeatedly detects the passcode by taking in frames from the Raspberry Pi camera. The Ribbon cable transmits data between the Raspberry Pi and its camera, allowing multiple bits to transfer concurrently, which speeds up the system's frame processing. The Raspberry Pi then sends a signal to the L298 motor controller through jumper wires, which lets the DC motor move in the respective direction to either lock or unlock the system. The entire system is powered by a power supply using AA batteries. These were chosen so the system's power source remains concealed, preventing porch pirates from tampering with the device's power.

The system also uses WiFi to enable communication between the mobile app and the Smart Lock. Through this connection, the user can wirelessly set, update, or disable passcodes from their phone, adding flexibility and convenience while ensuring the system remains secure without needing a physical connection. **WiFi was chosen over Bluetooth because it offers faster data transfer rates and a longer operating range, making it more reliable for communicating with the Smart Lock across typical residential distances, even if the user isn't directly nearby.** This ensures real-time control and monitoring without limitations tied to proximity.

The Raspberry Pi was selected over other microcontrollers because it can run Python libraries like OpenCV and PyTesseract, which are essential for the camera control and passcode recognition. Ribbon cables were chosen for their ability to transfer multiple data lines in parallel, improving speed. Jumper wires fit the GPIO and L298 pins cleanly while keeping the internal setup compact.

AA batteries were selected to make the system wireless and self-contained without exposed power cords.

Inputs:

- Camera images of passcodes on package labels, printed sheets, or app screens
- Passcode set by the user via mobile app

Outputs:

- Unlock/lock signal to DC motor via L298 motor controller
- System status feedback via lock position

Engineering Standards Followed:

- **IEEE 802.11 (WiFi)** — for mobile app communication to manage passcodes wirelessly
- **Python PEP 8** — for code readability, maintainability, and preventing logic errors in the Python scripts
- **IEC 62368-1** — standard for safety of consumer electronics controlling electric motors and battery-powered devices, ensuring safe operation without exposed wires or unsafe power connections
- **Jumper Wires and Ribbon Cable Best Practices** — ensuring reliable, organized, and safe connections for data and control signals within the system
- **AA Battery Safety Guidelines** — for using consumer-grade battery power safely in embedded systems

These standards were chosen to improve interoperability, system safety, and ensure the software remains clean and reliable.

Bill of Materials

Item	Part #	Item	Quantity	Total	Purchase Link

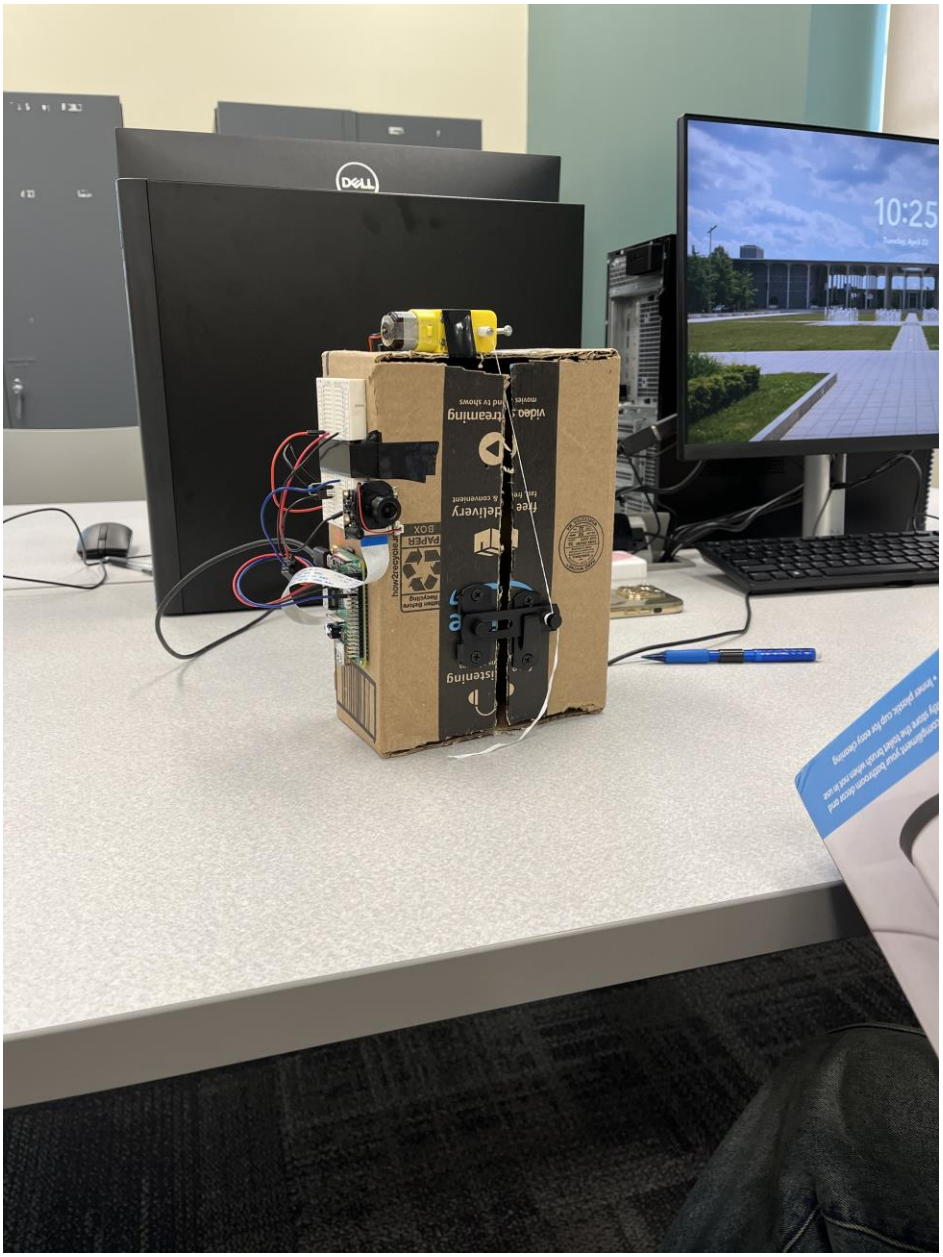
		Cost		Cost	
Door Latch	**B09ZNMWW8B**	**$10**	**1**	**$10**	https://a.co/d/iOhjrZj)
5V power supply	**N/A**	**$9.99**	**1**	**$9.99**	https://www.tindie.com/products/jouletime/boostmicro-5-volt-power-supply-assembled/#specs
Raspberry Pi Model 3A+	N/A	**$25.00**	**1**	**$25.00**	Raspberry Pi Model 3 A+ : ID 4027 : Adafruit Industries, Unique & fun DIY electronics and kits
DC Motor	3777	**$2.95**	**1**	**$2.95**	https://www.digikey.com/en/products/detail/adafruit-industries-llc/3777/8687221?gQT=1
LN298	B07WS89781	**$9.99**	**1**	**$9.99**	www.amazon.com/Controller-H-Bridge-Stepper-Control-Mega2560/dp/B07WS89781?source=ps-sl-shoppingads-lpcontext&ref_=fplfs&psc=1&smid=A2Z10KY0342329&gQT=2
Raspberry Pi Camera	B07G9VLPZH	**$15.99**	**1**	**$15.99**	https://www.amazon.com/Inno-Maker-Camera-Module-OV5647-Raspberry/dp/B07G9VLPZH?psc=1&pd_rd_w=uyYyE&content-id=amzn1.sym.ea1d9533-fbb7-4608-bb6f-bfdceb6f6336&pf_rd_p=ea1d9533-fbb7-4608-bb6f-bfdceb6f6336&pf_rd_r=R8BT3X5TF0MT2KA5HZZ2&pd_rd_wg=hyb1w&pd_rd_r=55c6bd8a-26d9-4016-9d08-c016672e5351&ref_=sspa_dk_detail_img_1&sp_csd=d2lkZ2V0TmFtZT1zcF9kZXRhaWxfdGhlbWF0aWM=

To ensure the effective operation of passcode recognition, the **Raspberry Pi Model 3A+** is essential as it supports the necessary Python libraries required for optical character recognition. The **Raspberry Pi Camera Module** is a critical component, providing real-time video input that the Raspberry Pi uses to capture frames and process them to verify whether the correct passcode is detected.

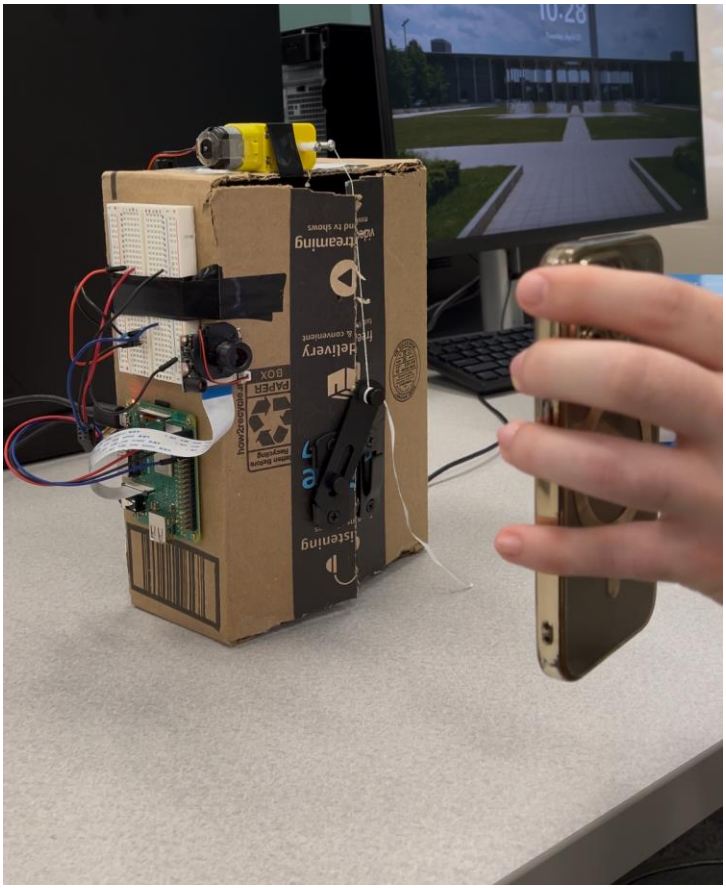
The **door latch** serves as the locking mechanism, physically securing the entry point. The **DC motor** is responsible for actuating the latch, turning it to unlock or lock the system. The **L298 Motor Driver** is vital for enabling bidirectional control of the DC motor, allowing the door latch to move in both directions without manual intervention.

Lastly, the **5V power supply** is required to provide power to the entire system, ensuring that each component operates reliably and consistently.

Proof of Concept Implementation



This image shows the latch attached to the outer flaps of a cardboard box (representing an entry point), demonstrating that the system can securely mount to various entry points.



The lock is unlocking after the Raspberry Pi camera successfully detects the correct passcode displayed in the Notepad app. This image demonstrates both passcode recognition and the system's ability to unlock.

The only functionality not currently supported is automatic relocking. This is because we were unable to obtain the L298 Motor Controller, which prevents us from controlling the lock's direction without manually switching the ground and GPIO pin.

Implementation & Testing Plan

System Verification Testing:

1. **Unlocking Time:**

Unlocking Time After User Verified			
Test	Desired(s)	Actual(s)	Difference(s)
1	2	1.69	0.31
2	2	1.65	0.35
3	2	1.72	0.28
4	2	1.64	0.36
5	2	1.67	0.33
6	2	1.71	0.29
7	2	1.65	0.35
8	2	1.67	0.33
9	2	1.7	0.3
10	2	1.63	0.37

LEGEND	
SUCCESSFUL -	
UNSUCCESSFUL -	

   a. **Test Method:** To test the unlock time, we showed the system the correct passcode. Once verified, we used a stopwatch to measure how long it took for the system to unlock.
   b. **Result:** The system's unlock time ranged between **1.6 to 1.7 seconds**, which is well below the **2 seconds** defined in the system requirement.
   c. **Conclusion:** The system **meets** the unlock time requirement.
2. **Relocking Functionality:**
   a. **Test Method:** Due to the absence of the L298 motor controller, we were unable to test the relocking functionality. This feature is crucial for relocking the system once the passcode is no longer detected.
   b. **Result:** This requirement could not be tested.
   c. **Conclusion:** The system **fails** the relocking requirement due to hardware limitations.
3. **Passcode Recognition:**

Test	Current Passcode	User's Passcode	System's Verdict
1	L798B3GN	L798B3GN	MATCH
2	JHK897FP	L798B3GN	NO-MATCH
3	KLG67890	L798B3GN	NO-MATCH
4	JJPNKGHA	L798B3GN	NO-MATCH
5	L798B3GN	L798B3GN	MATCH
6	1234567N	L798B3GN	NO-MATCH
7	GGGGGGGG	L798B3GN	NO-MATCH
8	YUNKPALK	L798B3GN	NO-MATCH
9	897654N1	L798B3GN	NO-MATCH
10	L798B3GN	L798B3GN	MATCH
11	L798B3GN	WKL9054D	NO-MATCH
12	WKL9054D	WKL9054D	MATCH
13	WKL9054D	WKL9054D	MATCH
14	WKL9054D	WKL9054D	MATCH
15	LLKNUIPO	WKL9054D	NO-MATCH
16	WKL9054D	WKL9054D	MATCH
17	167KJHG1	WKL9054D	NO-MATCH
18	WKL9054D	WKL9054D	MATCH
19	WKL9054D	WKL9054D	MATCH
20	WKL9054D	WKL9054D	MATCH
21	FBS 71190	FBS 71190	MATCH
22	7789LKNG	FBS 71191	NO-MATCH
23	WKL9054D	FBS 71192	NO-MATCH
24	1G6Jkl^a	FBS 71193	NO-MATCH
25	FBS 71190	FBS 71194	MATCH
26	&^&**HGJ	FBS 71195	NO-MATCH
27	FBS 71190	FBS 71196	MATCH
28	FBS 71190	FBS 71197	MATCH
29	&*()76541hjksm	FBS 71198	NO-MATCH
30	FBS 71190	FBS 71199	MATCH

LEGEND	
	- CORRECT
	- INCORRET

   a. **Test Method:** We tested the system's ability to recognize passcodes by showing the camera various passcodes (both correct and incorrect), both printed and electronic. The system was set to blink a **green LED** for correct passcodes and a **red LED** for incorrect ones.
   b. **Result:** The system correctly identified whether the passcode was valid or not for **30 consecutive tests**.
   c. **Conclusion:** The system **meets** the passcode recognizability requirement.

4. **Attachability:**
   a. **Test Method:** We mounted the system components onto a **cardboard box** to test Gwhether it could be easily attached to various entry points.
   b. **Result:** The system was successfully attached to the cardboard box. While the final version will have a protective case with mounting holes, this preliminary test confirms the system’s ability to attach to various entry points.

c. **Conclusion:** The system **meets** the attachability requirement.

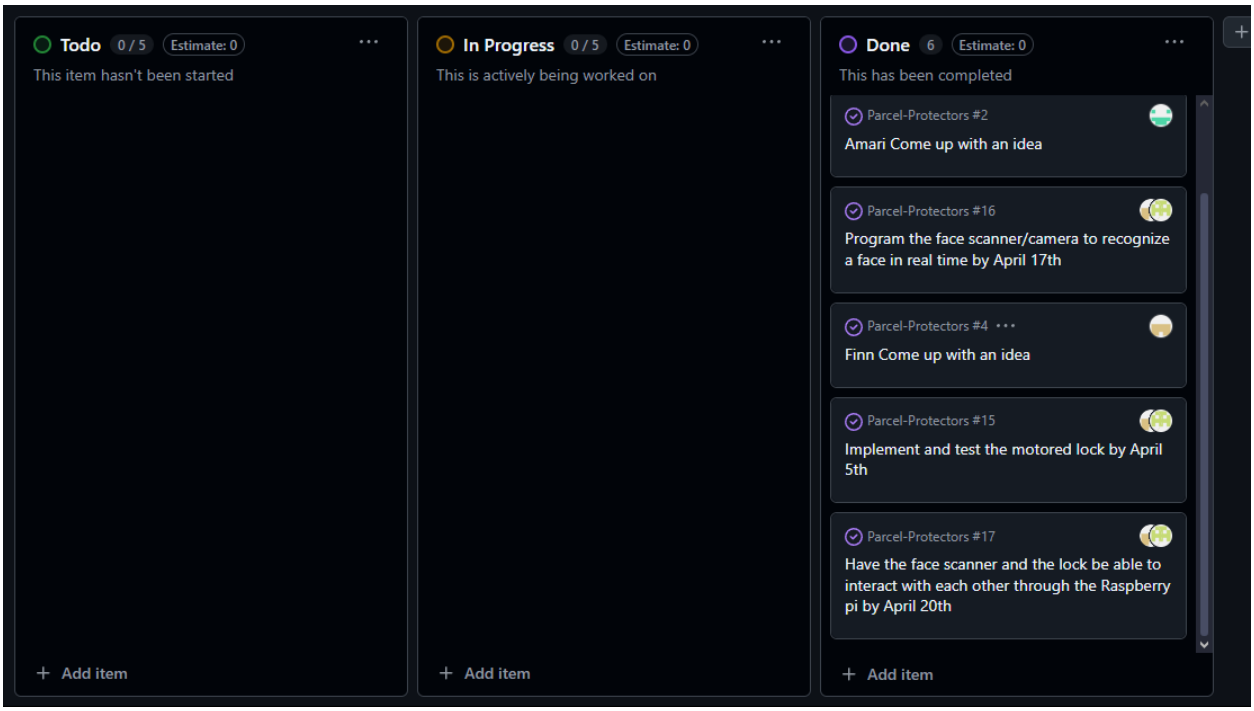
Conclusion

The Smart Lock system provides an innovative and reliable solution to the growing problem of package theft. By combining fast passcode recognition, quick unlocking, and versatile attachment options, the system ensures that packages are securely stored and easily accessible for authorized users, including homeowners and delivery personnel.

The system's ability to recognize passcodes from both printed and electronic sources in real-time is a significant advantage, allowing for seamless interaction between users and the system. Additionally, its ability to be attached to various entry points—such as doors, gates, and lockers—provides great flexibility, making it adaptable to different storage needs and package sizes.

The Smart Lock addresses the critical requirements for package security, offering a secure, efficient, and customizable solution that ensures packages are protected from theft while remaining accessible to authorized users. The system's design has the potential to enhance package security on a large scale, providing homeowners with peace of mind and contributing to a safer and more efficient delivery process.

GitHub Project Board



Github Link: Click Here

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