Camera Inventory System

Fall 2023

Design Document

Team 10

Krish Naik Aparaj (krishn2)

Rohan Harpalani (rohanhh2)

Rushil Duggal (rduggal2)

TA: Sanjana Pingali

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1. Introduction

1.1 Problem

In ECE 445, there is an outdated and labor-intensive system for handling the borrowing and returning of course components. This process not only places a significant amount of stress on teaching assistants (TAs) but also introduces unnecessary inefficiencies into the course logistics.

Currently, when students require specific components for their projects, they physically visit the inventory, select what they need, and then the TAs have to manually record each transaction. In addition, this manual record-keeping process is repeated when students return the borrowed items, and consequently, there is a recurring issue where some students forget or neglect to return what they borrowed. This not only complicates the TA's workload but also creates the need for them to invest additional time and effort in tracking down these missing items or addressing the situation, potentially involving charging students for unreturned components. However, this entire process can be streamlined and automated while ensuring it remains secure and reliable, and by doing so, the efficiency of the course logistics can be significantly improved without adding undue pressure on our TAs.

1.2 Solution

The design revolves around an automated camera-inventory system to change the way of managing component borrowing and returning in ECE 445.

The process begins with components being smartly tagged with QR codes and securely stored within a locked container. When students arrive to access these components, they will simply scan their iCard to unlock the container. This initial step not only grants access but also serves as an identification point, as it tracks who initiated the process. Once inside the container, students can select the specific parts they require. Then, when they hold these components up to the exterior camera, it quickly identifies the QR codes on the components. As it recognizes each item, it logs the transaction data in a backend system. Hence, the camera operates as a peripheral of a microcontroller and acts as the hub for this data collection and management process. In addition to the primary camera, a secondary camera peripheral is implemented which functions as a security measure to provide clear identification of individuals and avoid potential theft.

The same streamlined process applies when it comes time to return the components. Students will once again scan their iCard to unlock the container, and upon returning the borrowed items, they'll rescan the components, indicating their return. Evidently, this system promises not only enhanced efficiency but also a greater level of security and accountability.

1.3 Visual Aid

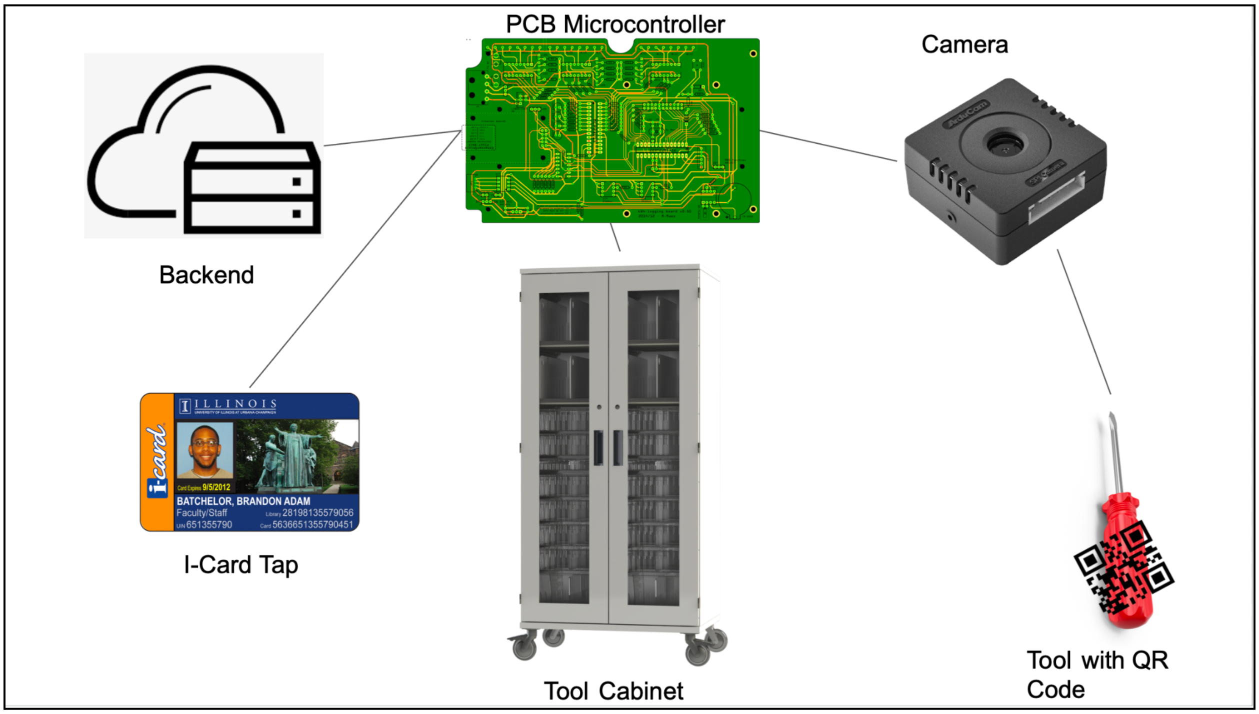

Figure 1: Block Diagram Overview for Camera Inventory System

1.4 High Level Requirements

- The system should unlock the tool cabinet in less than 7 seconds from when a student first taps their iCard on the RFID reader.
- The system should be able to scan and recognize each component's QR code in less than 6 seconds of first appearing in the frame.
- The system should correctly update the database in less than 6 seconds when a student borrows or returns a tool after receiving its unique identifier from the QR code.

2. Design

2.1 Block Diagram

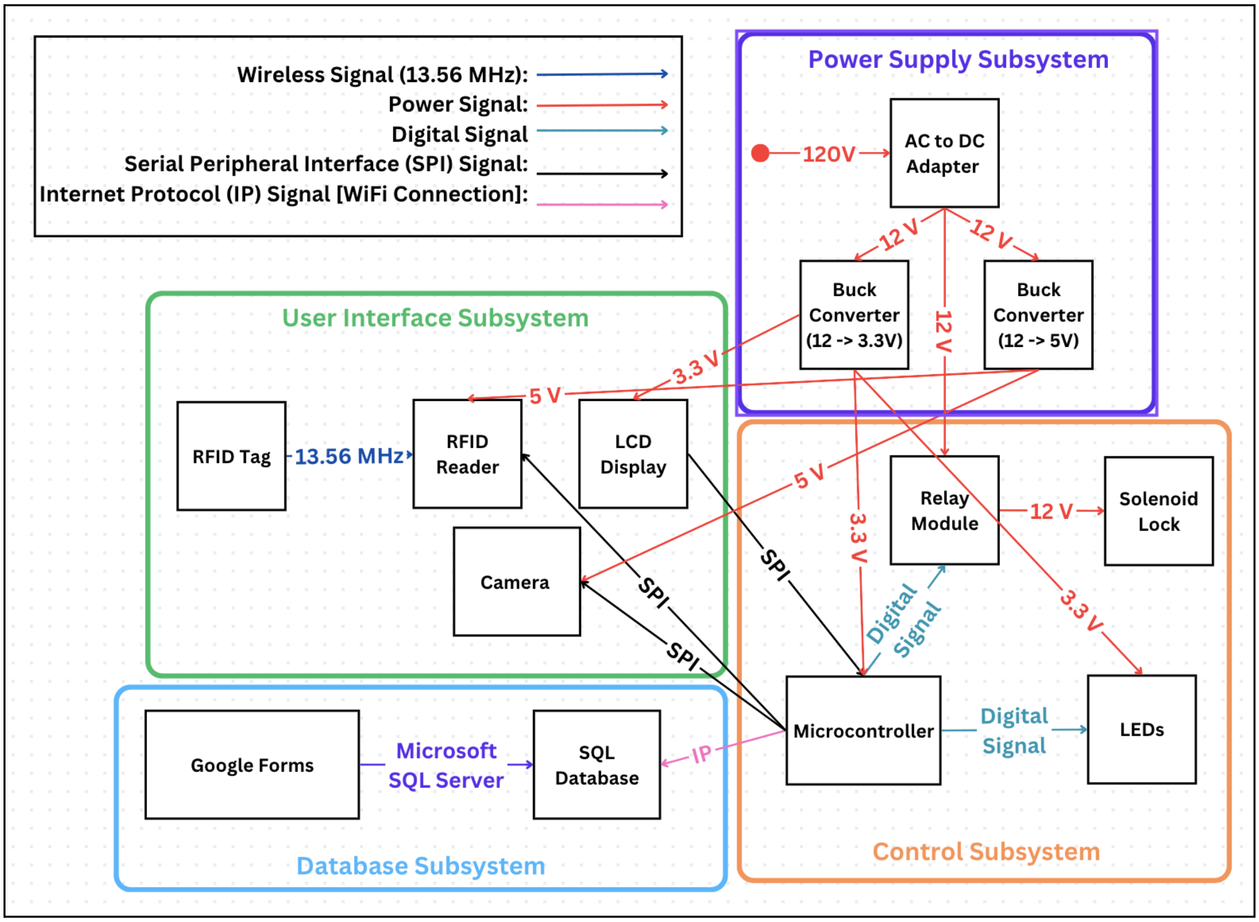

Figure 2: Block Diagram Overview for Camera Inventory System

2.2 Subsystem Descriptions, Requirements, and Verifications

2.2.1 User Interface Subsystem

This subsystem comprises several key components, including a display unit (LCD) that provides real-time information about the system's status, a RFID reader for students to input their iCard, and a camera which acts as a barcode scanner for QR codes affixed to the components they wish to borrow or return. Before students can scan their iCards which contain RFID tags, they must first complete a Google Form. This form collects essential personal information, such as their name and University Identification Number (UIN), which is then stored into the SQL database.

This information is vital for verification purposes and ensures that the student's identity matches the database records. Now, when a student approaches the container, they begin by scanning their iCard. This initiates a communication process with the control subsystem.

If the student is indeed authorized, the control subsystem, specifically the ESP32, sends a signal to the relay board, effectively unlocking the container. A visible indicator, the green LED on the LED subsystem, illuminates to signal that the container is now accessible. With the container unlocked, the student can enter and select the necessary components. Once their selection is complete, they employ the barcode scanner to register the borrowed components. The user interface subsystem transmits the barcode data to the control subsystem, and the control subsystem logs this transaction within the database, ensuring a record is maintained. Finally, a signal is sent to the relay board to lock the container securely. The red LED on the LED subsystem activates, visually indicating that the container is now locked.

The components of this subsystem have specific requirements. The display unit, responsible for providing real-time system status information, is expected to have a screen resolution of at least 1280x720 pixels and a refresh rate of at least 60 Hz, ensuring a clear and responsive user interface [4]. The RFID reader, used to scan student iCards, should operate at a frequency of 13.56 MHz, possess a reading range of at least 1 inches (with a tolerance of ±1 inch), and offer precise card detection [2]. The camera acting as a barcode scanner, employed for reading QR codes on components, should exhibit a scanning speed of a scan per 4 seconds (with a tolerance of ±1 seconds) and a scanning angle tolerance of ±5 degrees, enabling swift and accurate component identification. In addition, students are required to complete a Google Form with their name and University Identification Number (UIN) before accessing the system, ensuring proper identification.

Requirements	**Verification**
Verify that the camera system can detect and decode QR codes in 4 seconds or less	• Hold the QR code for a component in front of the system camera • Verify that the Arduino console identifies the QR code by printing a message out • Verify that the Arduino console identifies the correct component has been scanned
Verify that the LCD can display a message stating that the box has been unlocked after tapping iCard	• Tap iCard on the RFID reader to unlock the solenoid lock • Verify that the LCD displays a message stating that the box has been unlocked

Table 1: Requirements and Verification Table for User Interface Subsystem

2.2.2 Control Subsystem

This subsystem is made up of an ESP32 microcontroller, a relay board, electric solenoid lock, and LEDs. The control subsystem communicates to other parts of our system, such as the user interface, power supply, and database subsystems. When a student wants to access the container, they scan their iCard on the user interface, and consequently, the control subsystem checks with the SQL database whether the student is allowed to open the container. If they are, it sends a signal to the relay board to unlock the container. At the same time, it keeps a record of this transaction in the SQL database, like a digital logbook. The ESP32 has WiFi connection capabilities which allows us to produce bare-metal code to interface with the SQL database. When a student wants to borrow a component, they scan it with a barcode scanner, and the control subsystem records this in the database and then tells the relay board to lock the container securely until the next time it's needed. To make things even easier for users, the control subsystem controls two LEDs. When the container is open and ready for use, a green LED lights up, signaling that it's unlocked. When the container is locked, a red LED turns on, giving a clear visual indication that it is secured.

The ESP32 microcontroller should operate at a clock speed of at least 160 MHz, providing the computational power needed for system control. The relay board must be capable of handling high-current loads, up to 5A (with a tolerance of ±0.5A), to effectively manage container access [3]. The electric solenoid lock should exhibit an unlocking time of less than 3 seconds and demonstrate durability through a minimum of 200 unlocking and locking cycles, ensuring secure and reliable container access. LED indicators, including a green LED to signal an unlocked container and a red LED to indicate a locked container, facilitate clear user feedback and enhance the visibility of system status.

Requirements	**Verification**
The UID obtained from the RFID scanner should be mapped to a student in less than 3.5 seconds	● Scan iCard on RFID reader and print a message to the serial console stating that the UID was received from the RFID scanner. ● Use the ESP32 hardware timers and library to measure the time starting from when the UID was received. ● Wait until the UID is mapped to a

	student and print the student name and the time until the mapping process is complete and verify that the time taken is less than 3.5 seconds.
The relay should let 12V pass through the solenoid after the current UID was mapped to a student successfully, specifically if the current UID IS NOT the same as the previous UID. This indicates that a new student is attempting to open the box after a different student.	● Tap the iCard on the RFID reader and ensure that this iCard is not the same as the iCard that was previously scanned and the box is currently locked. ● Observe the current UID and previous UID printed on the serial output and validate that they are different. ● Use a multimeter to measure voltage from the exposed wire at the terminal on the relay which sends voltage to the solenoid.
The relay should not let 12V pass through the solenoid after the current UID was mapped to a student successfully, specifically if the current UID IS the same as the previous UID. This indicates that a new student is attempting to close and lock the box after a different student.	● Tap the iCard on the RFID reader and ensure that this iCard is the same as the iCard that was previously scanned and the box is currently unlocked. ● Observe the current UID and previous UID printed on the serial output and validate that they are the same. ● Use a multimeter to measure voltage from the exposed wire at the terminal on the relay which sends voltage to the solenoid.

Table 2: Requirements and Verification Table for Control Subsystem

2.2.3 Power Supply Subsystem

This subsystem comprises four integral components, which are an AC/DC adapter, a battery charger, a lithium-ion battery, and a voltage regulator, and plays a crucial role in maintaining system operation. The AC/DC adapter is responsible for converting the alternating current (AC) received from a standard wall outlet into direct current (DC), which is the type of electricity electronic devices require. Specifically, the AC/DC adapter employed in our automated camera-inventory system is rated for 12 volts (V) and 2 amperes (A), equating to a power output capability of 24 watts (W). This provides the necessary electrical foundation to drive the system's various functions. Adjacent to this, the battery charger is designed to replenish the energy stores of the lithium-ion battery when the system is connected to an electrical outlet. This charger, optimized for lithium-ion batteries, operates at a rating of 12.6V and 3A, delivering a charging capacity of up to 37.8 watts (W). This ensures that the lithium-ion battery is consistently prepared to power the system. The lithium-ion battery itself is a high-performance rechargeable energy source, and in our automated camera-inventory system, it boasts a capacity of 4400 milliampere-hours (mAh). This capacity translates to the ability to deliver up to 4.4 amperes (A) of current for one hour, demonstrating its ability to sustain system operation [6]. Lastly, the voltage regulator is tasked with maintaining a stable output voltage, specifically set at 12 volts (V) in the system. Regardless of fluctuations in the input voltage, the voltage regulator ensures that the supplied voltage remains unwavering, contributing to the system's reliability and consistency. Evidently, the power supply subsystem facilitates the operation of all other subsystems by providing them with the necessary electrical power.

The AC/DC adapter should efficiently convert AC power to 12V and 2A of DC power, maintaining voltage and current within tolerances of ±0.5V and ±0.2A, respectively, ensuring a stable power supply foundation [5]. The battery charger must effectively replenish the lithium-ion battery at 12.6V and 3A (with voltage and current tolerances of ±0.2V and ±0.3A), guaranteeing the readiness of the power source [1]. The lithium-ion battery should boast a capacity of 4400mAh, delivering a continuous current of at least 4.4A for 1 hour in order to indicate its capacity to sustain system operation during power interruptions. The voltage regulator is tasked with maintaining a steady 12V output voltage, with a tight tolerance of ±0.1V, regardless of input voltage fluctuations.

Requirements	**Verification**
The 12V from the AC/DC adapter should drop to 5V ± 0.5 through our linear regulator circuit	• Plug the AC/DC adapter to the barrel jack on the PCB to supply 12V to the PCB • Use a multimeter to measure one test point at the output of the linear regulator circuit and one ground test point (0V) and check if the voltage shown is 5V
The 12V from the AC/DC adapter should drop to 3.3V ± 0.5 through our buck converter circuit	• Plug the AC/DC adapter to the barrel jack on the PCB to supply 12V to the PCB • Use a multimeter to measure one test point at the output of the buck converter circuit and one ground test point (0V) and check if the voltage shown is 3.3V

Table 3: Requirements and Verification Table for Power Supply Subsystem

2.2.4 Database Subsystem

This subsystem manages and stores all the vital data required for smooth system operation. Through communication with the ESP32 microcontroller, it encompasses a wide range of information, including details about students, the components available, and the history of transactions within the system. Its role extends beyond storage as it actively communicates with the other subsystems to record transactions, fetch necessary data, and generate comprehensive reports. The database subsystem employs a Structured Query Language (SQL) database, which is a specialized language that computers understand to manage data effectively. The database itself is structured with three distinct sections: students, components, and transactions. Each section has a specific purpose. The students section is like a directory of student information, storing data such as their names and unique student IDs. The components section stores the component name and number as well as the quantity. Lastly, the transactions section records details such as when a transaction occurred and whether a component was borrowed or returned.

This subsystem operates using a Structured Query Language (SQL) database, organized into three key tables: students, components, and transactions. The students table stores student names and University Identification Numbers (UINs), ensuring accurate user identification. The components table records component names, numbers, and quantities, facilitating precise inventory management. Lastly, the transactions table logs transaction timestamps and transaction types (borrowed or returned), providing a comprehensive transaction history for system monitoring. To fulfill its role effectively, the SQL database must accommodate a minimum of 250 records in each of these primary tables, supporting simultaneous read and write operations from multiple subsystems. It should exhibit a rapid response time for transactions, completing tasks in less than 100 milliseconds (with a tolerance of ±10 milliseconds), ensuring near-instantaneous access to information [7]. In addition, a backup and recovery mechanism with data backup intervals not exceeding 24 hours should be in place, guaranteeing data integrity and availability.

Requirements	**Verification**
The SQL database should be able to accurately update a student's information in terms of what components they borrowed.	• Run SQL query in ESP32 again to pull up student information and their respective borrowed components. • Scan the iCard of the student on the RFID scanner and wait for the box to unlock

	● Hold up component to the camera and wait for the LED to light up to indicate that the SQL database was updated ● Run SQL query again to pull up student information and their respective borrowed components. There should be one more component in the table.
The SQL database should be able to accurately update a student's information in terms of what components they return.	● Run SQL query in ESP32 again to pull up student information and their respective borrowed components. ● Scan the iCard of the student on the RFID scanner and wait for the box to unlock ● Hold up component to the camera and wait for the LED to light up to indicate that the SQL databas e was updated ● Run SQL query again to pull up student information and their respective borrowed components. There should be one less component in the table.

Table 4: Requirements and Verification Table for Database Subsystem

2.2.4 Tolerance Analysis

We need to make sure that students are able to properly scan their QR codes using the camera connected to the ESP32. This interface is the essence of the project as a whole because it represents the system which replaces the manual process performed by the TA's currently. While it is the essence of the project, it is also the most challenging requirement as there are many factors that play a role when it comes to properly scanning the QR code. These factors are light intensity of the room, resolution of the camera, size of the QR code, distance between the camera and the QR code, and the density of the QR code.

However, due to the project, we can hold these following factors as constant and eliminate them from our tolerance analysis: light intensity of the room, resolution of the camera, and the density of the QR code. Therefore, the primary components that we need to pay attention to are the sizes of the QR codes and the distance between the camera and the QR code.

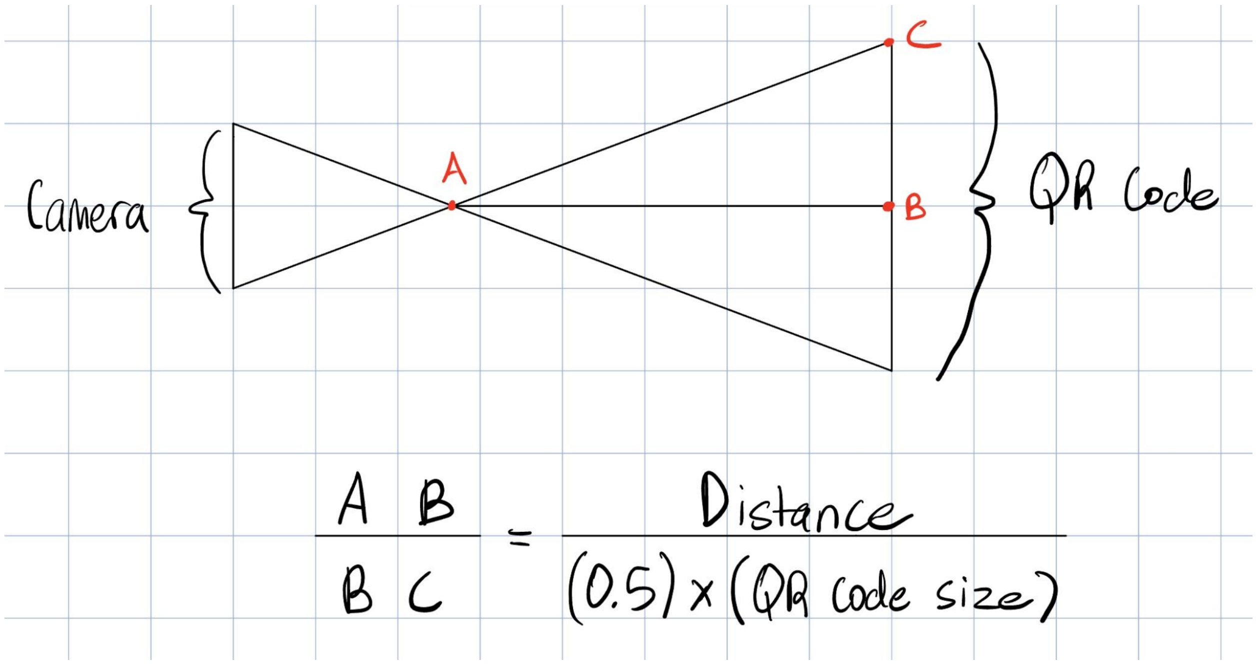

Figure 3: Camera and QR Code Diagram with formula including relative lengths

Using this derived formula and diagram, we can determine appropriate QR code sizes and corresponding distances that are ideal for the student without having to adjust too much. The units of measurements for both QR codes and distances would be in centimeters.

Component	Maximum Current Drawn (mA)
Microcontroller (ESP32)	95 mA
Red LED	20 mA
Green LED	15 mA
LCD Display	20 mA
I_{out} **(total)**	**150 mA**

Variable	Value
I_{out}	150 mA
V_{in}	12 V
V_{out}	3.3 V
Θ_{ja} (thermal resistance, junction to ambient)	70 °C/W
T_a (ambient temperature)	40 °C
T_j (max temperature)	150 °C

$$T = (I_{out}) * (V_{in} - V_{out}) * (\Theta_{ja}) + (T_a)$$
$$T = (0.165\,A) * (12\,V - 3.3\,V) * (70\,°C/W) + (40\,°C)$$
$$T = (0.165\,A) * (12\,V - 3.3\,V) * (70\,°C/W) + (40\,°C)$$
$$T = 131.35\,°C < T_j$$

Evidently, based on the above analysis, the AP62300TWU-7 buck converter (12 V to 5 V) would output the necessary power without overheating as the estimated temperature ($T = 131.35\,°C$) is less than the maximum operating junction temperature (T_j = 150°C).

Component	Maximum Current Drawn (mA)
Microcontroller (ESP32)	95 mA
Red LED	20 mA
Green LED	15 mA
LCD Display	20 mA

I_{out} **(total)**	**150 mA**

Variable	**Value**
I_{out}	150 mA
V_{in}	12 V
V_{out}	3.3 V
Θ_{ja} (thermal resistance, junction to ambient)	200 °C/W
T_a (ambient temperature)	40 °C
T_j (max temperature)	150 °C

$$T = (I_{out}) * (V_{in} - V_{out}) * (\Theta_{ja}) + (T_a)$$
$$T = (0.150\,A) * (12\,V - 3.3\,V) * (200\,°C/W) + (40\,°C)$$
$$T = (0.150\,A) * (12\,V - 3.3\,V) * (200\,°C/W) + (40\,°C)$$
$$T = 301\,°C < T_j$$

Evidently, based on the above analysis, the ZXTR2105F-7 linear regulator would NOT output the necessary power without overheating as the estimated temperature ($T = 301\,°C$) is significantly more than the maximum operating junction temperature (T_j = 150°C).

Component	**Maximum Current Drawn (mA)**
RFID Reader	50 mA
Camera	140 mA

I_{out} **(total)**	**190 mA**

Variable	**Value**
I_{out}	190 mA
V_{in}	12 V
V_{out}	5 V
Θ_{ja} (thermal resistance, junction to ambient)	70 °C/W
T_a (ambient temperature)	40 °C
T_j (max temperature)	150 °C

$$T = (I_{out}) * (V_{in} - V_{out}) * (\Theta_{ja}) + (T_a)$$
$$T = (0.190\,A) * (12\,V - 5\,V) * (70\,°C/W) + (40\,°C)$$
$$T = (0.190\,A) * (12\,V - 5\,V) * (70\,°C/W) + (40\,°C)$$
$$T \approx 133.1\,°C < T_j$$

Evidently, based on the above analysis, the AP62300TWU-7 buck converter (12 V to 3.3 V) would output the necessary power without overheating as the estimated temperature ($T = 133.1\,°C$) is less than the maximum operating junction temperature (T_j = 150°C).

3. Cost and Schedule

3.1 Cost

Labor Costs:

$50 (hourly wage) x 15 (hours per week of work) x 11 (weeks of work) x 2.5 (scaling cost) x 3 (3 people in the group) = **$61,875 (total labor costs)**

Description	Manufacturer	Manufacturer Product Number	Quantity	Unit Cost ($)
RF TXRX MOD BLUETOOTH CHIP SMD	Espressif Systems	ESP32-WROOM-32 (16MB)	1	$4.50
AC/DC WALL MOUNT ADAPTER 12V	Tri-Mag, LLC	L606H-120	1	$5.82
BATTERY LITH-ION 3.7V 4400MAH	Adafruit Industries LLC	ICR18650 4400mAh 3.7V	1	$19.95
IC BATT CNTL LI-ION 1CEL SOT23-5	Microchip Technology	MCP73812T-420I/OT	1	$0.73
AC/DC CONVERTER 12V	MEAN WELL USA Inc.	EPS-15-12	1	$9.92
IC REG LINEAR 3.3V 300MA 5TSOP	onsemi	NCP115ASN330T2G	1	$0.36
1 CHANNEL RELAY 3V RELAY MODULE	Pi Supply	PIS-1267	1	$5.59
SMALL LOCK-STYLE SOLENOID - 12VD	Adafruit Industries LLC	5065	1	$7.50
LED RGB CLEAR 4SMD	Kingbright	APHF1608LSEEQBDZGKC	1	$0.76
LCD MOD 32 DIG 16 X 2 REFLECTIVE	Lumex Opto/Components Inc.	LCM-S01602DTR/M	1	$10.47

UNIT CAM WI-FI CAMERA (OV2640)	M5STack Technology Co., Ltd.	U109	1	$10.95
ESP32-CAM WiFi+BT SoC 2MP Camera	CANADUINO	ESP32-CAM WiFi BT BLE	1	$9.72
RFID READER R/W 13.56 MHZ MOD	DLP Design Inc.	DLP-RFID2	1	$37.95

Table 5: Costs of Parts

Total Cost: $124.22

3.2 Schedule

Week	Task	Assigned Member
Sept. 24 - Sept. 30	Order Components	All
	Start Control Subsystem Schematic	Krish
	Start Power Supply Subsystem Schematic	Rushil
	Start User Interface Subsystem Schematic	Rohan
Oct. 1 - Oct. 7	Finish initial PCB design	All
	Design Review	All
	PCB Review	All
Oct. 8 - Oct. 14	Final Machine Shop revisions to build container after getting components	Rohan
	Make necessary revisions after PCB review	All

	First Round PCBway Order	Rushil
	Set up MySQL backend and link with Google Form	Krish
Oct. 15 - Oct. 21	Work on ESP32 programming and interfacing with backend	Krish
	Work on ESP32 and camera integration	Rushil
	Work on QR code identification with camera	Rohan
	Make PCB Revisions	All
	Second Round PCBway Order	Krish
Oct. 22 - Oct. 28	Work on integrating RFID reader and ESP32 for student identification	Krish + Rohan
	Work on integrating LCD and ESP32	Rushil
	Continue working on QR code identification and camera + ESP32 integration	Krish + Rushil
	Make PCB revisions	All
	Third Round PCBway Order	Rohan
Oct. 29 - Nov. 4	Start assembly	All
	Begin unit testing Control Subsystem	Krish
	Begin unit testing Power Supply Subsystem	Rohan + Rushil
Nov. 5 - Nov. 11	Finish assembly	All
	Begin unit testing User Interface Subsystem	Krish + Rohan
	Test functionality of subsystems working together	All

	Fix bugs	All
Nov. 12 - Nov. 18	Mock Demo	All
	Fix Bugs	All
Nov. 19 - Nov. 25	Fall Break	None
Nov. 26 - Dec. 2	Final Demo	All
Dec. 3 - Dec. 9	Final Presentation	All

Table 6: Schedule

4. Discussion of Ethics & Safety

One relevant ethical concern for this system would be regarding user privacy. Since users are expected to stand in front of a camera to scan their item, there may be concerns about storing their biometric/facial information in our system as well, which users may understandably be uncomfortable with. The ACM Code of Ethics specifically raises this concern in their principle to respect the privacy of users, making it all the more important to heed. To mitigate this concern, we could make it clear to users that no visual information is stored - the camera is only used to read the QR code.

Another ethical concern is to avoid discrimination. As detailed in the ACM Code of Ethics, this is especially important given that our project may lead to technology-driven discrimination in terms of monitoring the supply cabinet [8]. This project should not be used to prejudice or discriminate against any groups. To mitigate this, any violations found using our system should be thoroughly investigated by a user as well, to avoid any wrongful accusations.

5. References

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