UNIVERSITY OF ILLINOIS AT

URBANA-CHAMPAIGN

ECE 445: SENIOR DESIGN

Covid-19 Convenience Locker

Project Proposal

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1.**Introduction**

1.1 Problem and solution

COVID has affected students' lives for around a year and has caused tremendous inconvenience to us. It is likely that the COVID pandemic will continue for a long time. Here at U of I, we are required to take saliva tests twice a week at specific locations. The saliva test is an effective way against COVID virus, with testing sensitivity 96.7%[1]. However, the requirement of multiple testing per week makes our life inconvenient since we need to move to the Illini Union and somewhere else to take tests. In addition, according to data collected by Shield, there have been more than 152 thousand[2] tests taken by students and faculties in U of I so far. This large amount of testing will bring a huge cost and utilize many resources. For each test location, about 5 employees [2]are needed to monitor, distribute and collect testing tubes. Around 100 employees [2] are hired in different testing locations in Urbana-Champaign. Also, it is possible although the distance between people is strictly controlled in the testing location, it is still possible to cause potential infection when many people take tests in the same place and same time. Because of these reasons, we decided to design a convenience locker to help reduce the cost and trouble for testers.

We propose a locker with testing tubes inside located at each large student apartment. The students are required to access the testing tube every other day and then store it inside the locker before a specific time (For example 6 p.m every day). The testing staff will pick up the tubes twice per day. Our objective is to design a machine that can use mechanical structure to distribute and store the testing tubes. In this project, we will demonstrate the device could distribute and store 8 tubes. To identify the tester information, we would use an RFID reader for verification. A thermal printer will be used to print labels while the students should stick it onto the testing tube. A mechanical component should be designed for each user to pick up and store exactly one testing tube, for example, rotation distribution design. Since alcohol, IPA and ethanol with 60%-80% concentration [3] could effectively kill the covid virus, we have a spray nozzle to spread the sanitizer for sanitizing. A temperature sensor and a cooling fan are also designed to avoid high temperature inside the locker when it is in summer.

1.2 Visual Aid

Inspired by the convenience of vending machine design, this project aims to automate the covid-19 testing process. As described in the section 1.2, the design needs to be space-saving, low-cost, zero-human contact. With novel mechanical design and low cost circuit board, our team aims to design a programmable testing tube distribution system. Similar to vending machines, the testing machines are designed to locate inside all the students' apartments across the campus. And the testing machines could execute the testing procedure with one-stop services without any human assistance. A visualization is shown in Fig. 1. Detailed physical design could be referred to section 2.2.

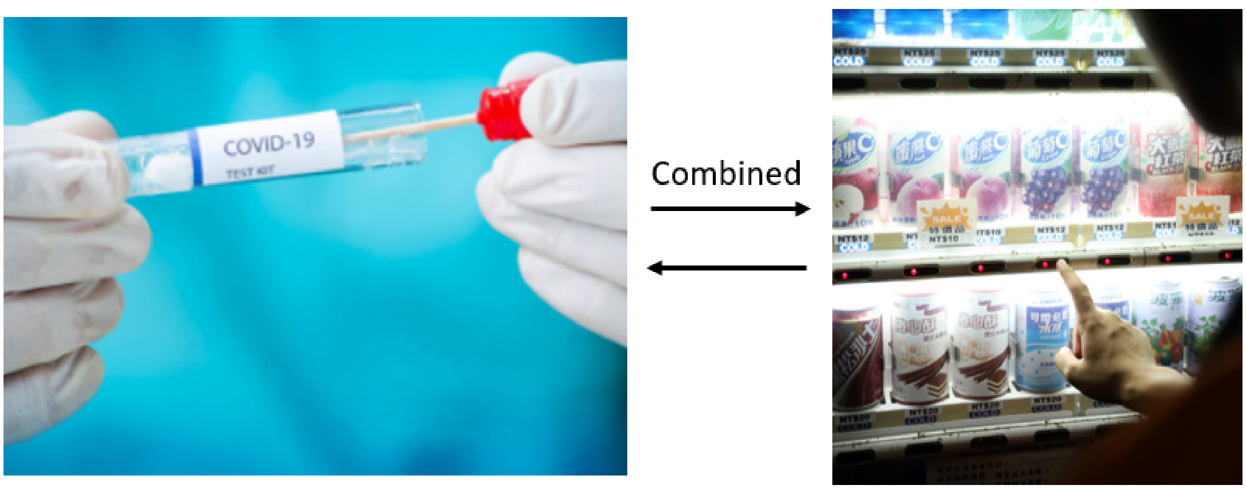


Figure 1. Visualization the goal of ECE445 Covid-19 Convenience Locker [4]

1.3 High-level Requirements List

- The internal rotator must be able to rotate $45^{\circ}(\pm\ 0.225^{\circ})$ each step to distribute and collect 8 testing tubes through servo motors.
- Student's I-card can be detected by RFID with accuracy above 95% and the identity information will be printed via thermal printer.
- The cooling fan and sanitizer sprayer should be able to control the locker environment (Temperature around $25\ ^{\circ}C$[8] and sanitized for each testing tube).

2.Design

2.1 Block Diagram

The success of this project relies on the successful operation of 6 modules: power unit, mechanical system, processing module, environment control module, identification module, and display module. The power module will handle the voltage conversion and continuously provide power to the other modules. The mechanical system will distribute and receive only 1 testing tube per test. The process unit will communicate with all the other electric modules. The environment control module will guarantee the storage temperature is around 25°C. The identification unit will identify UIUC i-card under 125kHz with above 95% accuracy and print the tube label with corresponding student's information. The display section will report the locker's temperature and student's information. If temperature is above threshold temperature, the LED will turn on and notify the students the locker is unavailable. Beside, a microcomputer will be used to upload the i-card information (unique ID) to the server, and the i-card owner will receive the identification information via Two-Factor Authentication (2FA). Due to the covid-19 impact and limited time, this part will be considered as future work. The detailed block diagram is attached as Fig 2 .

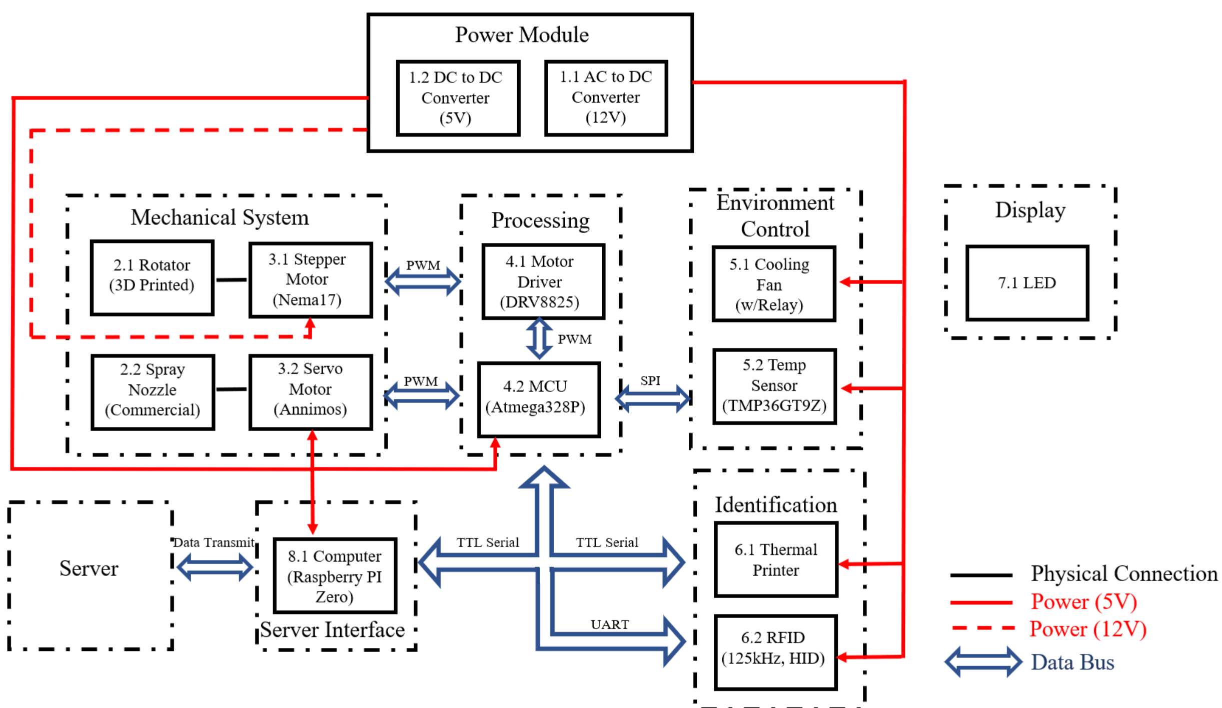


Figure 2. Block diagram of Covid-19 Convenience Locker

2.2 Physical Design

The detailed CAD assembly of covid-19 convenience locker is shown in Fig 3 and Fig 4. The connection between electronic devices is not shown in the figure.

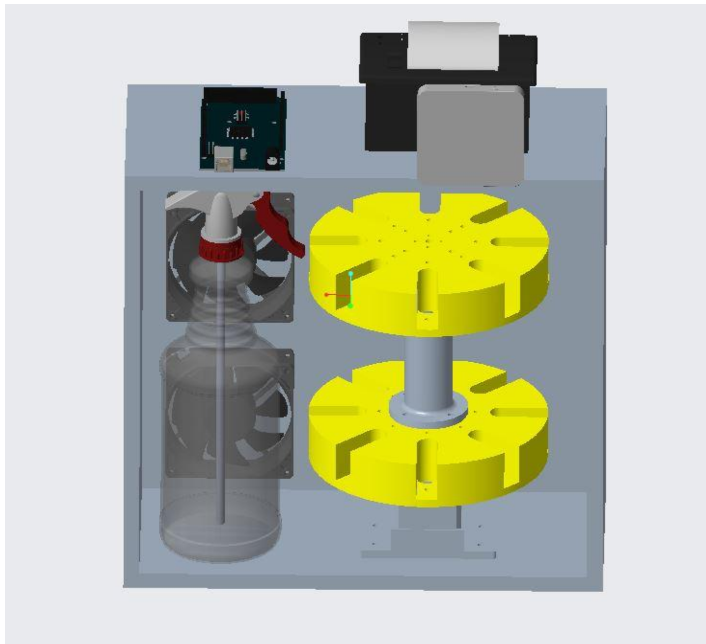


Figure 3. CAD assembly of Covid-19 Convenience Locker(no front cover)

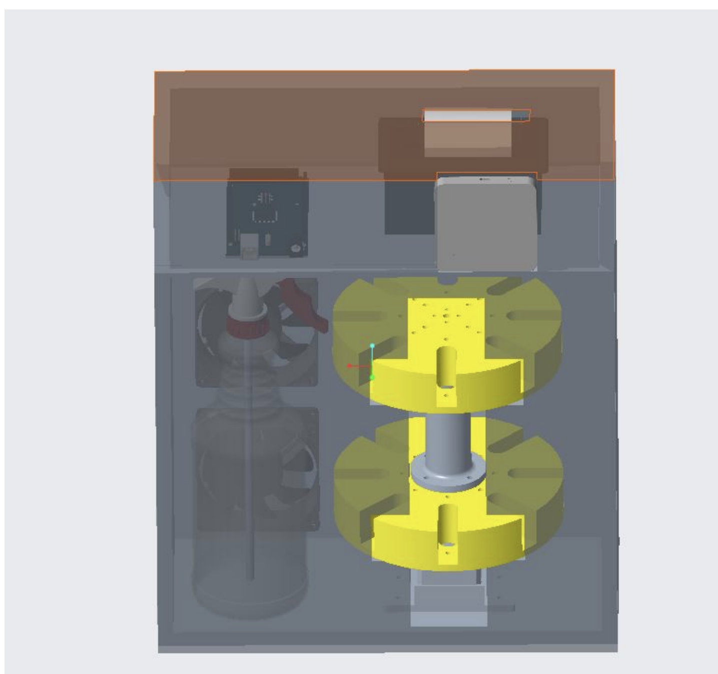


Figure 4. CAD assembly of Covid-19 Convenience Locker(with front cover)

2.2.1 Power Module

The power module takes 120VAC from the wall outlet as input power, and output 12VDC and 5VDC (± 3%)to our system. Since we assume that all the students' apartments have outlets inside the building, the battery (requires charging frequently) is not considered in this project. Our power budget is ~12.6W, which is mainly consumed by Nema17 servo motors(12V,0.35A), thermal printer(5V,1.5A), 2 x cooling fans(5V,0.18A).

2.2.1.A AC to DC Converter

ALITOVE DC 12V 5A Power Supply Adapter is used as the main power source of the project. Since the team is planning to directly use the US standard outlet as the main power source, AC to DC converter is important to continuously convert 120VAC to 12VDC power. Because the female socket (PPTC041LFBN-RC) connected to the power source could only handle the current smaller than 3A, the team needs to make sure the current draw from the power source never exceeds this threshold current. Also, The team needs to make sure the peak operating temperature (hotspot) is smaller than 120°C, which is the typical PCB operational temperature. [5] Considering a 10 percent safety factor, the threshold temperature is set to be 110°C.

Requirement	**Verification**
1.) Current drawing from the power source should be smaller than 3A. 2.) Local temperature of hotspot during operation should be smaller than 110°C (10% safety factor).	1.) Measure the total equivalent resistance from the open circuit of the final PCB design. Specifically, connect two probes of multimeters to the power input pins of PCB board. 2.)Connect a sliding rheostat directly to the power source, vary the sliding rheostat until the max current (3A) arrives. 3.) Compare the total equivalent resistance with the max resistance from experiment. If the total equivalent is larger, this implies our design is safe to operate. 3.) Utilize a temperature sensor, for example IR camera, to measure the PCB temperature near the input power source. Repeat the measurement several times to record the

	average operating temperature.

2.2.1.B DC to DC Converter

Except the 12VDC power used by a servo motor, other electronic devices operate at 5VDC signal. P78A-0500 linear regular is used in this project. P78A-0500 requires input voltage from 7-28 VDC, and will output dc voltage 5V (± 3%). Also, the max current limit for P78A-0500 is 500mA. Since the final device is targeted to operate in the Illinois area, the device should be able to functionalize between -20°C and 40°C .

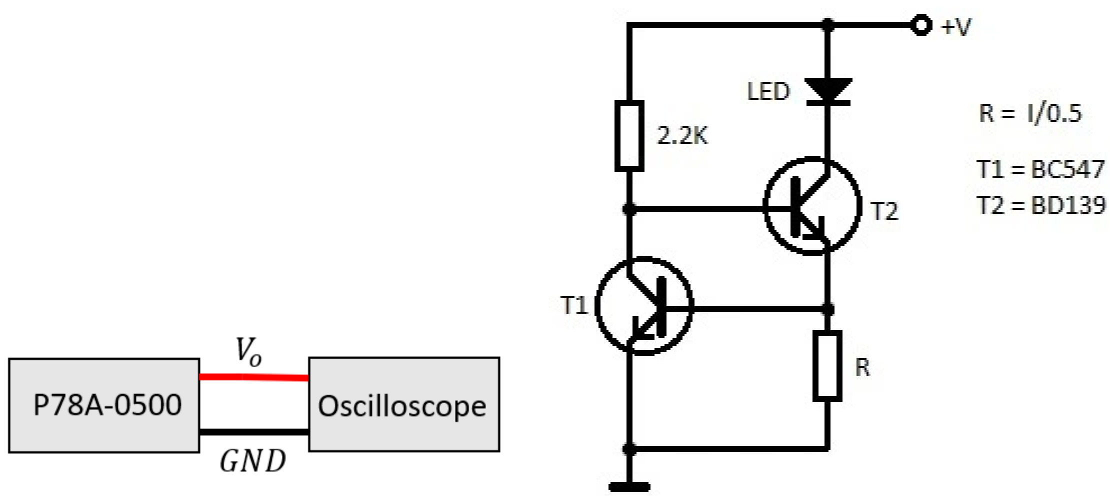


Figure 5.a.) Testing Circuit for a.)Voltage Accuracy b.) Constant Current Circuit [6]

Requirement	Verification
1.)The device can output dc voltage 5V ($\pm$ 3%). 2.) The device can provide constant current from 0-500mA. 3.) The device is able to operate normally at temperature between -20°C and 40°C.	1.) Use a high-accuracy oscilloscope to determine the output voltage accuracy, and measure the open-circuit voltage. 1.a) Power P78A-0500 with 12V from power source. 1.b) Connect the two outputs of P78A-0500 directly to the oscilloscope, and measure the output voltage Vo every 1 second. The circuit is attached as Fig. 5a. 1.c) Record the voltage w.r.t time, and compute the average and standard deviation of voltage measurement. 2.) Measure constant current 500mA via oscilloscope. A typical constant current circuit is shown in Fig 5. The output of P78A-0500 is connected to +V in the circuit. 3.) Check the functionality during the different temperature conditions varying from -20°C to 40°C. Measure the output voltage deviation at different temperatures.

2.2.2 Mechanical System

The mechanical system is related to the success of distributing/receiving testing tubes and sanitizing the interior area. The small servo motor is attached directly to the spray bottle to automate the sanitizing process, while a stepper motor is connected to the tube rotator system to distribute and receive the testing tubes.

2.2.2.A Servo Motor

DS3218 servo motor is used as the trigger mechanism of spraying sanitizer. The servo motor must be quick enough(large acceleration) to initiate enough pressure difference within the spray bottle. The approximation acceleration could be calculated using Bernoulli Equation. Assume no energy loss, for a spray bottle with height $\sim 20cm$, the required pressure difference is approximately 1956Pa. Given the mechanism configuration of the motor, the required torque is about 0.000246 $N \cdot m$. The detailed calculation is described in section 2.4.1. To make sure the spreading area is large enough to cover all the testing tubes, the servo motor should be able to press the spray multiple times within short time duration($\Delta t \leq 1s$).

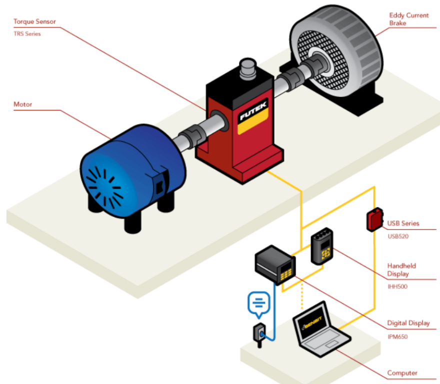


Figure 6. Typical Motor Torque Testing Setup [7]

Requirement	Verification
1.)The servo motor should be able to provide torque larger than 0.000246 $N \cdot m$ with 5V input voltage. 2.) The servo motor should be able to spray multiple times within short time duration($\Delta t \leq 1s$).	1.) Program the atmega328P to operate the servo motor, and use a dynamometer to measure the max operating torque. 1.a) Connect digit pin 9 from Atmega328P (PCB) to the signal pin of the servo motor, and connect the 5V pin from PCB to the servo motor. 1.b) Program the Atmega328P to rotate the spray back and forth between 20 degree and 50 degree, which is determined by the mechanical design. 1.c)Powered the servo motor with 5V input voltage. Clamp the shaft directly to the torque sensor dynamometer, and record the torque vs speed curve. Refer Fig 6. as a typical motor torque setup. 1.d) Repeat step 3 for several times and calculate the average optimal torque. 2.) Measure the continuous operating performance via a timer. 2.a) Draw a white line along the radius of the motor shaft to notate the rotating position of the motor. 2.b) Program the Atmega328P to rotate the spray back and forth repeatedly between 20

	degree and 50 degree. 2.c) Using a camera to record the motion of the white line repeating the process ten times. 2.d) Record the time intervals between two cycles and compare whether it is within 1s.

2.2.2.B Stepper Motor

The PID 324 Stepper Motor - NEMA-17 has 200 steps per revolution which gives 1.8 ($\pm\ 0.009^{\circ}$)degrees per step. NEMA-17 has an operating voltage ranging at 12V. It should be directly connected to the power supply. There are 8 testing tubes in the whole system. So, the stepper motor should rotate 45 degrees ($\pm\ 0.225^{\circ}$) each time which is 25 steps. Since there will be no load applying radially onto the shaft, the theoretical required torque is 0. The holding torque for the stepper motor is 1.6kg/cm which is above what we need for the locker. The stepper motor also needs to be connected to the motor driver to receive the PWM signal.

Requirement	**Verification**
1.)The stepper motor could rotate 45 degrees ($\pm\ 0.225^{\circ}$) each time and the error should be non-accumulative. In other words, the rotator will come back to 0 position during each cycle.	1.) Program the atmega328P to operate the step motor, and use a dynamometer to measure the max operating torque. 1.a) Connect digit pin 5, 7, 10, 8 from DRV8825 to the signal pin of the stepper motor, and connect the VCC, GND pin from DRV8825 to the servo motor. 1.b) Draw a white line along the radius of the motor shaft to notate the position of the motor 1.c) Program the Atmega328P to rotate the stepper motor 45 degrees (25 micro-steps) each time. 1.d) Utilize a camera to measure the position of the white line. 1.e) Repeat 1.c) and 1.d) 10 times, and calculate the corresponding average angle and standard deviation, and compare with the requirement.(45 degrees$\pm\ 0.225^{\circ}$)

2.2.3 Processing

2.2.3.A Software

There are several coding parts which are necessary to complete this project. The RFID part is programmed into the Atmega328, taking the ID-card information as input, outputting the ID information with the facility code. It will output the ID information to the raspberry pi. The Atmega328P is programmed such that it will be stuck within an infinite loop until the interrupt signal is triggered. When the interrupt signal turns on, the RFID will start reading the ID information. According to the testing, it is found that the UIUC I-Cards use 35 bits to identify the id information. Specifically, the first 2-14 will be facility code (FC), while the last 15-34 bits are card code (CC). To save bandwidth, only CC will be transmitted to both raspberry pi for further manupilation.

ID information will be input to the raspberry pi, and transmitted to the testing server using TCP communication through WIFI module. 2FA decision (2FA) and administrator decision (AD) will be returned back to atmega328P. Data transmission between raspberry pi and Atmega328P will be completed through the GPIO pin and will be programmed by Python. The server will compare the ID with the UIUC database, and return 2FA and AD based on the comparison, which will be used to unlock the box and rotate the distribution system.

Based on the 2FA and AD, Atmega328P will output 4bits, 4bits and 1bit control signals (CS) to the rotator motor, locker motor and sanitizer motor respectively. Due to the AccelStepper library, the spinning speed, acceleration, and direction could be controlled. The detailed required motor parameter could be referred in section 2.2.2A and 2.2.2B.

The environment control is independent from the main program. The Atmega328P will receive the voltage signal V_T (8bits) from the temperature sensor. Using the conversion factor from the datasheet, the voltage signal will be converted into temperature. When the temperature is larger than 25 Celcius, Atmega328P will turn the control signal (CS) into HIGH to enable the relay to turn on the cooling fan for 5 mins. Atmega328P will keep reading temperature data, and turn the CS into LOW when the temperature is below 25 Celcius.

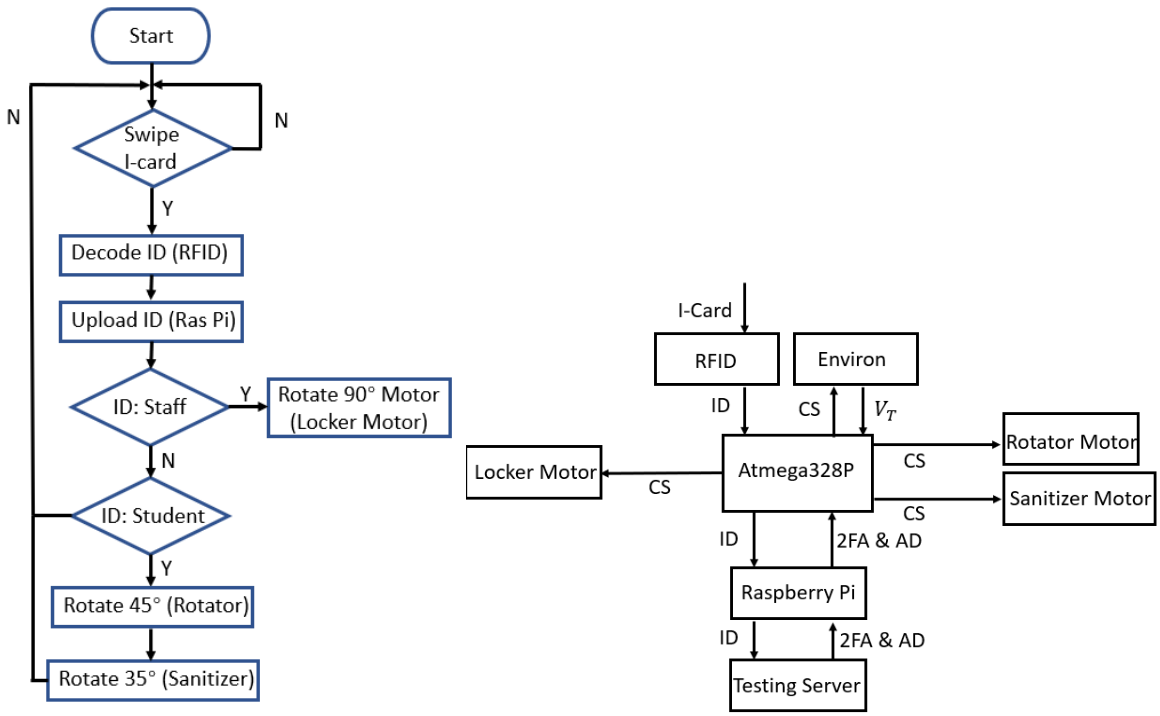


Fig 15. Software Schematic: a.) Flowchart b.) Block Diagram

2.2.3.B Micro-controller

The Atmega328P is the central controller of the whole system. Every command should be sent from Atmega328P. The Atmega328P has an operating voltage ranging from 1.8V to 5.5V. A DC converter will help to transfer the 12V input voltage to the proper voltage range. Also, atmega328P requires a 16MHz as internal clock. The temperature range for the Atmega328P is from -40 Celsius to 85 Celsius. According to the temperature distribution among the Illinois area, this could be satisfied. Power Consumption at 1MHz, 1.8V, 25°C for the Atmega328P is 0.2mA at active mode. By P=UI, we can get the power is 0.36 mW. We would write programs for each part separately and test them through the Atmega328P.

Requirement	**Verification**
1.) The micro controller should be able to send signals to each part and receive data from each part. Specifically, the	1.) The micro controller should connect to the DC converter which has 5V output through the VCC pin. Port B/D are 8-bits

mico-controller should be able to transmit the data via SPI/I2C/TTL Serial/UART. 2.) The mico-controller requires a 16MHz internal clock.	bi-directional I/O output. We would test our program one by one. For each transmit protocol, we would use an oscilloscope to test the behavior of dataline to prove the functionality. The specific verifications for each module which use Atmega328P as the microcontroller are listed in the verifications for each module. 2.) Utilizing a 16MHz crystal and two capacitors, we are able to generate an internal clock with low noise. Use an oscilloscope to check the behavior of this generating clock.

2.2.3.C Motor Driver

The DRV8825 is integrated as the IC of the motor driver to control the NEMA17 which requires 12V input. Due to the internal voltage regulator, the DRV8825 could accept a 8.2V to 45V operating supply voltage. Importantly, the DRV8825 could module the PWM signal from the microcontroller, and generate the high voltage PWM waveform into the stepper motor. Therefore, the DRV8825 will provide a 12V supply and 350mA current wave signal to the Nema17. Also, The DRV8825 provides controbility to the user side (micro-controller) to choose the microstepping of the stepper motor.

Requirement	**Verification**
1.)DRV8825 should be able to receive PWM signal from the Atmega328 2.)The internal voltage regulator inside DRV8825 should be able to convert the 12V power into 3.3V. 3.) DRV8825 should be able to provide constant 400 mA current to Nema17.	1.) After transmitting PWM signal from the Atmega328, We would test whether DRV8825 could function properly by recording the output waveform via an oscilloscope. 1.a) Power the motor driver Pin VMOT with 12V. Power the RST and SLP pin with logical 1 to enable the function of DRV8825. Connect Pin 2, 3 from Atmega328P to STEP and DIR on the motor driver to control the behavior of DRV8825. 1.b) Connect B1,B2 to channel 1 of the oscilloscope, while A1,A2 to channel 2. 1.c) Program the atmega328P to input the square waveform with duty cycle 50%, 5V peak voltage, 4s time period onto Pin 2,3.

	1.d) Record the waveform from channel 1 and channel 2. Two waveforms should follow the same duty cycle and time period except with 12 peak Voltage. Also, two waveforms should differ the phase by half of the duty cycle. 2.) Using an oscilloscope, we could measure the open circuit voltage after the internal DC converter. 2.a) Power the motor driver Pin VMOT with 12V. 2.b) Attach the probe tip of the multimeter onto Pin 15 on the motor driver, and record the deviation (percentage difference) with 3.3V. 3.) Tuning the rheostat on the PCB and measuring the current output to the motor until the current is 350 mA. 3.a) Power the motor driver Pin VMOT with 12V. Power the RST and SLP pin with logical 1 to enable the function of DRV8825. Connect Pin 2, 3 from Atmega328P to STEP and DIR on the motor driver to control the behavior of DRV8825. Connect B2,A1 and A2 on the motor driver to Nema17. 3.b.) Connect B1 to the oscilloscope to measure the current flow into the motor. 3.c) Adjust the rheostat until 400mA is reached on the oscilliscope.

2.2.4 Environment Control

It is important to control the surrounding temperature of testing tube samples to keep samples fresh. Room temperature(25°C) is a suitable temperature to store samples.[8] Time is another factor which can affect the detection of viruses. The figure below shows the relationship.

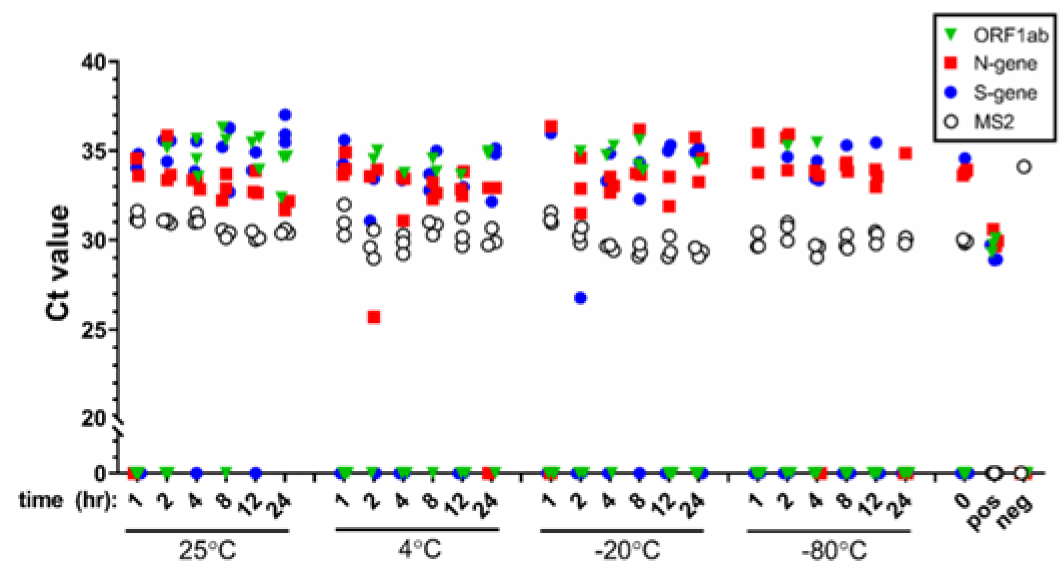


Figure 7. Stability of saliva samples [8]

Although samples can be stored under room temperature, it is better to deliver samples to the lab within eight hours. If samples are stored more than 24 hours, saliva samples will become unstable, which will result in detection inaccuracy.

2.2.4.A Temperature Sensor

The TMP36 is the temperature sensor in our design. When the temperature is too hot, it should send commands to the Atmega328P and the Atmega328P will send commands to the cooling fan. The TMP36GT9Z has an operating voltage ranging from 2.7V to 5.5V. A DC controller will help to transfer the 12V input voltage to the proper voltage range. The self-heating of the temperature sensor is as low as 0.1 Celsius in the air. The temperature sensor could provide typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C. The TMP36 we used has a 10 mV/°C scale factor and it provides a 750 mV output at 25°C.

Requirement	**Verification**
1.) The TMP36 correctly output 750mv at 25°C 2.) We could detect a 10 mV/°C scale factor when the temperature changes.	1.)Utilize the multimeter to measure the output voltage at room temperature. 1.a) Connect Vout pin to pin 10 on the Atmega328P, 5V power source to Vcc and GND to GND 1.b) Connect the output voltage pin to the multimeter, and record the voltage after reading the stabilized. 1.c) Repeat 1.b) for 10 times and compute the average output voltage, and compare with 750mV. 2.) Increase the environment to determine the conversion factor of the temperature sensor. 2.a) Connect Vout pin to pin 10 on the Atmega328P, 5V power source to Vcc and GND to GND 2.b) Connect a 100kohm resistor directly to a power supply, and place the testing temperature sensor and calibrated temperature sensor 5cm away. 2.c) Connect the output voltage pin to the multimeter. 2.d) Turn on the power source and increase the input voltage until the calibrated temperature indicates 10°C increasing in temperature. And then measure the output voltage. The conversion factor could be calculated as, C = $(V_f - V_i)/10$. 2.e) Cool the resistor back to room temperature. 2.f) Repeat 2.d) and 2.e) for 10 times, and compute the average conversion factor.

2.2.4.B Cooling Fans(w/Relay)

We would use 2 USB DC fans as the cooling component. The operating voltage is 5V and we would use the Atmega328P to control the fans. Atmega328P will compare the real-time temperature with the setting threshold temperature (25℃)all the time. When above threshold temperature, the Atmega328P will enable the relay, which effectively turns on the cooling system.

Requirement	**Verification**
1.) The fan should start when it is above 25°C. Testing the functionality of Relay.	1.a) Connect the V_{on} port from cooling fan with the relay input. Connect pin 4 from atmega328P with the relay control signal. 1.b) Program atmega328P such that when the temperature is higher than 25°C, the relay control signal turns to HIGH, which functionalizes the cooling fan. 1.c) Power a heat gun and place the temperature sensor 10cm away to prevent overheating, and monitor the temperature reading from Atmega328P arduino serial monitor. 1.d) Monitor the fan status when the temperature is higher than 25°C.

2.2.5 Identification

2.2.5.A Thermal Printer

The ADA597 will be used as a thermal printer. The ADA597 has an operating voltage ranging from 5V to 9V and an operating current of 1.5A. We would use a DC converter to reach this goal. This printer uses common 2.25" wide thermal paper which is widely available.

Requirement	**Verification**
1.) The printer should print correctly according to the Atmega328. Specifically, the printer should be able print with different styles(for example, bar code, bold, italic, etc.)	1.a) The printer will be connected to Vcc, GND, pin 14, 15 on the Atmega328P, 1.b) Modify the sample code using different styles following the A_printertest.c. 1.c) Print out the testing thermal receipt,

	check the readability of the result.

2.2.5.B RFID Reader

The HID 5455BkN00 will be used as a RFID reader. The average operating voltage and operating current is 25 mA at 5 V. The operating temperature is -30°C to 65°C. The size is 127mm*127mm so it could perfectly fit into our locker. The RFID frequency range for the reader is 125KHz, which fits our i-card.

Requirement	**Verification**
1.) The HID reader could read the correct the ID information (35bit) and sent to the Atmega328 2.) The RFID should be able to successfully detect I-Card's unique ID with a successful rate higher than 95%.	1.a) The HID should connect to the Vcc, GND and pin 16, 17, 18, 19 which are I/O pins. Specifically, Red wire - Vcc, Black - GND, Green - Data 0, and White - Data 1. 1.b) Program the HID reader following the sample code such that the atmega328 could successfully communicate with HID. Display the ID information on the monitor whenever swapping an I-card. 1.c) Check the bit length of the I-card, and compare the first 4 characters (facility code) with UIUC I-card manufacturer code. 2.a) The HID should connect to the Vcc, GND and pin 16, 17, 18, 19 which are I/O pins. Specifically, Red wire - Vcc, Black - GND, Green - Data 0, and White - Data 1. 2.b)Program the HID reader following the sample code such that the atmega328 could successfully communicate with HID. Display the ID information on the monitor whenever swapping an I-card. 2.c)Swap the I-card, and record the ID number. 2.d) Repeat 2.c) for ten times and compute the corresponding accuracy, 2.e) Change an I-card belonging to a different person, and repeat 2.d).

2.2.6 Display

2.2.6.A LED

The WP7113ID can emit high efficiency red light. The operating voltage is 1.5V for this diode at 25°C. The red light should be on when the temperature is above the threshold temperature. It will receive a signal from the Atmega328P and turn on.

Requirement	**Verification**
1.) The red light should be on when the temperature is above the threshold temperature (25°C).	1.a) Test the functionality of the fan when directly connecting to the power source. We will use an analog pin which outputs 1.5V on Atmega329. 1.b) Program the atmega328P to compare the temperature reading from the temperature sensor according to the clock signal. Whenever the environment temperature is larger than the threshold temperature, the control signal will turn on, and the red light will be on. 1.c) Place a heat gun 10cm away from the temperature sensor to prevent overheating. And check the LED status when turning on the heat gun.

2.3 PCB Design

2.3.1 Schematic

Power Module

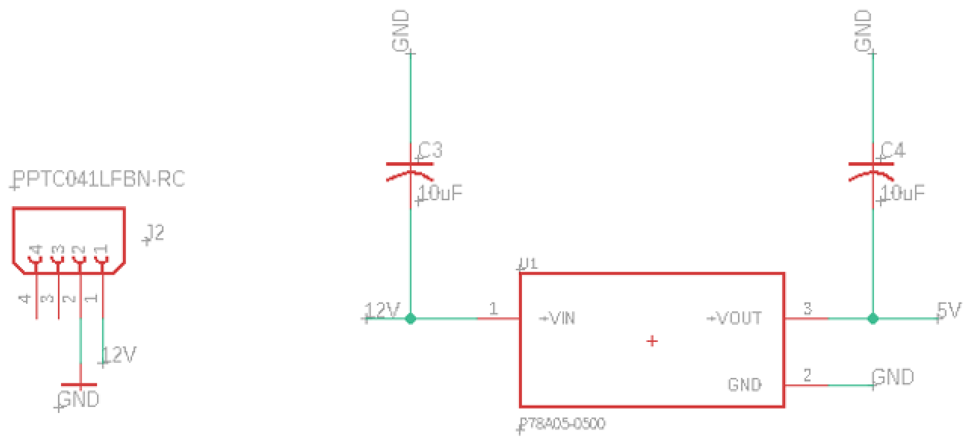


Fig 8. PCB Schematic of Power Module

MCU

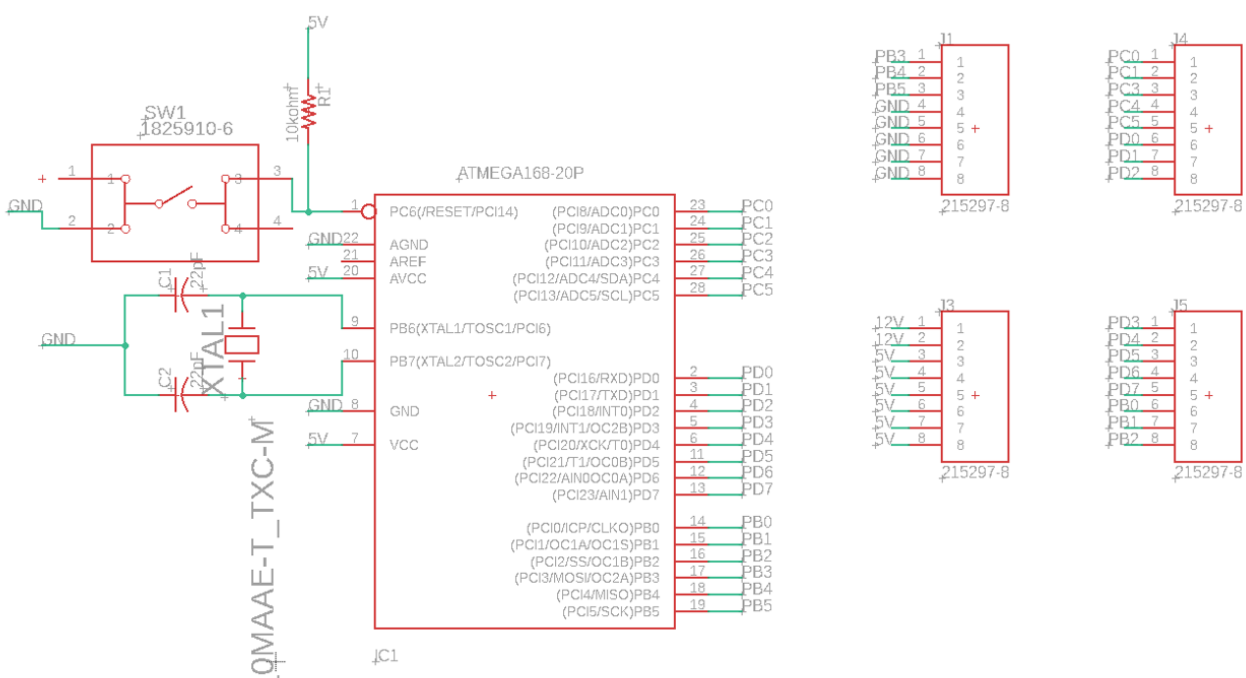


Fig 9. PCB Schematic of Microcontroller Module

Stepper Motor Driver

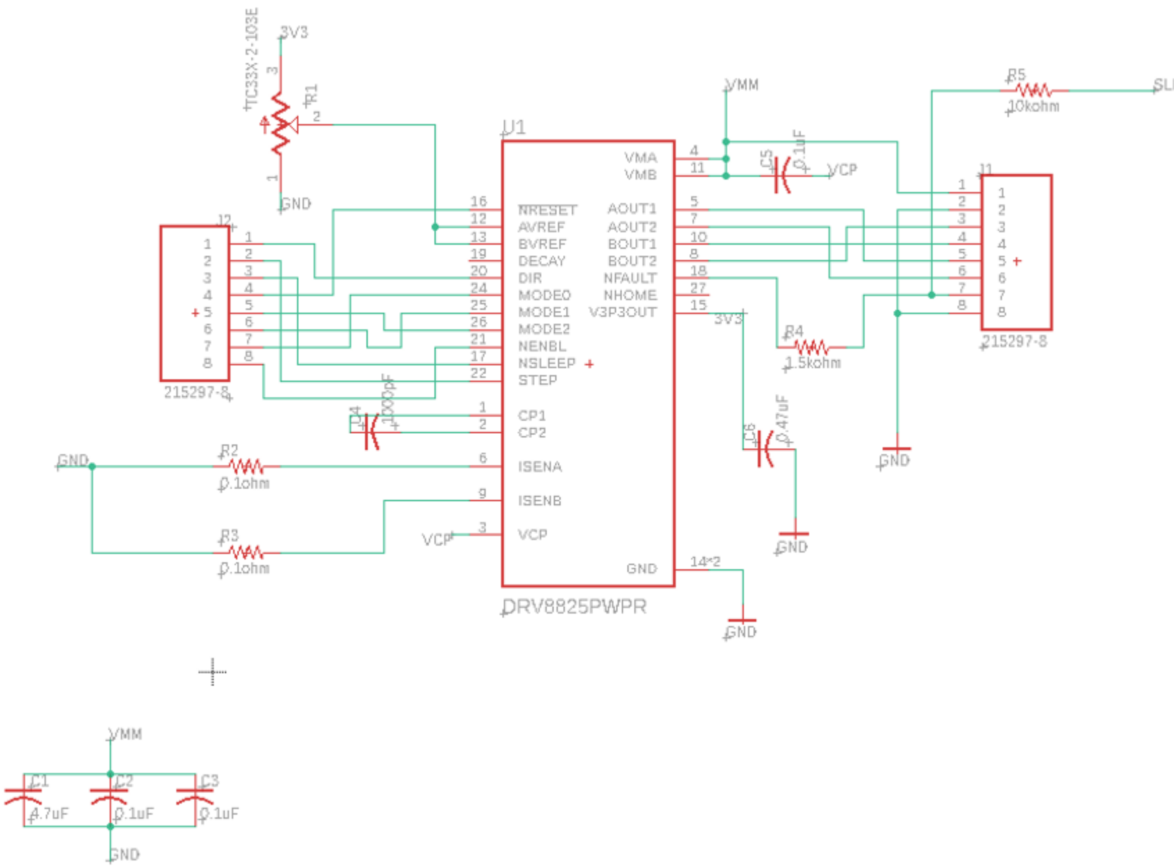


Fig 10. PCB Schematic of Stepper Motor Driver Module

2.3.2 PCB Layout

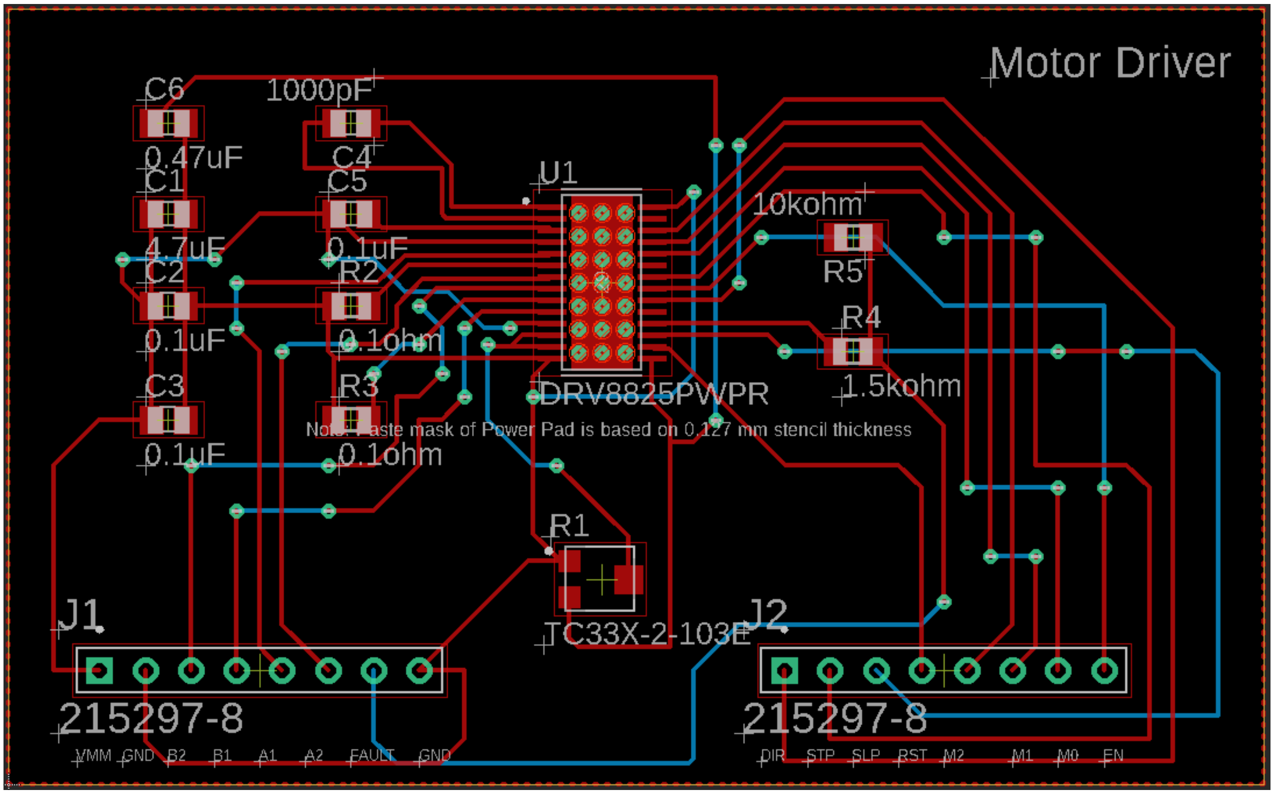


Fig 11. PCB layout of a Motor Driver Unit

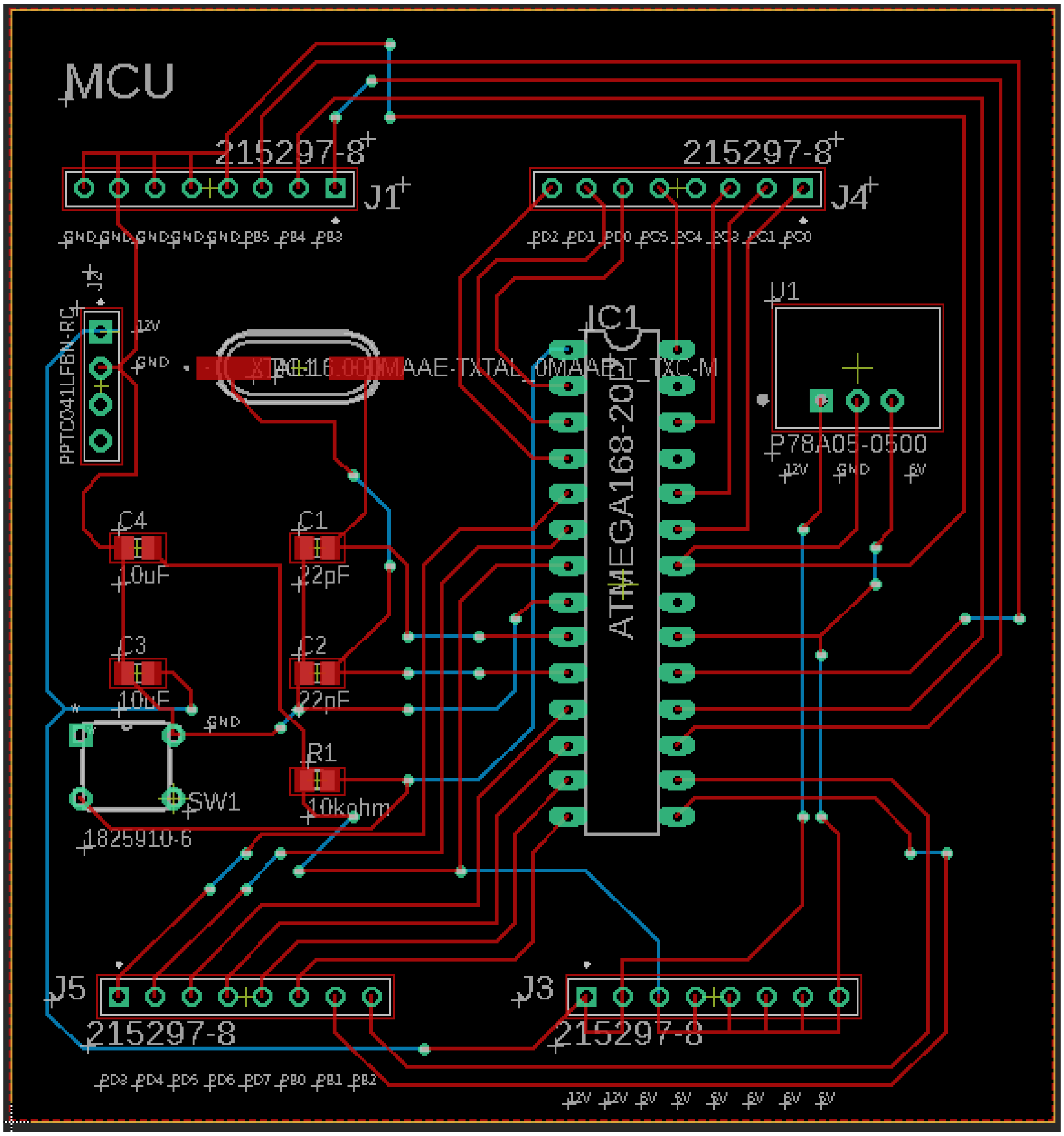


Fig 12. PCB layout of a Microcontroller Unit

2.4 Supporting Material

2.4.1 Pressure Analysis of Sanitizing System

To achieve the sanitizing function, in this project, we incorporate a commercial spray bottle with a servo motor. The servo motor is attached to a spray arm to trigger the misting. The key to the success of spraying the sanitizer is to guarantee the pressure difference within the bottle is large enough, which means the servo motor has to create a large enough force, or acceleration, to trigger the spraying. The theoretical calculation of the pressure difference is important. With assumption that no energy loss and quasi-equilibrium, general bernoulli equation [15] Eqn.1 could be simplified to Eqn.2.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2 \quad (1)$$

$$\Delta P = \rho g H \quad (2)$$

Since $\rho = 997 kg/m^3$, $g = 9.81 m/s^2$, $H = 0.2\,m$, the pressure difference could be solved as $\Delta P = 1956$Pa. Measuring the tube diameter to be 2mm, the estimating force could be calculated as 0.006145N. The length spray arm is 0.04m. Using Eqn.4, the definition of the torque, the torque required from the servo motor is 0.000246N·m.

$$F = \Delta P \cdot A \quad (3)$$

$$\tau = F \cdot L \quad (4)$$

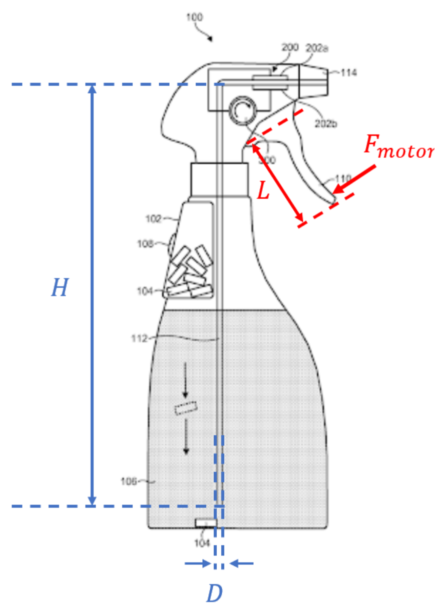


Fig 13. Typical Schematic of a Commercial Spray Bottle

2.5 Tolerance Analysis

2.5.1 Temperature Control Analysis

Temperature, as one of the most critical elements in our project, needs to be considered with proper discretion. Our project is designed to locate within the student's resident hall. According to the survey [12], the USA resident hall's average temperature is 75F, which is 24 $^{\circ}C$. The three dimensional laplace heat transfer equation [13] is shown in Eqn 5.

$$\frac{d^2T}{dx^2} + \frac{d^2T}{dy^2} + \frac{d^2T}{dz^2} + \frac{Q'''}{k} = \frac{1}{\alpha}\frac{dT}{dt}$$

(5)

During the first case, there is no cooling fan in the system, which means external heat flux term $Q''' = 0$. According to the definition of steady state, the temperature gradient w.r.t time dT/dt = 0. With assumption temperature profile is along x direction, the Eqn 5 could be further simplified into Eqn. 6. This leads to a uniform temperature profile or linear temperature profile. Since the steady state doesn't allow temperature to fluctuate, the solution vanishes to a uniform temperature profile. In other words, the temperature profile is shown in Eqn 7, where Tr is the room temperature, which is 24 $^{\circ}C$.

$$\frac{d^2T}{dx^2} = \frac{1}{\alpha}\frac{dT}{dt} = 0$$

(6)

$$T(x) = T_r \tag{7}$$

Considering the second case, two cooling fans are located within the system. For simplification purpose, we assumed the volumetric heat dissipation rate due to fans are constant, which equals to $-Q'''$. Also, assuming the temperature gradient is along the x-axis and it is steady state. Eqn.5 could be simplified as,

$$\frac{d^2T}{dx^2} - \frac{Q'''}{k} = 0 \tag{8}$$

This theoretical analysis is set up as Fig 14. Applying boundary conditions, the DFQ could be solved as,

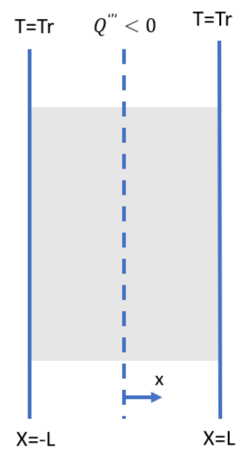
$$T(x) = T_r - \frac{Q'''L^2}{2k}(1 - (\frac{x}{L})^2)$$

(9)

Eqn.9 qualitatively estimate the temperature profile of covid-19 convenience locker under the condition of constant volumetric heat dissipation rate. From Eqn.9, it could be concluded that the temperature is decreasing from the boundary toward the center. Since the tube will rotate within x=-L and x=L, the tube temperature will always be lower than room temperature Tr. For future more accurate calculation, the volumetric heat dissipation rate should be calculated as shown in Eqn 10 [14], where h is the convective heat transfer coefficient, which is a function of airflow v. The real time temperature T(t) is a function of time t. To predict the accurate real-time transient temperature, simulation software such as Computational Fluid Dynamics(CFD) needs to be brought into consideration.

$$Q''' = h(v) \cdot [T(t) - T_r]$$

(10)



L

Fig 14. Temperature Analysis Theoretical Model

2.5.2 Motor Position Analysis

The Nema17 stepper motor should be made sure that it could move to the right position. The Nema17 uses PID control but there could be a chance that it has an error regarding the location of any steps. This error is not cumulative. To prove our design actually works well, we would suppose the error is cumulative. According to [11], a typical stepper motor may have a 0.05 ° error each whole cycle. Nema17 has 200 steps in a whole cycle and we need 45° as our design requirements. Suppose the system will fail if it deviates from half of the design requirements which is 22.5°. The system runs twice a day since students need to do testing and staff needs to collect the samples. This will result in a lifetime of 225 days which is absolutely enough. Also, please note that we are calculating the cumulative errors while the actual errors are not cumulative. So, we prove that the tolerance for the stepper motor is totally fine.

3.**Cost and Schedule**

3.1 Cost Analysis

Our fixed development costs are estimated to be $35/hour, 10 hours/week for three people. We will work for this project for 12 weeks.

Labor:

Team member	Hourly wage	Weekly hours	Number of weeks	Multiplier	Cost per member
Yimeng Qin	35	10	12	2.5	$10500
Chenghao Lu	35	10	12	2.5	$10500
Junsheng Liu	35	10	12	2.5	$10500
				Total labor cost	$31500

Parts:

Part	Cost(prototype)	quantity	total
ALITOVE DC 12V 5A Power Supply Adapter	$11.99	1	$11.99

P78A05-0500 DC to DC converter	$4.53	1	$4.53
DS3218 servo motor	$16.99	1	$16.99
PID 324 Stepper Motor - NEMA-17	$20.56	1	$20.56
TC33X-2-103E potentiometer	$0.26	1	$0.26
CRM0805-FX-R100ELF resistor	$0.66	2	$1.32
CR0805-FX-1501ELF resistor	$0.1	1	$0.1
DRV8825PWPR motor driver	$4.49	1	$4.49
Female socket 215297-8	$1.97	6	$11.82

C0805X475M8RACAUTO capacitor	$0.62	1	$0.62
C0805C102J1RACTU capacitor	$0.44	1	$0.44
C0805C474K3PAC7800 cpacitor	$0.76	1	$0.76
CRGP0805F10K resistor	$0.21	1	$0.21
C0805C106K8PAC7210 capacitor	$0.14	2	$0.28
C0805X104J1RAC7800 capacitor	$0.54	3	$1.62
C0805C220F4HACAUTO capacitor	$0.31	2	$0.62
Atmega328P	$2.3	1	$2.3
MCU socket 1-2199298-9	$0.76	1	$0.76

16MHz Crystal 9C-16.000MAAE-T	$0.3	1	$0.36
Tactile Switch 1825910-6	$0.1	1	$0.1
Female socket(4 pin) PPTC041LFBN-RC	$0.45	2	$0.9
Adafruit Mini Thermal Receipt Printer	$49.28	1	$49.28
HID card scanner	$35	1	$35
Spray bottle	$7.91	1	$7.91
TMP36GT9Z temp sensor	$1.48	1	$1.48
Motor coupling	$10.58	1	$10.58
Cooling fan	$9.99	1	$9.99
WP7113ID LED	$0.35	1	$0.35

		Total cost	$195.58

3.2 Schedule

Week (Mondays)	Yimeng Qin (online)	Chenghao Lu (in-person)	Junsheng Liu (online)
March 1	Finalize and Order version 1 PCB Design	Finish ordering all required parts in all modules	Finalize the temperature sensor coding part

March 8	Finalize Version 1 CAD Design	Begin breadboard PCB testing	Finalize the AC to DC converter and DC to DC converter cording
March 15	Testing and Iteration of Mechanical Design	Finalize power module components; review design to see if anything need changes	Finalize the stepper motor coding
March 22	Finalize and Order Version 2 PCB Design	Finalize mechanical modules; review design to see if anything need changes	Finalize the motor driver coding
March 29	Review and Modify Design Document based on CAD and PCB design	Finalize environment control module; review design to see if anything need changes	Finalize the temperature system coding
April 5	Finalize and Order Version 3 PCB (if needed)	Finalize identity recognition module; review design to see if anything need changes	Finalize the RFID reader coding

April 12	Finalize all the design work and prepare for mock demo.	Assemble everything and test whether each module is working	Sum everything up and be ready for the demo
April 19(Mock demo)	Mock Demo	Make sure subsystem is working	Mock Demo
April 26	Summarize all the design paperwork and prepare for demonstration/Presentation	Begin final report and prepare for final presentation	Begin final report and be ready for the final presentation
May 3	Write final report	Write final report	Write final report

4.Discussion of Ethics and Safety

4.1 Safety

There is obviously some concern since this locker is designed to store and dispense COVID testing tubes. It is quite possible that this machine will become a disease vector after some COVID-positive people use it. We need to minimize this risk and try to make the inside of the locker clean. The spray bottle filled with alcohol is designed to reach this task. The spray bottle will dispense alcohol after someone uses the locker in order to keep the inside clean. In addition, we should be aware of the danger caused by alcohol when the temperature is high. This is a locker which means it will have higher temperature than outside in the summer. We must take close attention to the temperature sensor in order to prevent fire. Also, the project is a COVID convenience locker which may include risks when transferring testing samples and doing tests, it is necessary to wear masks when using the convenience locker. We have to follow the Saliva

Collection and Handling Advice[10] to correctly collect and ship all testing samples. We are responsible for the safety of our project.

4.2 Ethics

Both of the IEEE and AMS codes of ethics need us to hold paramount the safety, health, and welfare of the public. There is a possibility that COVID positive patients use the locker and then contaminate it unconsciously. This risk will be minimized by our design. [11] The IEEE ethics code 6 requires us "to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience."[11] The IEEE ethics code 2 requires us to "improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies, including intelligent systems."[11] In other words, we want to make this project beneficial to the society and to improve the COVID testing system in UIUC. This is why we choose this project. We are eager to help the whole society by having more convenient ways to take COVID tests under such a hard circumstance. We want to make as few unnecessary contacts as possible to reduce the risk of infecting by COVID virus. There also exists possible privacy concerns. We would use a 2FA server to protect the privacy of users. The IEEE ethics code requires us to "to protect the privacy of others"[11]. The user of the convenience locker will by no means access any personal information of others. If the user passed the 2FA verification, only one testing tube would be shown to the user. This will avoid the user touching any other tubes.

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