Electronic Replacement for COVID-19 Building Monitors at UIUC

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1 Introduction

1.1 Objective

Human building monitors around the UIUC campus pose an unnecessary risk to students and staff, when a technological solution could be implemented. These monitors are in place to make sure that the right people are being let into the right places, using the Safer Illinois App developed by the university. This app provides access to testing results for the students, and faculty, and creates a randomized, unique building access pass, so it cannot be replicated. Even with this amazing software, we still put these human monitors at risk, and those who have to interact with them, at risk.

Our goal is to create an automated replacement system for these building monitors that still adequately protects the residents of the building. We will do this by creating a physical two-factor authentication network, that uses a central microcontroller to monitor the door for suspicious activity. As we do not have access to the backend of the Safer Illinois application, or the ability to use campus buildings as a workspace for our project, we will be designing a proof of concept 2FA system for UIUC building access. Our solution would be composed of two main subsystems, one that allows initial entry into the "airlock" portion of the building using a scannable QR code, and the other that detects the number of people that entered the space, or a form of people counter, to determine whether or not the user will be granted access to the interior of the building.

1.2 Background

COVID-19 has put everyone across the world in dire straits. Every system or service that is a part of life has been put through one of the most extreme stress tests we have seen in over a hundred years. However, places like the University of Illinois have been trend setters for solutions to the many problems that COVID has placed upon these systems. They have developed new forms of testing, state of the art tracking applications, and many other procedures and systems. However, even with these huge strides in innovation, some approaches are archaic in comparison.

Studies show that appropriate social distancing and mask wearing results in an approximately 3% transmission rate of SARS-CoV-2 [1]. While this seems positive in the grand scheme of things, these monitors are still at risk, and taking away the human element could potentially save these people from infection. On average, humans make about 4-6 errors per hour [2]. Let's say in the case of a building monitor, this error includes misuse of masks or improper social distancing, this creates great risk for all involved, and is not isolated to the monitor either. Since the students/staff being checked are interacting with those monitors, they make errors as well, further complicating the issue. People are not perfect, and human error will always find a way to create problems. With a fully automated system, we can remove that human element, and create a system that can monitor all buildings on campus around the clock.

1.3 Physical Design

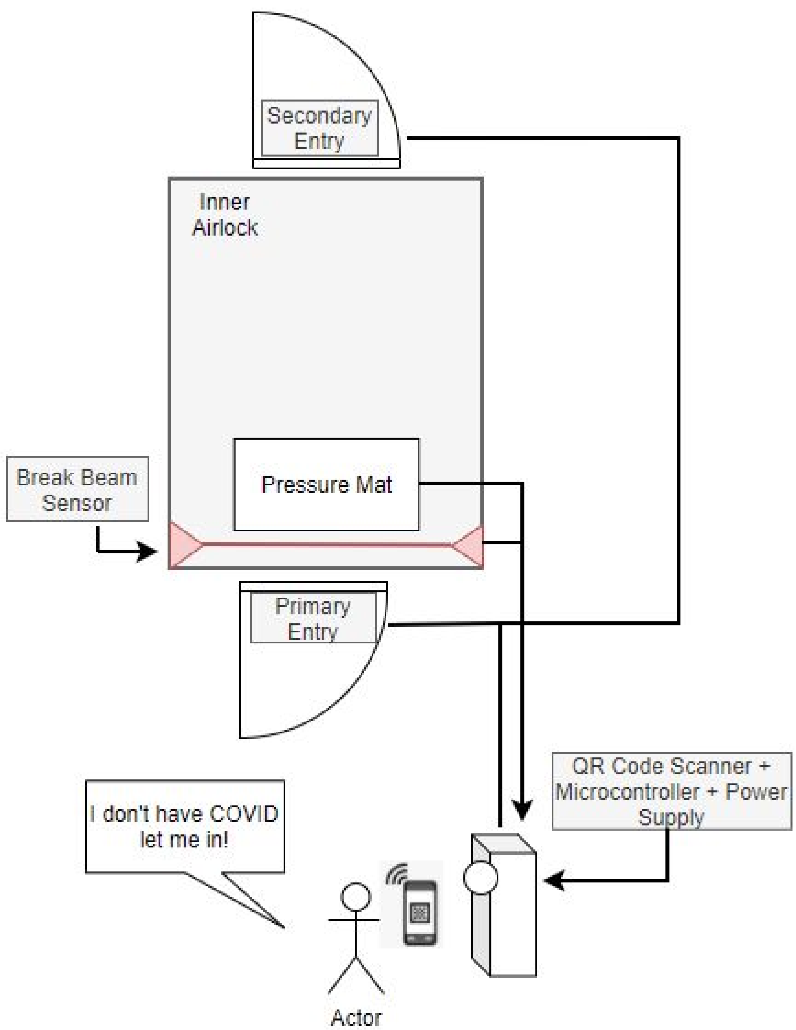

Figure 1: High Level Pictorial Diagram of Design

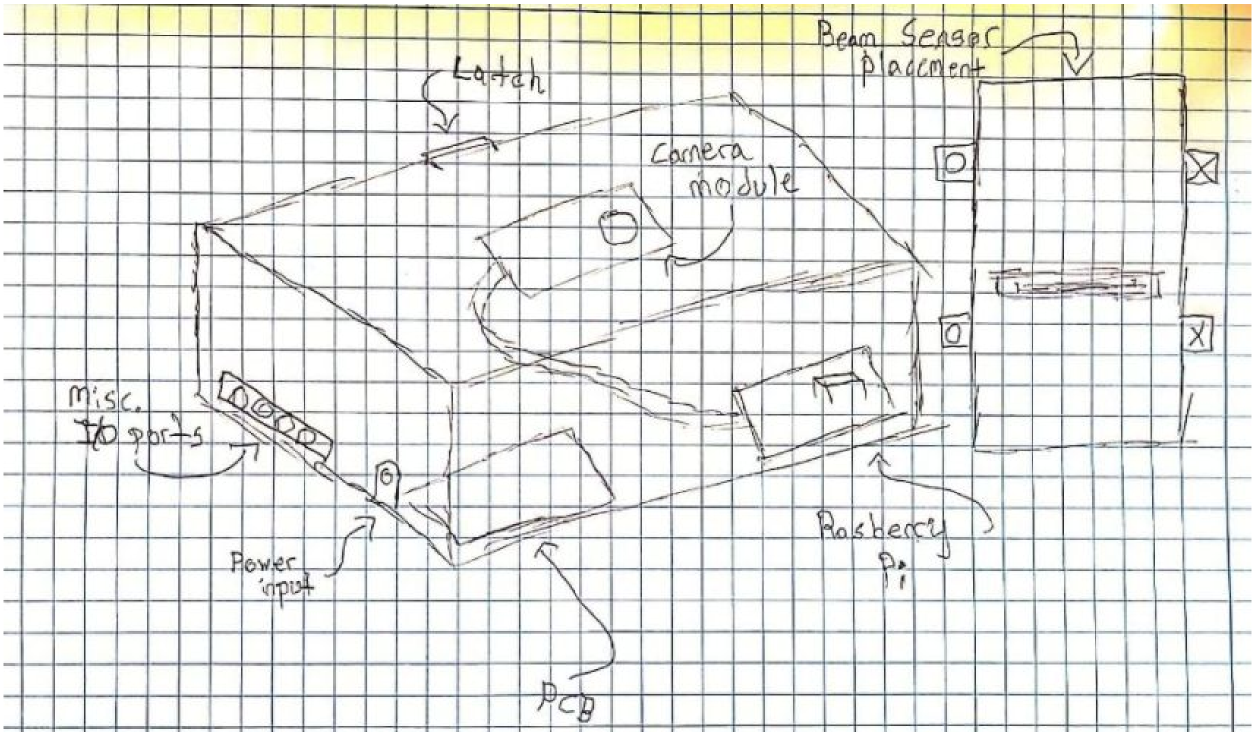

Figure 2: Low Level Pictorial Diagram of Design (Control Unit + Beam Placement)

1.3 High-Level Requirements

- Must be able to decode the encoded QR code automatically, within 3 seconds of presented code. Must also be able to determine the initial positive/negative testing requirement for entry. (“QR Code Scanner should be able to determine if the user is allowed primary entry using the encoded information from the generated QR code”)
- Break-beam sensor and pressure mat within the airlock must work synchronously to determine the presence of a single student/faculty member, as well as accurately keep track of entries with a <5% error rate. (Will use an extensive list of outlier situations for testing).
- The system must be able to process each person within a 30 second time frame, to prevent congestion at the entryways of buildings across campus.

2 Design

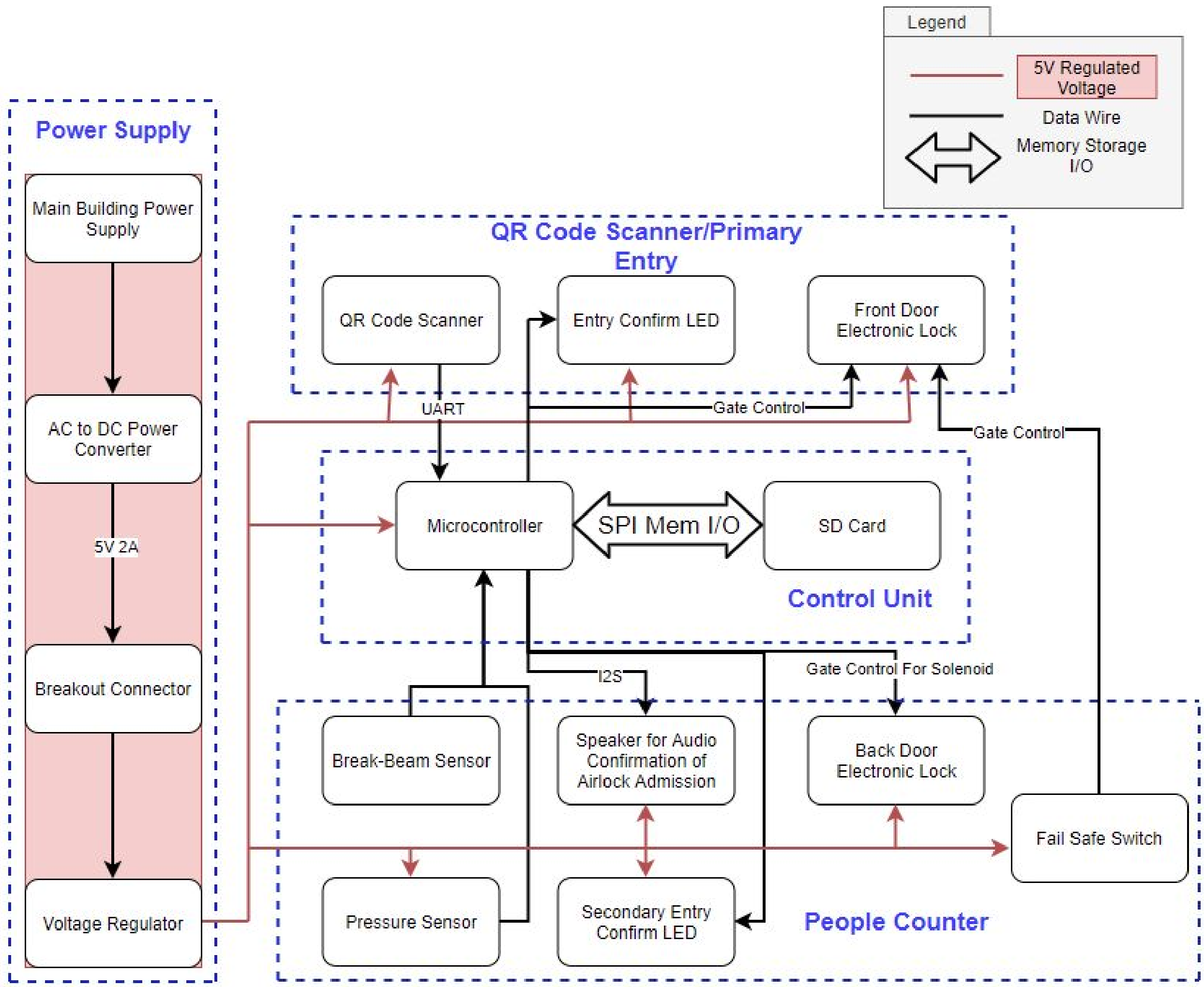

Figure 3: Block Diagram

2.1 Power Supply

A power supply is required to keep the communication network up continually. Power from the main building supply will charge a battery, which is then regulated to 3.3V for the rest of the system. We have a seperate battery supply in the instance the power from the building is cut, and the system needs to continue operating.

2.1.1 Main Building Power Supply

The system needs the power to work properly. Since the system was installed at the door, it can get power directly from the building. Also, it needs to provide enough power for the Li-ion charger, in case the main power supply has any problem.

Requirements	Verification
1. Must provide stable power of 110V-120V, which can power the system.	A. To verify an AC power, set the multimeter to AC mode. Use one hand to hold the red and black probes to ensure safety. Do not let the metal parts of the probes touch each other to avoid short circuit.Insert the red probe into the smaller slot and the black probe into the larger slot. If it gives a reading of 110v-120v, the outlet is qualified. B. To verify a DC power, set the multimeter to DC gear. Use the red probe to touch the positive terminal of the battery and the black probe to the negative terminal of the battery. If it gives a correct reading, the power supply is qualified.

2.1.2 AC to DC Power Converter

To convert the AC power from the supply to the DC power that can be used in the system, a converter is required. Using a VEL24 power converter, we can convert 120V AC to the 12V DC, which is prepared for the voltage regulator.

Requirements	Verification
1. 1.Must be able to convert 110V-120V AC to 12V (+/- 10%) 2A DC.	A. A multimeter will be used to check if the output voltage is equal to 12V 2A, and an oscilloscope will be used to check if the voltage signal is steady.

2.1.3 Breakout Connector

Requirements	Verification
1. This connector should break out the micro USB's pins to VCC, GND, ID, D+, and D-.	A. Use a wall outlet adapter to connect to a micro USB to USB A cable. Plug the micro USB part into the Breakout Connector. Use the multimeter to measure the voltage. If the measurement is correct, then the Breakout connector is qualified.

2.1.4 Voltage Regulator

We will use a L7805 series voltage regulator. This part of the power supply can convert 12V to the required 5V to the whole system.

Requirements	Verification
1. Must be able to convert 12V (+/- 10%) DC to 5V (+/- 5%) DC.	B. A multimeter will be used to check if the voltage is equal to 5V, and an oscilloscope will be used to check if the voltage signal is steady.

2.2 QR Code Scanner/Primary Entry

This part of the system will be installed on the first/outside door. It is used to make sure everyone entering the area between the outside and the inside door is safe and authorized.

2.2.1 QR Code Scanner

We are planning to use Raspberry Pi 4 and a camera module to build a QR Code Scanner by ourselves. With the help of OpenCV library, we can implement a program continuously reading the QR code and sending the information to the microcontroller. The QR Code Scanner is able to scan the QR code on every student's phone. Only when the QR code is scanned, the information will be sent to the Control Unit. The scanner needs the reliable power of 5V to work properly, and uses UART RS232 to connect to the microcontroller.

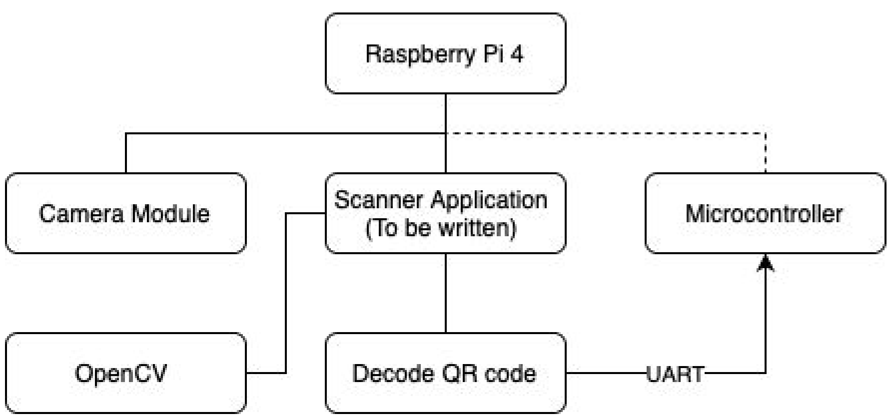

Figure 4: The workflow of Raspberry Pi based Scanner

Requirements	Verification

1. Since the system must be able to process each person within a 30 second time frame, it's important to have the scanner have a high accuracy (> 95%) to detect the QR code. 2. The scanner will be put outside, so it must be able to work properly under the sunlight.	A. Connect the scanner to a monitor directly. Instead of sending information to the microcontroller, we may display the information on the monitor. B. Test the scanner in different environments, and make sure it works well under the sunlight.

2.2.2 Entry Confirm LED (LTL1BEKVJNN)

We are using a two-color LED, LTL1BEKVJNN, as the entry-confirm LED. When the QR Code Scanner scans the correct QR code, it will send the information to the Control Unit. After that, the Control Unit will switch the LED light on to tell the person to come in.

Requirements	Verification
1. The Entry Confirm LED must be clearly visible from 0.5 meters away. 2. The LED runs well under 2.1V (+/- 5%) and 30mA (+/- 5%).	A. Check the LED from 0.5 meters away. B. Build a simple circuit containing only LED, power supply and resistor. The power supply will be 5V, and the resistor will be 100Ω.

2.2.3 Front Door Electronic Lock

At the same time of the LED on, the Control Unit will also unlock the outside door lock to let the person enter the People Counter area. Using a Mini Push-Pull Solenoid, we can easily control the process of lock/unlock by controlling the voltage.

Requirements	Verification
1. The lock will work under 5V, and when receiving the signal from the microcontroller, it must unlock/lock the door in a short period of time to avoid the congestion of the crowd.	A. Build a small circuit on a breadboard, and verify when the 5V voltage power supply is turned on, the lock is unlocked and when the power supply is cut, the lock is locked.

2.3 Control Unit

The Control Unit is able to control the whole system as well as the computation of the logic. It will control and decide the status of the inside door based on the data collected from the sensor as well as the information scanned from the QR code.

2.3.1 Microcontroller

The Microcontroller is the core of the Control Unit. It will be in charge of the control of the whole system and make the decision of the lock status of the inside door. We will be using the recommended ATMEGA 32A to run our system.

Requirements	Verification
1. The microcontroller must be able to communicate over CAN, UART, I2S, and SPI simultaneously. It needs to process the data sent by both sensors at the same time, and send the control signal to the LED, speaker and electronic lock. 2. The microcontroller can transfer data over Serial UART at the baud rate of 9600 and 115200.	A. Connect the microcontroller with the bootloader (It can be an Arduino). Connect the bootloader to the computer, and open a port console. Start to send data to the microcontroller over the baud rate of 9600 and 115200.

2.3.2 SD Card

The microSD card will hold the information needed for the system to operate, ranging from the data required to decode the provided QR code data, and sort through the information provided by the different sensors.

Requirements	Verification
1. The SD card must provide both read and write function.	A. Plug the SD card on a computer. Put a random file into the SD card and unplug it. Plug it again and check if the file is there. If it is, then the SD card is qualified.

2.4 People Counter

This module can count the people entering the first/outside door. When more than one person enters the area between two doors (which means unauthorized people enter), the second door will not open and people will be notified to leave the area.

2.4.1 Break-Beam Sensor

The sensor will count the number of times that the line connecting them is broken by some external object. This information will then be sent to the microcontroller to be processed, and determine the number of people who crossed the passageway.

Requirements	Verification
1. The Break-Beam Sensor can work under 3.3V/5V DC, and it must have enough accuracy to avoid the false alarm.	A. Connect the sensor with 5v DC power. Perform multiple tests and calculate the accuracy rate to see if it is within the range.

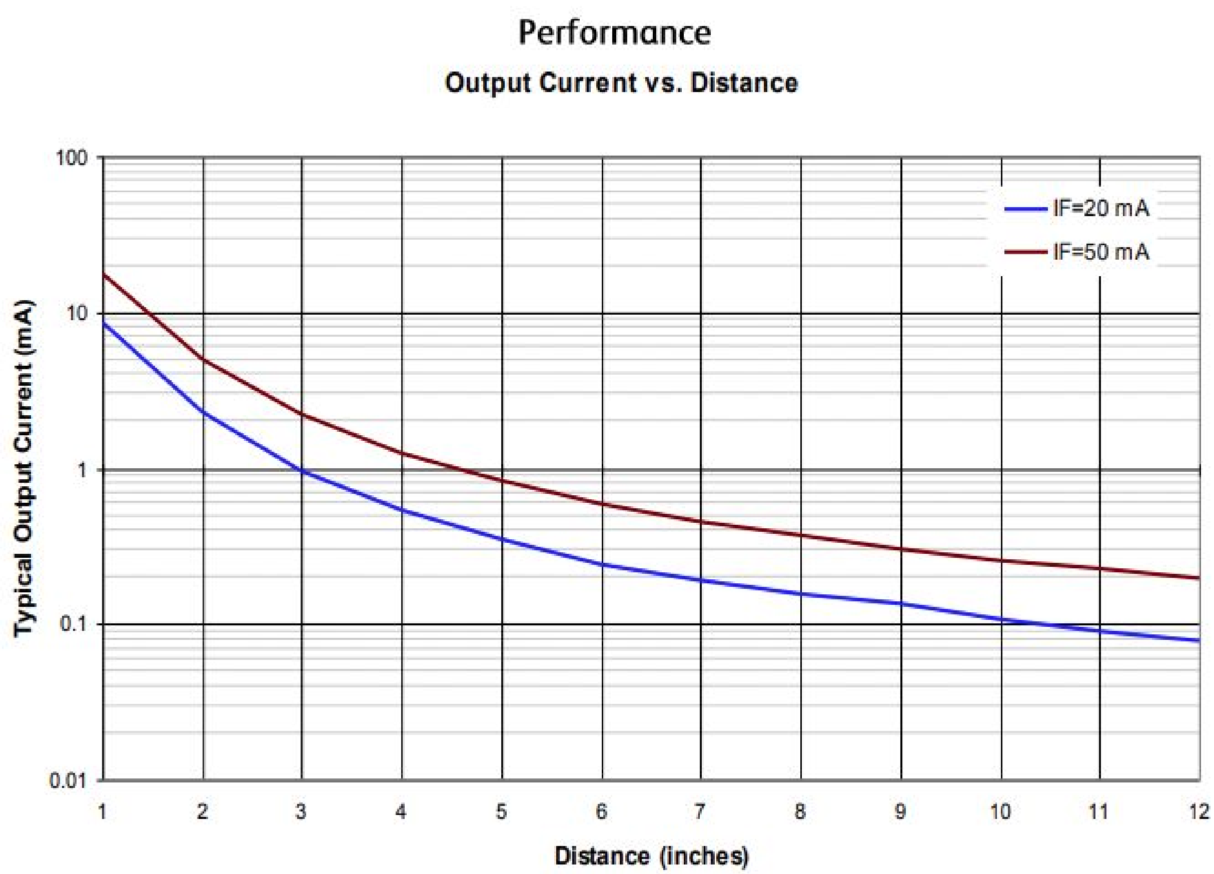

Figure 5: Current output of our Break-Beam Sensor vs. Distance from Data Sheet [5]

2.4.2 Pressure Detection Sensor

This sensor will detect the number of unique pressure points present across the mat, and send that information to the microcontroller, to add more information required to determine the number of people present. This will be done with an array of small pressure sensors, underneath a standard mat. We will then process the information sent from that array, to better understand the placement of feet on the mat.

Requirements	Verification
1. The Pressure Detection Sensor needs to be installed at a place where people who enter the building must pass. 2. Across a wide range of unique pressure profiles, the MCU must be able to make a rough estimate as to how many feet are preset on the mat, as well as consider outliers such as crutches or wheelchairs	A. Try to enter the building multiple times with the Pressure Detection Sensor installed to see if it can detect every time a person enters. B. We will construct 6 unique tests, to determine the accuracy of our system: - 1 person walking in normally as a baseline - 1 person walking in sideways - 2 people walking in back to back - 2 people walking in sideways - Wheelchair entry - Person walking in on crutches

2.4.3 Speaker & Amplifier

The speaker will be used to tell the person whether he is authorized to enter the next door, or there's more than one person in the area so they are required to leave and enter the area one by one. It will be driven by the MONO 2.5W CLASS D AUDIO AMPLIFIER, which is working under 5V and can drive the speaker of 2.5W at 4Ω.

Requirements	Verification
1. The speaker must be clearly heard when people stand in the counter area. 2. The system must be able to communicate with the I2S interface on the MCU. 3. The Amplifier can drive the speaker of 2.5W at 4Ω.	A. Attach the amplifier to a speaker with 4Ω and 2.5W. Turn on the amplifier and the speaker to see if the amplifier works properly. B. Repeat this step in the counter area to see if they can be heard clearly.

2.4.4 Secondary Entry Confirm LED

We are using a two-color LED, LTL1BEKVJNN, as the entry-confirm LED. The LED will be switched on when the person is allowed to enter the second door.

Requirements	Verification
A. The Entry Confirm LED must be clearly visible from 0.5 meters away. B. The LED runs well under 2.1V (+/- 5%) and 30mA (+/- 5%).	A. Build a simple circuit containing only LED, power supply and resistor. The power supply will be 5V, and the resistor will be 100Ω. B. Check the LED from 0.5 meters away.

2.4.5 Back Door Electronic Lock (Mini Push-Pull Solenoid)

The control unit will decide whether the person is allowed to enter the second door, and send the signal to the Electronic Lock. Using a Mini Push-Pull Solenoid, we can easily control the process of lock/unlock by controlling the voltage.

Requirements	Verification
1. The lock will work under 5V, and when receiving the signal from the microcontroller, it must unlock/lock the door in a short period of time to avoid the congestion of the crowd.	A. Build a small circuit on a breadboard, and verify when the 5V voltage power supply is turned on, the lock is unlocked and when the power supply is cut, the lock is locked.

2.4.6 Emergency Button

When unexpected system failure occurs, like both the inside and outside doors are locked, people in the People Counter area can use this button to manually unlock the outside door to leave.

Requirements	Verification

1. The emergency button must be easily-pressible. 2. The emergency button must be large enough for people to find.	A. Press the button and make sure it can be pressed without problem. B. Put the button at 1 meter distance and make sure it can be found easily.

2.5 Case

Requirements	Verification
1. The case should be IP55 environmental protection.	A. Water projected by a nozzle (6.3 mm (0.25 in)) against enclosure from any direction. Check the inside of the case, make sure it's dry. B. Put the case in a dusty environment for over 24 hours. Open the case and make sure there's no dust in it.

2.6 Server & Software

The server will be running on a Raspberry Pi 4 (the same as the one used as QR code scanner). On the server, we need an OS, a server application (Apache), a database (MySQL). The server will be used to store user information and generate the QR code. The PHP code will be running on the server to retrieve user information from the SQL database and generate the corresponding QR code.

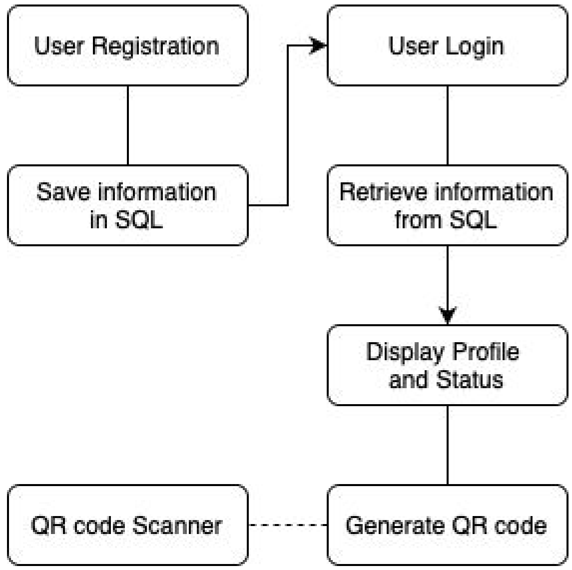

Figure 6: The Workflow of the server

Requirements	**Verification**
1. Can be accessible from different devices, and generate the correct QR code for each person.	A. Set up a test database with different usernames and covid-19 test results. Log into the website with different usernames from different phones, and make sure the displayed user profiles are correct. Using the QR code scanner we set up before to scan the generated QR code, and make sure the information retrieved from the QR code is correct and the same as the user's status.

2.7 Circuit Schematics

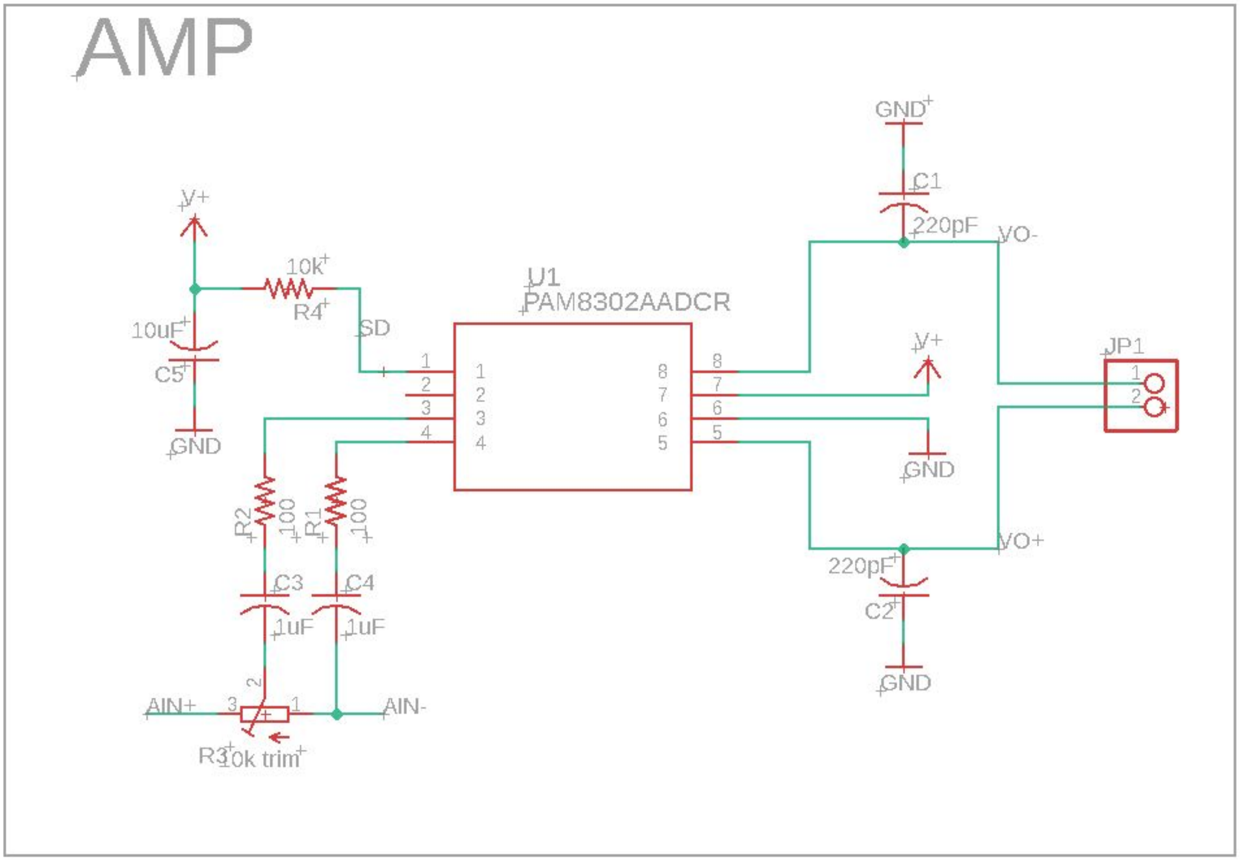

Fig. 7: Amplifier Schematic

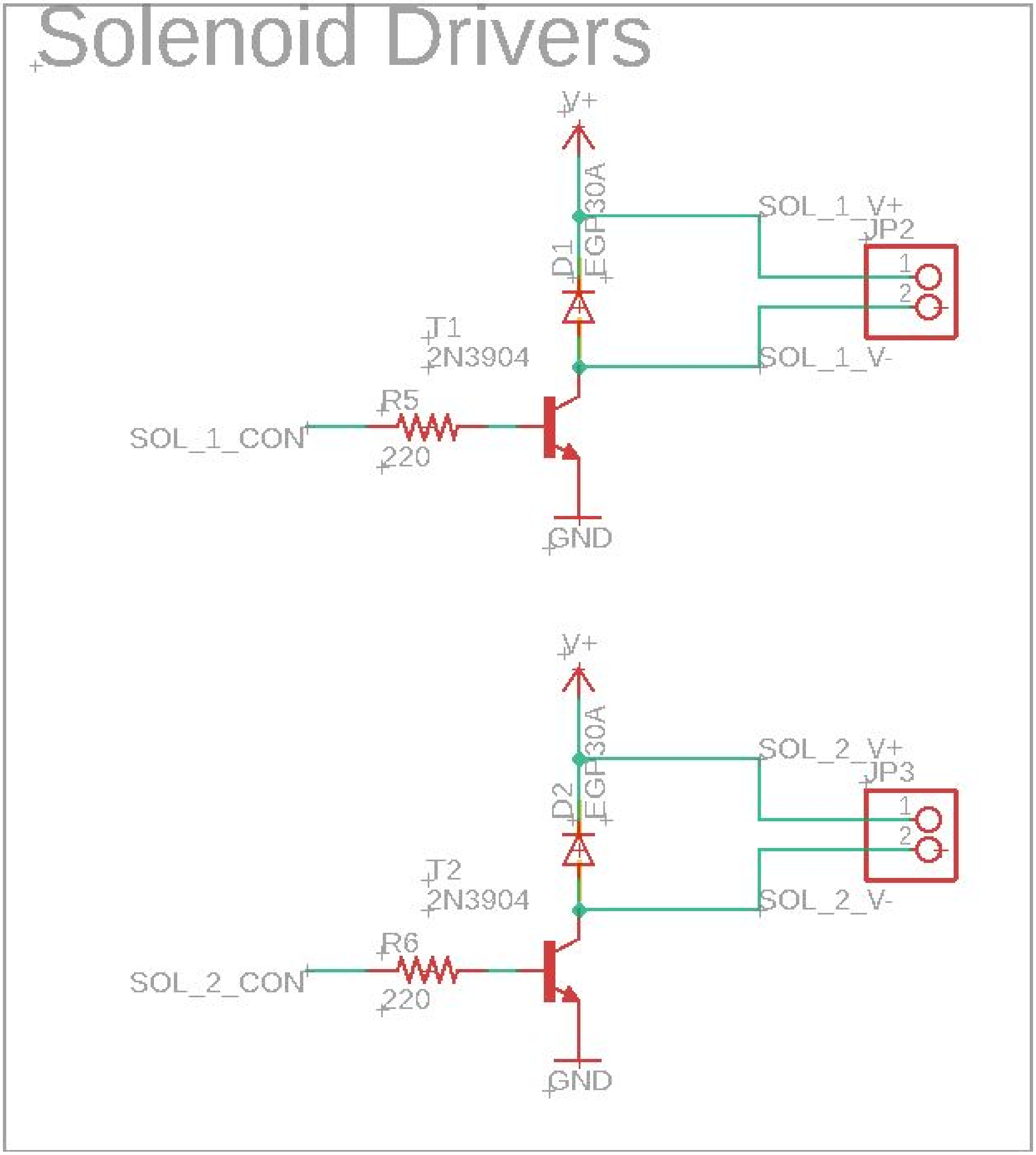

Figure. 8:. Solenoid Driver Schematic

2.8 Tolerance & Risk Analysis

One important tolerance that we must maintain is the current draw of our system. Since we have solenoids to act as our electronic locking system, and they don't have a separate power supply, we must be keenly aware of the current draw of our system. Each solenoid has a current draw of 1A, while the MCU has a rated current of 200mA. This means that if both solenoids were to be in the active state at the same time, then power would be lost to the MCU, causing the entire system to reset. This doesn't take into account the other power hungry devices of our circuit either. As each sensor, and the amplifier, will require some amount of additional power/current to run properly. To counteract this, we will fire the solenoids with the intention of all other components of the circuit resetting. This means that there must be a sequence of events, where this reset of sensors and other ICU's will not affect the overall integrity of the system. As the firing of the solenoid is the final step at the end of each of our sub-systems, this should be relatively simple. However we must make sure that at all costs the MCU is never reset, as this could cause issues with people being left locking within the "airlock" of our system, requiring usage of our fail-safe switch to safely exit.

Another Tolerance that we will have to analyze closely is the bandwidth of our system. Currently, we plan on having a 30 second processing time, per person entering the system. This means that from the time of scanning the QR code, the user should be able to enter the "airlock", the system should process the number of people within the space, and a decision should be made whether to let that person in or not within that 30 second window. To make this happen we plan on going forward with a pipeline style approach. Once a user has scanned, and been let into the inner space, the system will then prime the scanner to scan the next potential user, and have them queued up for entry into the "airlock" following the processing of the initial user. This should allow for a quicker processing time, as the next user will already be ready to enter the space, while the initial user is being processed. To further expand upon this 30 second requirement, we should take a loot at the sensors involved, and their processing speed. As the two main sensors within the device are a break-beam sensor and a pressure pad sensor, the speed at which these devices can update the control unit with information is very important to meeting this requirement.

The Break-Beam sensor needs to detect the numbers of people coming across it, so it needs to be set at a proper threshold. We need to use our devices to test enough times to get the expected time of one person walking across the sensor. For example, if the threshold is set to a very small number, when one person walks across the sensor, the system may detect both of the legs as two people then send out a false alarm and slow down the whole system.

The other risk is how to successfully and correctly detect the people entering the first door by the pressure detection sensor. When a person with luggage enters the building, we have to detect "one person with a luggage" and "two people", or it will be a false alarm. Also, the miss is a more critical risk. If two people enter the building together and the system fails to detect that, it will increase the risk of spreading the COVID-19.

3 Safety and Ethics

According to ACM's ethical guidelines [4], we should use personal data legally and collect only the necessary personal information. Given that this project cannot use data from safer Illinois, this project will simulate a two-factor authentication system. Therefore, this project will not collect data from users and will not use biometric information. If this project does go into realization, the system will not collect biometric information from students and will only use publicly available identifying information, such as students' name, and their NetId. And they will not be made public by this system.

Potential security issues for this project may include the use of electricity. This project may use 120v and convert it to low voltage for use. Therefore, the risk of electrical shock to humans is extremely low.

This system will use lithium batteries as a backup power source. According to Occupational Safety and Health Administration, lithium batteries can be damaged by physical impacts including shocks, punctures and crushes, posing a risk of explosion. In addition, high environmental temperatures can shorten battery life. Therefore, this project will protect the lithium battery from physical shocks and ensure that the lithium battery works in a suitable environment. The batteries will be checked regularly and replaced with new batteries when needed. There will be routinely checks to ensure that there are no short circuits in the system and that circuits will only be operated and modified when they are not charged.

Since the system involves a closed space that we are nicknaming the "airlock", there is a chance of a malfunction that could result in a user being locked within this environment. The main reason this could occur is that both Solenoids fired at the same time, resulting in a system reset, leaving the user within. The workaround for this issue will come in the form of a fail switch within the "airlock" that will be hardwired into the control circuit of the entrance solenoid, allowing the door to be unlocked, and letting the user leave the space.

Some of the devices in this project will work outdoors, such as the QR code scanner. Given that it is difficult to guarantee a dry environment outdoors all the time, all devices outdoors must meet the IP76 standard to guarantee safety.

Another safety problem is "hijacking" the system. Since People who haven't got a negative COVID-19 test result recently cannot generate a QR code with permission of entering the building, they may force or "borrow" the QR code generated by another person with the negative test result. This problem can't be solved since we are lacking a biometrics ID system, but adding a webpage for "reporting" may partially solve the problem. The University or the other administrations may use the information reported to start an investigation, and it can reduce the possibilities of people "hijacking" the system.

To avoid the system adding any other new safety problems and concerns to the campus society, the system is hand-free and adds no steps to the original people-checking process. The system just uses a QR code scanner to avoid the possibility of human processing errors as well as not decreasing the efficiency of entering the building. Also, since there can only be one person in the people detecting area, it will not violate the Social Distancing regulations in Illinois and UIUC campus.

4 Costs

Our fixed development costs are estimated to be $35/hour, 10 hours/week based on the average salary of entry level ECE graduates [6]. Operating on a 16 week semester results in a total cost of:

$$2.5 * \frac{\$35}{hr} * \frac{10hr}{wk} * 16wks \ = \$14,000$$

A breakdown of our components can be seen below, and the total cost of our prototype comes out to be roughly $128.48. This is with an estimated cost of smaller components such as resistors/capacitors and small IC's.

Part	**Cost**
1 Channel Amp (PAM8302AADCR)	$0.65
Break-Beam (1528-2526-ND)	$6.50
MCU (MSP430G2553IPW28R)	$2.83
Wall Adapter (5VDC, 2A)	$5.95
MicroB USB Breakout	$2.75
BiColor LED x2 (LTL1BEKVJNN)	$0.74
Raspberry Pi + Camera Module	$72.21
Assorted Resistors, Capacitors, ICs, Sockets (Digikey; est.)	$7.00
Floor Mat Switch (KIT-AC-700-30-926B)	$19.95
Solenoid Actuators x2 (adafruit 2776)	$9.90
Total	**$128.48**

Table 1: Cost Analysis

We are also considering the construction of our own pressure sensors using aluminum foil and cardboard, as mass market options are quite expensive. This would also allow us to have an array of them, so the detection of multiple pressure points would be an attainable goal. This would reduce the cost by about $15.00.

5 Schedule

Week	Patrick	Zewen	Yijie
3/1	Hardware search, and schematic creation. Cost Analysis and Schedule Creation. MCU Research	RV Table Creation and QR Code Sensor Development.	Hardware Search.Server Database research. QR Code Sensor Development
3/8	Prepare for Design Review/Finalize Subsystem #1 Schematic/Begin Subsystem #2 Schematic	Create QR code scanner from raspberry PI	Research into UART data transmission for encoded QR code information
3/15	Finalize Subsystem #2 Schematic/Begin PCB Design. Construction of Pressure Plates.	Start research into MCU programming, and I/O port usage.	Create backend for subsystem #1 though Server creation on PI.
3/22	If first round PCB orders were not met, revise issues and make sure round 2 is met. Begin Testing subsystem #1 for edge cases/ Meeting Verifications	Continue research on MCU programming, and implementing the final code base onto the chip.	Extensive range testing on Scanner and Break-beam sensors, evaluating the accuracy of our sensors.
3/29	Sanity Check, are we meeting deadlines, and if we are behind, where do we need to catch up?	Sanity Check, are we meeting deadlines, and if we are behind, where do we need to catch up?	Sanity Check, are we meeting deadlines, and if we are behind, where do we need to catch up?
4/5	Begin construction of our proof of concept work space (Small doors, detection field.)	Begin working on 3D printed Case	Begin Testing of Subsystem #2 for edge cases of people counting/Meeting Verifications
4/12	Conduct environmental testing on Subsystem #2	Conduct environmental testing on the QR Code Scanner + Case	Conduct environmental testing on QR Code Scanner + Case

4/19	Mock Demo Preparation + Final Checklist of R/V Tables	Mock Demo Preparation + Final Checklist of R/V Tables	Mock Demo Preparation + Final Checklist of R/V Tables
4/26	Prepare Final Presentation/Paper	Prepare Final Presentation/Paper	Prepare Final Presentation/Paper

Table 2: Team Scheduling

Orange = Sub-System 1 (QR Code Scanner/Initial Detection)

Green = Sub-System 2 (People Counting Solution)

References

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