ECE 445

Senior Design Laboratory

Design Document

Inventory Tracker

Team 46

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Abstract

This document provides details on the proposed design and components of an inventory tracking system. It includes a proposed schedule for the project construction and testing and total estimated cost of the project.

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1 Introduction

1.1 Problem

Inventory tracking is an essential process in all types of applications ranging from small businesses to larger ones. It helps business owners keep track of their supplies and optimize their inventory levels based on demand. In addition, controlling the inventory could increase profitability when performed accurately. The process of tracking inventory is often done manually as it helps reduce cost, but this results in inaccurate results and discrepancies in the available supply due to human error. Moreover, it can be burdensome and time consuming as it often becomes repetitive which leads to inefficiency. As a result, automation has revolutionized the inventory tracking process. Although automating inventory tracking has been applied in several industries, small startups and business owners are still required to manually process their inventory due to the high cost of automation. Therefore, it is essential for them to shift to automating the process for a sustainable solution with less cost. Moreover, manual tracking is not only unreliable but it also poses a threat to the inventory as it remains unsecure at all times.

1.2 Solution

One proposed solution to the problem of asset tracking in small-owned businesses is a low-cost fully automated inventory management tracking system. This system would use an RFID scanner to scan an ID and unlock supply boxes to give users access. For additional security, it will allow users to only access inventory they are authorized to. The user would then be able to check the supplies available to them. The system would be connected to a web database that would display the stock of each item, what items have been checked out by which users and how many items have been checked out. Moreover, the system would allow a supervisor to access all supply boxes and restock products and update the total in the database. This would also help the user in visualizing the stock of inventory to see which items are in demand and thus increase efficiency and productivity.

Moreover, the system would alarm the user if unauthorized access has been detected. This would be established through a locking mechanism for the boxes. The boxes would be locked with a magnet and current carrying wire to hold them shut. Once a user scans their RFID card, only the boxes they have access to will unlock and a message would appear in the display to mark which box has been unlocked.

Finally, if a box is opened forcefully, this will alarm the user through the database that an unauthorized person has opened it.

1.3 Visual Aid

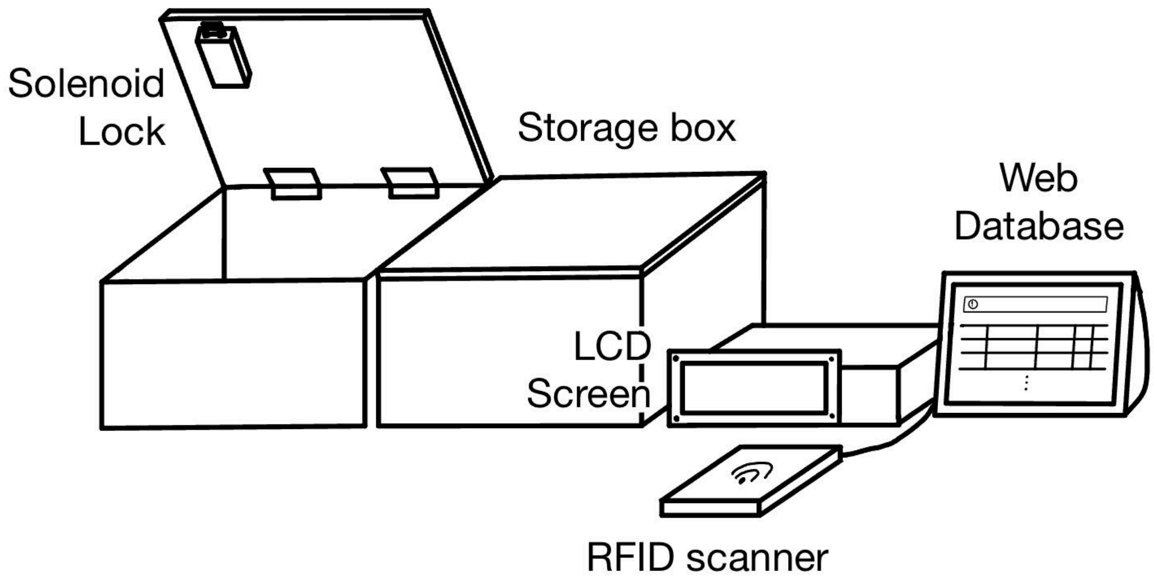

Fig. 2: PCB Schematic

1.4 High Level Requirements

1. When the user scan's their RFID card, the solenoids on the boxes the user has access to should unlock within 5 seconds and the LCD display should display the boxes the user has access to in the same timeframe.
2. When the user takes an item out of a box, the web database should display the item taken out and what user took it out within 5 seconds. The webpage should always display the number of items in stock and keep track of items checked out and who checked them out.
3. The alarm system should be triggered when force is applied to a locked box. Within 5 seconds of force being applied to the box door, both the LCD and web database should display that someone has tried to open a locked box.

2 Design

2.1 Physical Design

The system will be powered by a 120 V AC to 5V USBC connector. The ESP32 microcontroller will provide a Wifi/Bluetooth module, which will connect to a webpage to monitor parts that have been checked out and the total stock of each item. Two boxes will hold items and each will be held shut by a 12V solenoid lock. A boost converter will be used to step up the input voltage for the solenoid. Load cells will be in the boxes to measure the weight of the items in each box. Changes in this weight will determine if an item is checked out. The microcontroller will monitor this weight and communicate with the webpage when an item is checked out. An RFID module will allow users to scan in and unlock the drawers they have access to. When a user scans in, the microcontroller will allow power to be sent to the corresponding solenoid, unlocking the box the user has access to. An LCD screen will display to the user which boxes they have access to so they know which box to open. When this user takes an item out of the box, the microcontroller will communicate which part and what user took it to the webpage and the webpage will display this information and the total stock of all parts. Force sensitive resistors will be underneath the door and locking mechanism. It will sense if someone is trying to open a locked box by varying the voltage across it when force is applied. When this occurs, the microcontroller will communicate with the LCD and webpage and each will display a message that an unauthorized person is trying to open a box.

2.1.1 Schematic

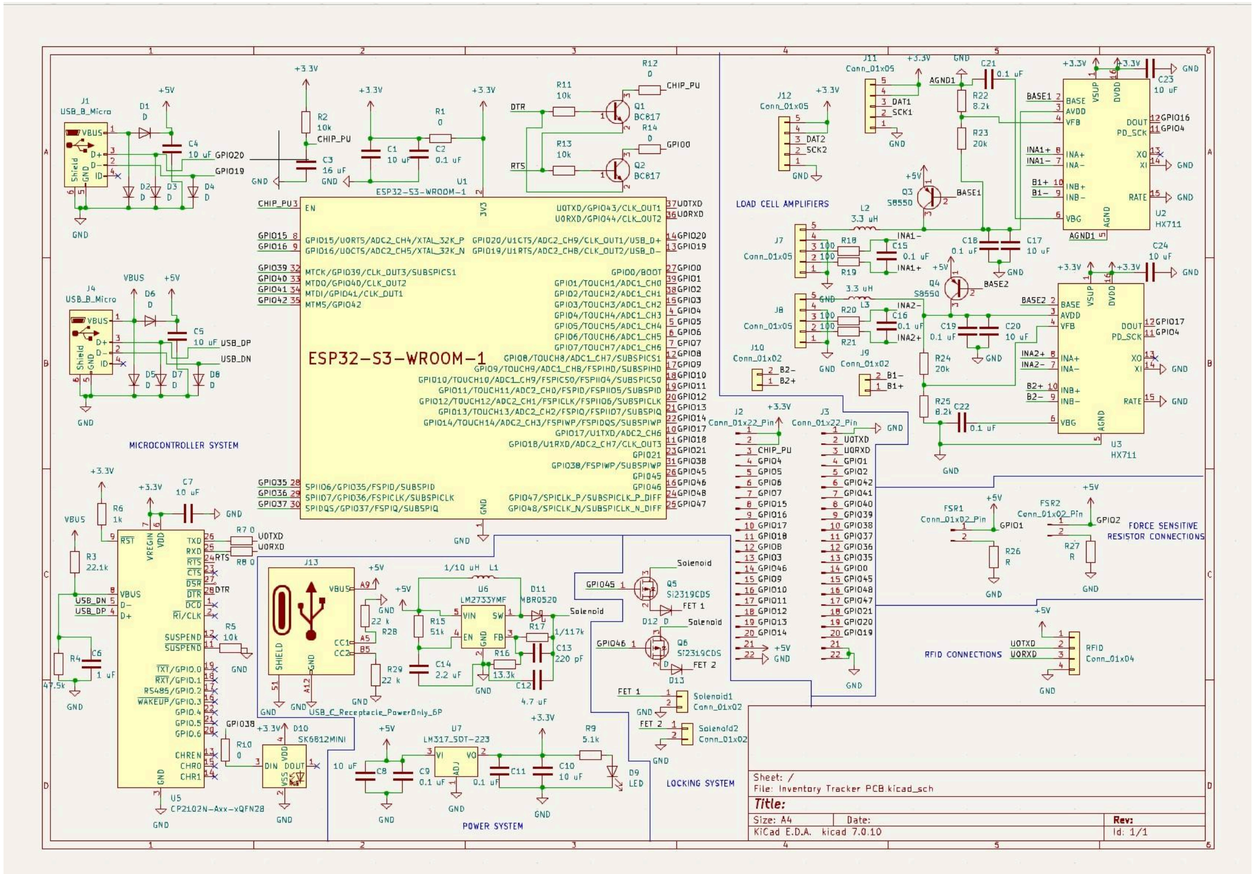

Fig. 2: PCB Schematic

2.2 Block Diagram

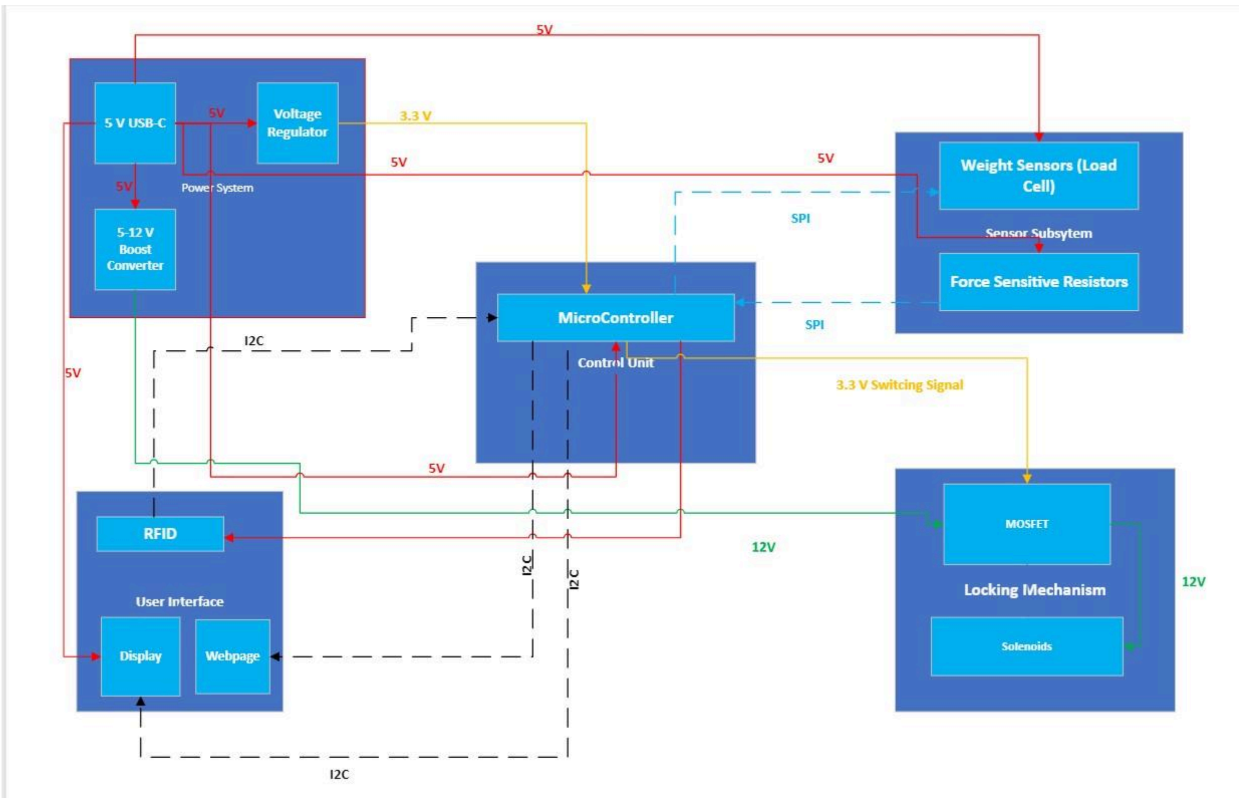

Fig. 3: Subsystem Block Diagram

2.3 Functional Overview

2.3.1 Power Subsystem

The power subsystem is responsible for providing power to all of the components of the project. The system is expected to be powered by a 120V AC to 5 V DC USB-C connector, which will output 5 V and 3 A. At normal operation, the system should draw around 2.12 W and at maximum load, which is when both solenoids are being unlocked, it should draw about 11.02W. The solenoids need 9-12 V for power and when unlocking they each will draw 350 mA. A boost converter will be used to step up 5 V to solenoids' rated voltage. The planned components are an LM317 5 V to 3.3 V voltage regulator, LM2733 boost converter, and a 120 V AC to 5 V DC USB-C plug and cable. Every component should be powered by 5 V, except for the solenoids and microcontroller and load cell amplifiers. The microcontroller and amplifiers will be powered with 3.3 V and the solenoids will be powered with 12 V.

Requirements	Verification
The USB-C should supply between 4.75 V and 5.5 V and it should be able to supply at least 2.2 A to power the system at maximum load.	- An oscilloscope probe should be used to measure the voltage across the connector and ground. The oscilloscope's current probe should be placed on the USB-C cable to measure the total current running through it. - With the system powered on and the probes connected as described above, scan the RFID module to unlock both solenoids and use the oscilloscope to monitor the voltage and current through the cable. Unlocking both solenoids should draw the maximum amount of power the system is designed to handle.
The voltage regulator should output between 3.0 and 3.6 V, which is the range needed to power the microcontroller.	- An oscilloscope probe should be used to measure the voltage between the regulator output and ground.
The boost converter should output between 9 and 12 V, which is the range needed to power the solenoids.	- An oscilloscope probe should be used to measure the voltage across the converter output and ground. - With the system powered on and the probes connected as described above, scan the RFID module to unlock both solenoids and use the oscilloscope to monitor the voltage of the converter.

Table 1: Power Subsystem Requirements & Verifications

2.3.2 Sensor Subsystem

The sensor subsystem is responsible for sensing the different weight of the items tracked and accurately distinguishing between them. We will implement the weight-scaling by using two load cells placed at the bottom of the boxes. Due to the load cells having a few volts as an output, an amplifier will be needed for that. The HX711 Load Cell Amplifier will be used and then it will be connected to the ESP32-Microcontroller. Moreover, this subsystem should measure how much force was applied to open the lid of the box. This will be used by using force sensitive resistors, also known as FSR's. The FSR's tend to have decreasing resistance with increasing force. A voltage divider will be used between the microcontroller and the FSR to determine the change in voltage.

Requirements	Verification
The load cells should accurately measure the weight of the items. It should report the weight with an approximated error of about 0.5% than its real weight.	- Take an item and weigh it with an accurate weight scale and record its weight. - Next, connect the load cell to the HX711 Amplifier. Connect the Red wire from the load cell to E+ on the amplifier, Black Wire from the load cell to E-, white wire from the load cell to A-, and green wire from the load cell to A+. - Connect the HX711 to the microcontroller. GND to GND, DT to any Data Pin available on the microcontroller, SCK to SCK and VCC to 3.3V pin on the ESP32 - After building this circuit, put the same item that was weighed earlier on the load cell and observe the measured weight. - If the measured weight is satisfactory (about +- 0.5% in accuracy), this step is completed. - Else, the load cell needs to be recalibrated.
The FSR should accurately measure how much force is put onto the box when opening it with +/- 10% in accuracy.	- Connect the FSR to the microcontroller with a Voltage Divider Circuit with a resistor in between the microcontroller and the FSR. - Lightly touch the FSR with your thumb and the value read should be 132-421 (depending on the value of the resistor that was used when calibrating the sensor) - With no pressure, the FSR should read a value of 0. - With a higher pressure onto the FSR, the value should increase correspondingly. - Test these again, when opening and closing the box and the value of the FSR should be between 150 - 350.

Table 2: Sensor Subsystem Requirements & Verifications

2.3.3 Control Subsystem

The Control System is the main subsystem that connects all the different components of the design together. It is responsible for receiving the weights of the different items from the weight sensors. When a user checks out an item, based on its weight, the microcontroller should send the updates with the items checked out to a web database. We will use the ESP32 microcontroller which has a built-in WIFI module to regularly update the web database when a user checks out an item. Moreover, the microcontroller should also communicate with the RFID Module to determine which box to unlock based on the specified access. This will be done through the communication between the ESP32, the solenoid locks, and the RFID Module. Finally, the microcontroller should determine when there is too much pressure put onto the FSR, and therefore trigger the web database to alert the user that someone is trying to access the inventory without authorization.

Requirements	Verification
Correctly interpret the weights of the items checked out with its corresponding name.	- When the box is open, take out the items and make sure that the correct item is displayed onto the web database. - Similarly, return an item into the box and the web database should also update successfully. - This should be done with all items in the box to make sure that the tracking is accurate and successful.
Send the data to the web database within 5 seconds.	- Close the lid of the box and scan the ID again to confirm that there is no more need of items checked out. - Check the web database and it should be updated to the most recent version with the ID of the user, Items Checked Out, and the number of items checked out, and the initial time of the ID-scanning and the final time of the scan. - This process should take no more than 5 seconds.
Differentiate between the users' scanned ID to only unlock the authorized boxes by controlling the switching signal to the solenoid.	- Connect the microcontroller to the solenoid lock . - Have a user who only has authorized access to only one box scan their ID onto the RFID, and make sure that only the specified box will unlock within 3-5

	seconds. - Have a user who has access to both boxes scan their ID, and make sure that both boxes should unlock.

Send an alarm to the web database when triggered by the FSR.	- This should be verified in these two scenarios:
	    - Scan an ID of a person who has authorized access to Box A and not Box B. After Box A is unlocked, try opening Box B by pushing into the lid or applying a strong push on the lid.
	    - The microcontroller should send a signal to the web database to alarm the user of unauthorized access.
	    - The second scenario is if a person does not scan their ID, and still tries to access the locked inventory. Don't scan your ID, and try pushing into the box to open it.
	    - Similarly, the microcontroller should send a signal to the web database to alarm the user of unauthorized access.

Table 3: Control Subsystem Requirements & Verifications

2.3.4 User Interface Subsystem

The user interface consists of the RFID module and a display. The RFID module will allow users to access the selection of boxes they have been given access to through their RFID card. It will communicate with the microcontroller, which will communicate with the locking system for successful operation. A web database consisting of items checked out by the user, along with the current stock of items, will be visible on a web page.

Requirements	Verification
The web database should be accurately updated with the user's information with the items they checked out	- Scan the iCard of the student on the RFID scanner and wait for the box to unlock, then correctly update the item checked out with the student's information. - The updated database will be pulled up and using SQL queries to correctly maintain the item stock.

The web database should be accurately updated with the user's information with the items they returned	- Scan the iCard of the student on the RFID scanner and wait for the box to unlock, then correctly update the item returned with the student's information. - The database should be pulled up and updated using SQL queries to correctly maintain the item stock.
There should be an alert displayed on the web when there's been a suspicious activity trying to open the box when there's no access granted	- Try to open the door by force when the box is still locked. - An alert notification should be displayed on the web with the time and the box # to report a suspicious activity.
RFID correctly reads the user data within 3 seconds when iCards is scanned	- RFID correctly reads and sends the user information when the iCard is scanned to the control subsystem
Display which box has been unlocked on LCD within 3-5 seconds. Ensure that the other box which the user is not authorized to access are locked.	- Scan the ID of the authorized user into the RFID scanner. - Wait for about 3 seconds and see which bx number is displayed onto the screen. - LED displays the unlocked box #. After the display, try unlocking the other box and make sure it remains locked.

Table 4: User Interface Requirements & Verifications

2.3.5 Locking Mechanism Subsystem

The Locking Mechanism Subsystem is added for safety reasons and to trigger the user when unauthorized access has been determined. This subsystem consists of two solenoid locks and a Force Sensitive Resistor which will be mounted on top of the locks to determine whether force is applied to the lid. The solenoid receives a signal from the microcontroller after a user scans their ID. The microcontroller's signal will specify which box to unlock and the solenoid will only unlock the specified ones. The solenoid locks will be connected to a MOSFET and to the boost convertor. The MOSFET's switching signal will be sent from the microcontroller to ensure that it is only unlocked when an authorized user tries to access it.

Requirements	Verification
Unlocks the solenoid of correct box within 5 or less seconds	- Connect the solenoid to the microcontroller. - Scan an ID of a person who has access to one of the boxes. - Wait for about 5 seconds - The solenoid lock should only unlock the authorized box.

Locks the solenoid of correct box within 5 or less seconds	- Connect the solenoid to the microcontroller. - Scan an ID of a person who has opened the box again. - Wait for about 5 seconds. - The unlocked box should now be locked. - Make sure that the box is only locked when the same person that has initially unlocked it, scans their ID.

Table 5: Locking Mechanism Subsystem Requirements & Verifications

2.4 Tolerance Analysis

One major aspect of this project that is critical to its success is ESP32 microcontroller. The microcontroller needs to have consistent power in order to work properly. To power the microcontroller, the LM317 voltage regulator will step down 5 V to about 3.3 V. The voltage regulator must be able to do this consistently and not overheat. According to the ESP32 datasheet [2], it can operate with an input voltage from 3.0 V to 3.6 V, so the voltage regulator must be able to stay within that range. According to the Wiki page on the ECE 445 website [1], the equation to determine the operating temperature of the voltage regulator is $T = i_{out}(v_{in}-v_{out})\theta_{ja}+T_a$ where θ_{ja} is the junction-to-ambient thermal resistance and T_a is the ambient temperature, assumed to be 25 °C.

According to the datasheet of the regulator [4], it can operate at temperatures up to 150 °C and is recommended to operate at less than 125 °C. It also has a junction-to-ambient thermal resistance of 66.8 °C/W. According to the ECE 445 Wiki page, the ESP32 should draw at maximum 355 mA. Using these parameters and the equation above, assuming in the worst case we operate at the minimum 3.0 V, the maximum calculated regulator temperature is 72.43 °C, which is within the recommended operating range.

To make sure the weight sensor we will be using can accurately sense the weights of all items we plan to put into the inventory, we have to find the appropriate range of weights that different kinds of weight sensors can support. Some weight sensors also need to be calibrated with known weights to function correctly, so deciding the range of weights/force and carefully choosing the right sensor are crucial for the system to work properly and accurately.

Force sensitive resistors (FSR) vary their resistance depending on how much pressure is being applied to the sensing area. Depending on the size of the resistor, FSR can sense applied force anywhere in the range of 100g - 10kg or as low as 2g. These sensors are simple to set up and great for sensing pressure, but they aren't incredibly accurate.

A strain gauge load cell is a type of electronic sensor used to measure force or strain. It comes in 1kg, 5kg, 10kg, and 20kg. For this load cell, we need to make sure to pick the one that has at least twice the max force/weight we intend to apply, the weights of items, so we get the most precision with the right range. So picking a 1kg strain gauge means the total weight of items for this section needs to be under 0.5kg for precision. Picking the 20kg strain gauge means we can have the weights of items to be up to 10kg.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Labor Cost

Assuming the average salary/hour of an ECE graduate is $50, expecting an 8 hours of work each week for 10 weeks of project execution for a team of 3 engineers, the labor cost can be calculated as below:

50 x 8 x 10 x 3 = $12,000

3.1.2 Cost of Parts

Description	**Manufacturer**	**Part Number**	**Quantity**	**Unit Cost ($)**
Solenoid locks	Adafruit	5065	2	$7.50
Load sensor	Sparkfun Electronics	SEN-10245	2	$4.50
Force Sensitive Resistor (FSR)	Adafruit	SEN-09376	2	$3.95
RFID Read/Write Module	Parallax Inc	PARALLAX 28440	1	$49.99
LM317 Regulator	Texas Instruments	M317MDCYR	1	$0.68
LM2733 Boost Converter	Texas Instruments	LM2733YMFX/NOPB	1	$1.73
HX711 Chip	Avia Semiconductor	HX711 SOP16	2	$0.495
LCD Display	Adafruit	181	1	$9.95
Total				**$95.24**

Table 5: Itemized List of Components and Costs

3.1.2 Total Cost

Summing up the labor cost and the cost of all parts, the total cost turns out to be **$12097.49**.

3.2 Schedule

Table 6: Assigned Schedule for Project Pt.1

Week	**To Be Completed**	**Assigned Member**
Week of 2/19	Complete PCB Schematic	Alex
	Acquire Parts	Sara
	Complete Sketch for the Machine Shop	Sooha
	Finish Design Doc	All
Week of 2/26	Design Review	All
	Complete PCB Design	All
	Acquire Parts	All
	PCB Review	All
Week of 3/4	Order PCB	All
	Start interfacing the Sensors with the microcontroller	Sara
	Start testing components for the Power Subsystem	Alex
	Start testing RFID with the microcontroller + Start web database	Sooha
Week of 3/18	Start testing the solenoid locks with the MOSFET and microcontroller	Sara
	Start on the identification process of the RFID and determining controlled access	Sooha

	Second Round of PCB Order	All
Week of 3/25	Test Sensor Subsystem	Sara
	Test Power Subsystem	Alex
	Test Locking Subsystem	Sara + Alex
	Test User Interface (RFID)	Sooha
	Test all these systems together	All
Week of 4/1	Begin Soldering	All
	Test PCB	All
	Begin Assembly of the system with the machine shop	All
Week of 4/8	Test PCB and the system	All
	Order 5th Round of PCB if necessary	All
Week of 4/15	Mock Demo	All
Week of 4/22	Final Demo	All
Week of 4/29	Final Presentation	All

Table 7: Assigned Schedule for Project Pt.2

4 Ethics and Safety

To ensure we work on this project in an ethical and safe manner we plan on following the IEEE Code of Ethics [3]. When issues arise between group members we will try to go through each person's point of view on the problem and try to find a good solution for everyone in a fair and efficient way. We understand the necessity of bringing up problems early before they can make working together a major difficulty. Along with that, we understand that this is a learning experience and we will focus on learning throughout this project.

Regarding privacy of data collected by the web database for user inventory tracking, we will ensure user data remains private and is only confined to the web database. The user's personal information will not be visible to the public and only necessary information will be kept. There will be no sensitive information stored in our database that can be easily used by the public to identify users (ex. names). We plan on only storing a form of identification number as user information. To further mitigate this concern, we plan to control access to the database with a PIN code so only authorized users can view the database of inventory tracking records.

Another concern is temperature regulation. The ESP32 can operate at up to 105 ºC [3] and most other components can handle up to 125. Using components above their rated temperature could cause components to burn and create safety hazards. In order to mitigate this, team members must determine the maximum temperature of components under the intended operating conditions and measure temperature of components during the testing procedure. Team members must disconnect power when it is determined that components are overheating, in order to mitigate damage to the system and avoid potential safety hazards.

5 References

[1] ECE 445. “Linear Regulators”. https://courses.engr.illinois.edu/ece445/wiki/#/regulators/index. (accessed Feb. 20, 2024).
[2] Espressif Systems. “ESP32-S3-WROOM-1 ESP32-S3-WROOM-1U Datasheet”. Espressif.com. https://www.espressif.com/sites/default/files/documentation/esp32-s3-wroom-1_wroom-1u_datasheet_en.pdf (accessed Feb. 8, 2024).
[3] IEEE. “IEEE Code of Ethics”. IEEE.org. https://www.ieee.org/about/corporate/governance/p7-8.html (accessed Feb. 8, 2024).
[4] Texas Instruments. “LM317 3-Terminal Adjustable Regulator”. https://www.ti.com/lit/ds/symlink/lm317.pdf?ts=1708370372081&ref_url=https%253A%252F%252Fwww.ti.com%252Fproduct%252Fes-mx%252FLM317. (accessed Feb. 20, 2024).