MazEscape

ECE 445 Final Report - Spring 2025

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Abstract

This is the report for our ECE 445 Spring 2025 project MazEscape which is an escape room/maze system. MazEscape has 2 smart-locks: a challenge lock and an escape lock. In this, we use custom PCBs which has a ESP32 microcontroller, a LCD display, a keypad, a PIR motion sensor, and a solenoid lock. The microcontrollers communicate with each other using Wifi and present multiple-choice quiz questions which determine when and which locks unlock. Buck converters are used to drop the 12V to 5V for the mechanical subsystem and another one is used to supply 3.3 V to the microcontroller and sensors. The motion sensor detects motion within 3-5 meters, displays questions immediately after and unlocks locks within seconds of correct input and unlocks the escape lock when 3 incorrect answers are entered.

This report includes the subsystem designs, validation of our high-level requirements, cost and schedule analysis, our ethical considerations, and any future applications.

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1. Introduction

1.1 Problem

Modern-day theme park immersive games have become stale and predictable, so we wanted to make them more entertaining by seeing if it is possible to mix some of them. So, we devised a fun idea for a mix between a maze and an escape room where the participants will enter a labyrinth and answer questions to move onto the next level or to the next room and complete the game.

1.2 Solution

To tackle this challenge, we have decided that there will be a set of four smart lock systems, two of which will have an LCD screen along with a keypad with which the user will be able to interact with the whole system, and the other two will be the emergency escape lock system. Each set of smart lock systems will be attached to a door that will open up to the next part of the maze or the next level or to a door that will take them out of the maze and back to the starting point. The questions that will be asked on each of the smart locks will be related to small puzzles or general knowledge questions that they will get one chance to answer, as all the questions displayed will be multiple-choice. The players will answer the questions using the keypad by selecting one of four choices: A, B, C, or D.

There will be a total of two levels: an entry-level or the first level, which will be the first instance where the player will be asked to answer a question, and upon successfully answering the question, the system will unlock the gate and the player will be able to move onto the next level and which will be the second or the final level. The player will then again be asked to answer a question, and if they get the correct answer, they exit the maze and claim their prize. If, however, in any of the two levels, the player selects the wrong answer, then the smart lock will send a signal automatically to the escape smart lock system, which will be put on an escape gate to unlock the gate so that the player can leave the game and go back to the starting point. Each of the two smart locks, which will have an LCD screen, will also have a motion sensor so that the smart lock can automatically detect if a player has approached it, and then it can display its question.

The smart lock systems that ask questions will also be able to communicate with each other so that the user is not introduced to the same question. The player will also have an additional option to leave the game by pressing a leave button on the keypad, upon which the smart lock system will send the escape lock system a signal to unlock the gate.

1.3 Visual Aid

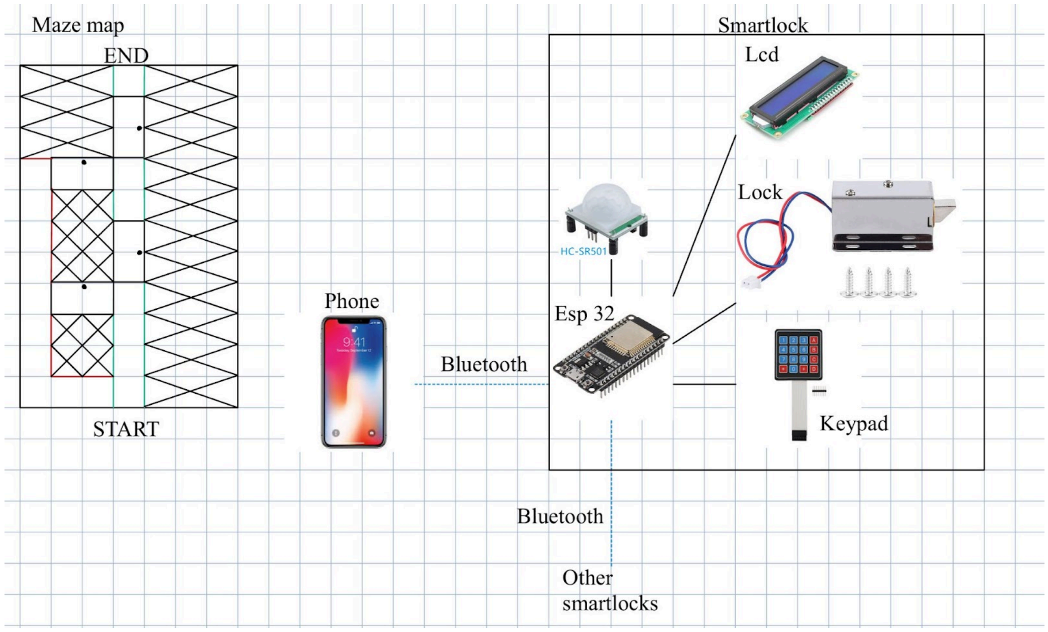

Figure 1. Visual Aid for MazEscape (note: should state Wifi instead of bluetooth)

Figure 1 is a visual aid for how every subsystem connects with each other at a larger scale with real pictures of the different parts.

1.4 High-level requirements list

- The system shall unlock the door within 2 seconds of receiving correct input from the participant to ensure a smooth and engaging user experience.
- The motion sensor must detect an approaching participant within 3-5 meters and trigger the display of the quiz question within 1 second to facilitate prompt interaction.
- The Wifi module integrated within the smart lock systems shall reliably exchange data—specifically transmitting quiz questions and lock/unlock commands.

2. Design

2.1 Physical Design

Our physical design comprises six parts: the solenoid lock, the infrared sensors, the keypad, the LCD screen, the microcontroller, and the power supply. We plan to have all components in a single lock box for seamless integration. The user can see the screen, the keypad, the sensor, and the lock. The Microcontroller and the power supply will be hidden from the user. The user only intends to interact with the screen and keypad, as the screen will display the question and the keypad will be used to answer the question.

2.2 Block Diagram

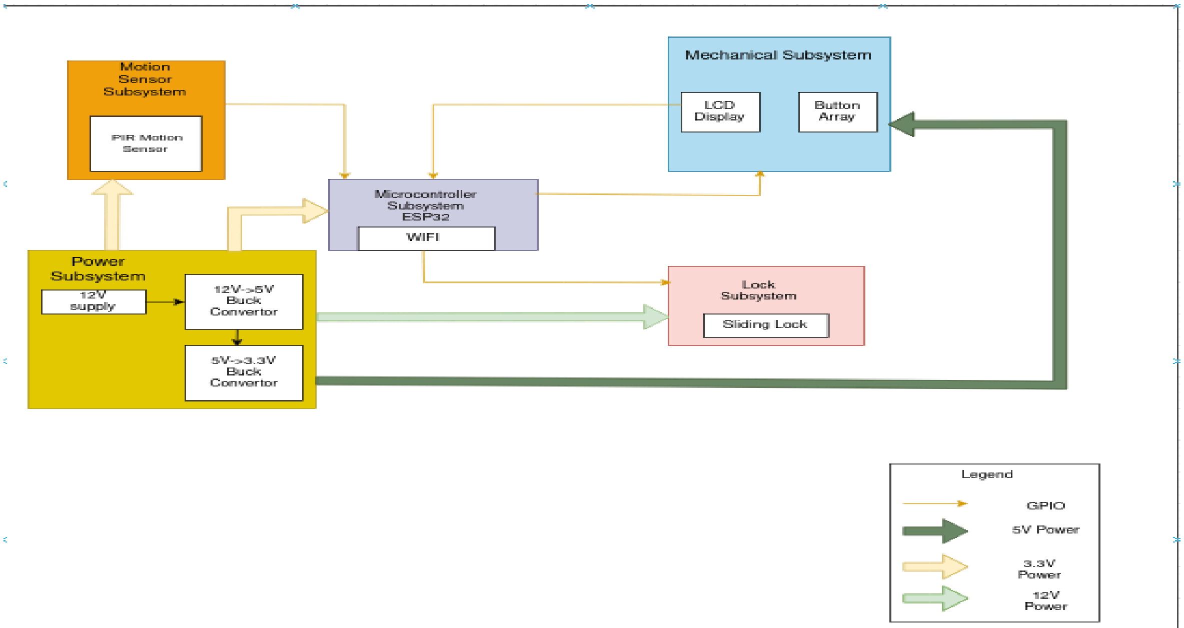

Figure 2. Block Diagram for the project

Figure 2 shows how everything integrates as a whole in the form of a block diagram. All the components connect to the microcontroller and PCB via GPIO pins and there is a deeper dive into how each component connects to what and what it does not connect to.

2.3 Mechanical Subsystem:

We will use a 1602 LCD Display Module to display the problems the user will solve and a Numeric Keypad to input their answers. The LCD module will be very important for the user interface as all the information the user will need to use the device properly will be available on the LCD display. The user will be able to navigate the different functionalities using the keypad. The LCD module and the keypad will communicate via the SPI protocol with the microcontroller.

Requirements	**Verifications**
- The LCD display must update content reliably at ≥60 Hz. - The keypad must accurately capture and transmit inputs within 0.5 seconds.	- Implement a software timer system to record the duration between subsequent screen refreshes. - Access an external tool that can timestamp both the physical press and the system's input reception.

2.4 Microcontroller Subsystem:

The ESP32 microcontroller will have different types of questions organized into various questions (MC questions about trivia and general knowledge questions answered with pressing buttons).

Requirements	**Verifications**
• The microcontroller, ESP32, must be able to interpret the status of the user input • 3.3±0.5V must supply the microcontroller	• Record the behavior of the DC solenoid lock in response to each command using an oscilloscope. • Use a multimeter to measure the voltage of the microcontroller • Ensure voltage readings are within 3.3±0.5V for each microcontroller.

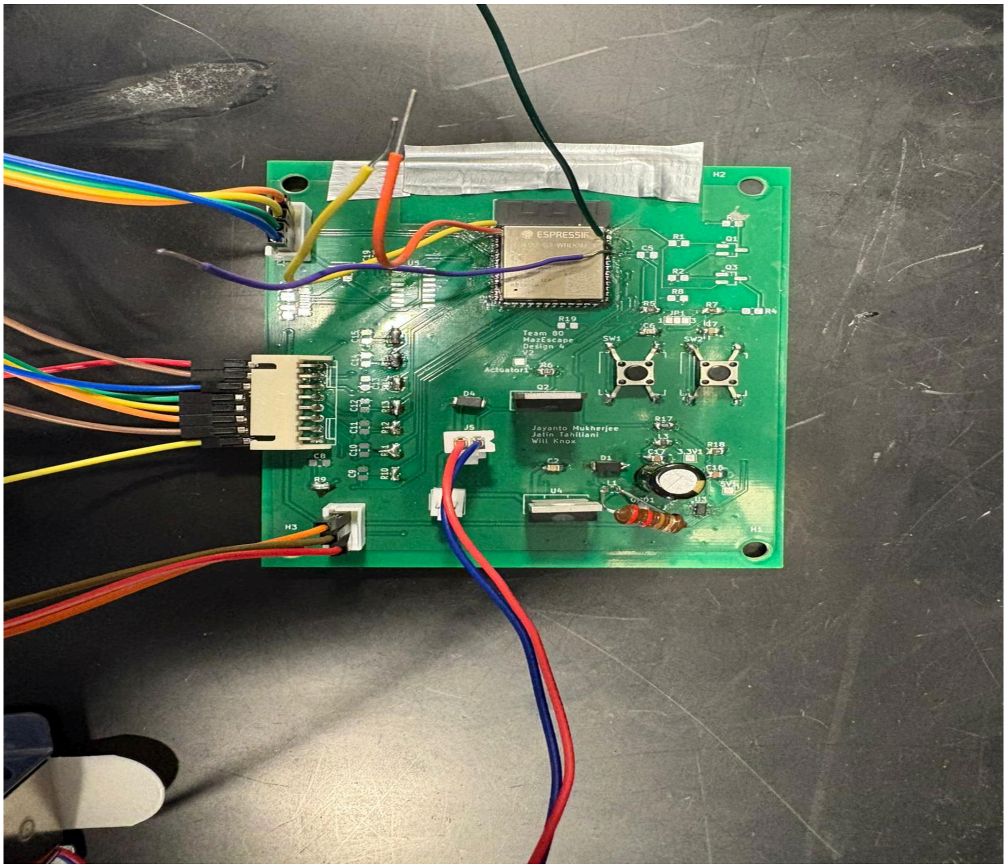

Figure 3. Top view of the PCB

This figure shows all of the components and subsystems soldered onto the PCB and working with the microcontroller.

2.5 WiFi Subsystem:

We will use the ESP32 Microcontroller as a Wifi module to connect all the LCD screens. The Wifi module will also allow the smart lock system to signal the escape lock system in case the player gets the question wrong or wants to leave the game.

Requirements	Verifications
- Provide stable and responsive (<100ms input lag) Bluetooth connection - It must interface seamlessly at 3.3V logic levels with the ESP32 microcontroller to relay commands accurately.	- For stability, tests should be performed in an environment crowded with Bluetooth (ECEB) and range tests. - Test the amount of time it takes to receive the updates. - Ensure voltage readings are within 3.3±0.5V for each microcontroller.

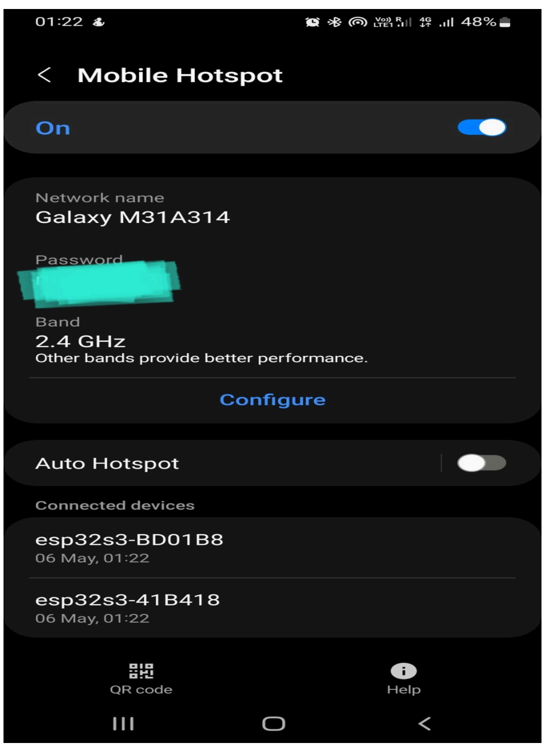

Figure 4. Screenshot of the mobile hotspot

As seen in the above Figure 4, the bandwidth of the Wifi connection is 2.4 GHz and below are shown the two connected ESP32 microcontrollers.

2.6 Motion Sensor Subsystem:

To have a unique and interactive experience, we will implement an HC-SR501 Infrared PIR Motion Sensor Module that will interact with the user by detecting them, and then once the user is detected, it will prompt them with a question to unlock the system.

Requirements	Verifications
• When there is no human present, the PIR sensor module should output Logic Low (0 V) • The PIR sensor module should output 3.3±0.5V digital pulse when a human is detected • The output signal must be at a 3.3V logic level to be compatible with the microcontroller's digital inputs.	• Use a multimeter to measure the voltage of all sensors • Ensure voltage readings are within 3.3±0.5V for each sensor • Have a person walk before the sensor and observe a logic high pulse on the analyzer, with a parallel voltmeter reading about 3.3 V (±0.3 V). Repeat this procedure multiple times and confirm the expected behavior occurs.

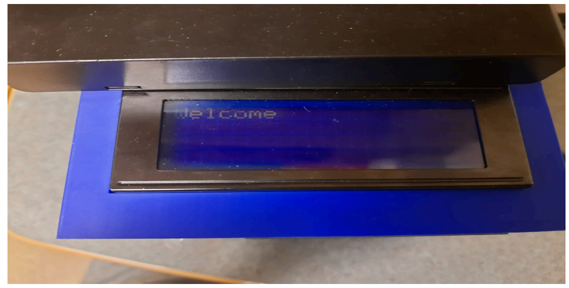

Figure 5. Above shown is the LCD screen before the motion sensor is activated (left) and then after it has sensed motion (right)

2.7 Lock Subsystem:

We will use a sliding solenoid lock when the questions are answered. It will unlock the door, and it will lock after the user closes the door. When the questions are fully answered, the sliding lock will be in the form of a rod and operated by a motor on command. The lock will be connected to an IRL40S212 power Mosfet which will be connected to the microcontroller so that we may be able to reliably control it.

Requirements	**Verifications**
• The digital control interface must reliably receive 3.3V logic-level commands from the microcontroller.	• Use a multimeter to measure the voltage of the microcontroller • Ensure voltage readings are within 3.3±0.5V for each microcontroller.

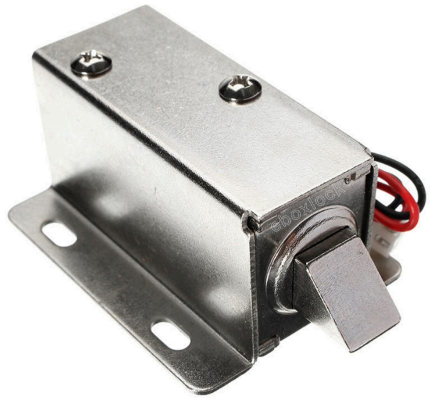

Figure 6. Visual of the solenoid lock

2.8 Power Subsystem:

We will be using a standard 12V battery source,the 12 Volt power source itself will be used to power the solenoid lock, and in order to ensure that we can power all our other subsystems we will be making use of two buck converters.

The first buck converter will be making use of the LM2575-12BT buck converter that will be stepping down the 12V power source to a 5V power supply which will be used to power the mechanical subsystem.

We will then be using a second buck converter to step down the 5V power source to a 3.3V power source to supply the microcontroller and the motion sensor subsystem, for the 5V to 3.3V buck converter we will be using the LM2575-3.3BT. These converters will ensure a fixed and steady supply of power that will also ensure that all our components are working within their recommended parameters.

Requirements	Verifications
- The 12 V to 5 V buck converter must provide a regulated 5 V±0.5V output under the maximum operational load of the mechanical subsystem. - The 5 V to 3.3V buck converter must provide a regulated 5 V±0.5V output under the maximum operational load of the mechanical subsystem.	- Connect the Buck converter to a 12 V battery and measure its 5 V output while varying the load from 25% to 100% of the mechanical subsystem's maximum current. The output must remain between 4.5 V and 5.5 V during all load conditions - Connect the Buck converter to a 5 V battery and measure its 3.3V output while varying the load from 25% to 100% of the mechanical subsystem's maximum current. The output must remain between 3.8 V and 2.8 V during all load conditions

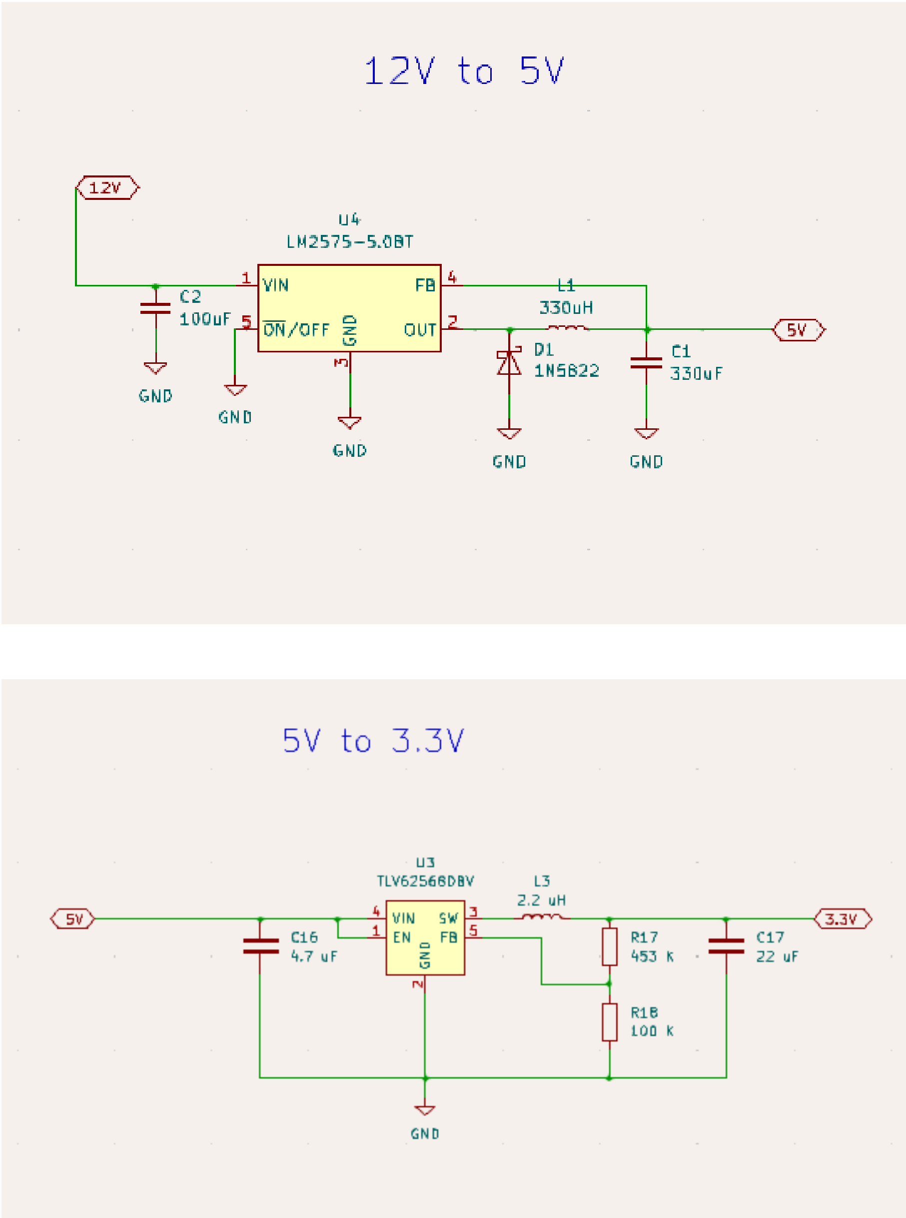

Figure 7. The figure shows the buck converter schematics for dropping the voltage down from 12V to 5V and then from 5V to 3.3V.

3. Cost and Schedule

3.1 Cost Analysis

The total cost for all parts, as seen in the table below, is **$131.56.** We can expect a salary of $35/hr x 2.5 hr x 60 = $5250 per team member. Since our group consists of 3 members, we must multiply this value by the number of members, $5250 x 3 = $15,750 in labor cost. Adding the labor cost to the cost of all components, we get a final project cost of **$15881.56**

Component	**Part #**	**Quantity**	**Price per unit**	**Total Price**	**Source:**
Solenoid Lock	Electromagnetic Lock	4	7.98	31.92	Amazon Zopcs Shop
LCD Screen	LCD2004	2	7.99	15.98	ECE 445 Inventory/20 70 Lab
Microcontroller	ESP32-S3-WROOM-1	4	3.35	13.4	ECE 445 Inventory/20 70 Lab
Microcontroller Development Board	ESP32-S3-WROOM	1	16.53	16.53	ECE Electronic Shop
Keypad	Uxcell 4*4 matrix	1	7.99	7.99	ECE 445 Inventory/2070 Lab
Buck converter 5-3.3	TLV62568BDV	4	0.92	3.68	Digikey
Buck converter 12-5	LM2575-12BT	4	3.58	14.32	Digikey
Resistor	1k Ohm	52	Free	Free	ECE 445 Inventory/20 70 Lab
Resistor	10k Ohm	16	Free	Free	ECE 445 Inventory/20 70

					Lab
Resistor	100k Ohm	4	Free	Free	ECE 445 Inventory/20 70 Lab
Resistor	453k Ohm	4	Free	Free	ECE 445 Inventory/20 70 Lab
Capacitor	1uF	32	Free	Free	ECE 445 Inventory/20 70 Lab
Capacitor	330 uF	4	0.14	0.56	ECE 445 Inventory/20 70 Lab
Capacitor	0.1 uF	16	Free	Free	ECE 445 Inventory/20 70 Lab
Capacitor	10 uF	4	Free	Free	Digikey
Capacitor	22uF	4	0.12	0.48	Digikey
Capaciotr	100uF	4	0.56	2.24	Digikey
Inductor	2.2 uH	4	0.12	0.48	Mouser
Inductor	330 uH	4	Free	Free	ECE 445 Inventory/20 70 Lab
Usb-Uart conector	DSD TECH SH-U09C5	2	7.39	14.78	Amazon
Diode	SS14	8	0.28	1.68	Digikey
Vertical pin connector 1x02	B2B-XH-A	4	0.1	0.4	Digikey
Vertical pin connector 1x03	B3B-XH-A	4	0.13	0.52	Digikey
Vertical pin connector 1x04	B4B-XH-A	4	0.15	0.6	Digikey
Vertical pin connector 1x08	B8B-XH-A	4	Free	Free	ECE 445 Inventory/20 70 Lab
Battery Pack		2	3	6	Amazon
TOTAL COST				**131.56**	

Table 1. Overview of the cost of all the parts

3.2 Schedule

Week	Tasks	Person
March 3rd	PCB Design; Breadboard Design	Group
March 10th	Integrate the Solenoid Lock, Send out the PCB order	Jayanto and Will, Group
March 17th	Integrate the Motion Sensor	Will and Jatin
March 24th	Testing and Debugging(if any)	Group
March 31st	Get the bluetooth operational(SPI Protocol), Place order for PCB, Individual Progress Report	Jatin, Group, Group
April 7th	Integrate the LCD and Button Array(GPIO protocol), PCB Order	Jatin and Jayanto, Group
April 14th	Solder PCBs Testing and Debugging, Team contract assessment	Group, Group
April 21th	Mock Demo	Group
April 28th	Final Demo, Mock Presentation	Group, Group
May 5th	Final Presentation, Final Papers	Group, Group

Table 2. This is an overview of the schedule that we worked on the project on.

4. Conclusion

4.1 Successes

The project worked as intended. Every subsystem in the project was powered through the appropriate buck converters, which gave a stable and protected the different components from any overcurrents or overheating. Another success was that the two ESP32 microcontrollers communicated effectively via a WiFi connection, and the keypad inputs were processed properly on the main microcontroller and the LCD output. Depending on the questions displayed on the LCD and the input from the keypad, both the solenoid locks are locked and unlocked accordingly on the escape and main boxes. The PCBs were soldered carefully, and integration between all the project's connections and parts was seamless. The motion sensor also worked as intended, as it could sense a human coming within 3-5 meters of it and switch from the standby screen to the welcome screen.

4.2 Challenges

We faced many challenges throughout our project. One of the early issues we came across was the fact that when we placed our orders for the second order of PCBs, we did not account for the USB to UART connection, so we had to account for that and place the order in the third round. This set us back in our timeline and slowed down our progress. Furthermore, when we did get the third round of PCB orders, we had made the wrong USB footprint: we designed it for a through-hole, but in reality, it was surface mounted. So, to work around this, we soldered the RX-TX connection wires directly onto the microcontroller so that we could program it, as shown in Figure 3. We also originally used Bluetooth in our project, but could not get 2 PCBs to communicate with it, so we moved on to a Wi-Fi connection instead. When we switched to Wifi, we could not find the second ESP32's IP address, so we could not send it a message. After multiple attempts at debugging, we could get the IP address to show on the serial monitor, and we could start sending signals then. We also had hardware issues, like making sure the buck converters worked as intended, and the LCD screen kept getting fried. These were primarily soldering issues and using new parts to make the project work.

4.3 Ethical Considerations

We ensured we did not collect any data or conduct any experiments without the approval of our group members. Additionally, we conducted regular testing and maintenance of all our components and subsystems to ensure that they operate safely within their parameters, per the ACM Code of Ethics 2.1. We also foresaw safety issues with the power aspect of our project. We used buck converters to keep the voltage contained according to our project and not damage anything, following the IEEE code of ethics 7.8.I.1.

4.4 Future Applications

We plan to expand our project, which has 2 PCBs, to 4/6 or even more PCBs to make the design more intricate and expand the project's scope. Furthermore, our PCB was very big, so we could make it much more concise. We even used the same PCB for the escape lock, and we could make this concise as well, removing all the parts pertaining to the LCD screen, keypad, and motion sensor. Finally, we could attach our project to real-life doors and make it into a real escape room/maze so that the product is ready for the market and for customers.

5. References

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