COVID Convenience Locker
ECE445, Senior Design

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Abstract

The purpose of this project is to provide automation solutions to the Covid-19 routine testing. This project aims to realize zero-contact by combining a mechanical tube distribution system and electronic controlling system to automate the whole testing process. An additional environment control system is attached to keep the sample fresh and clean. Moreover, the project is designed to be low-cost so that the Covid-19 Convenience Locker could be distributed widely across the campus.

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1. Introduction

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 tests taken by students and faculties in U of I so far.[2] This large amount of testing will bring a huge cost and utilize many resources. For each test location, about 5 employees are needed to monitor, distribute and collect testing tubes.[2] Around 100 employees are hired in different testing locations in Urbana-Champaign.[2] 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 7 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 could effectively kill the covid virus, we have a spray nozzle to spread the sanitizer for sanitizing.[3] A temperature sensor and a cooling fan are also designed to avoid high temperature inside the locker when it is in summer.

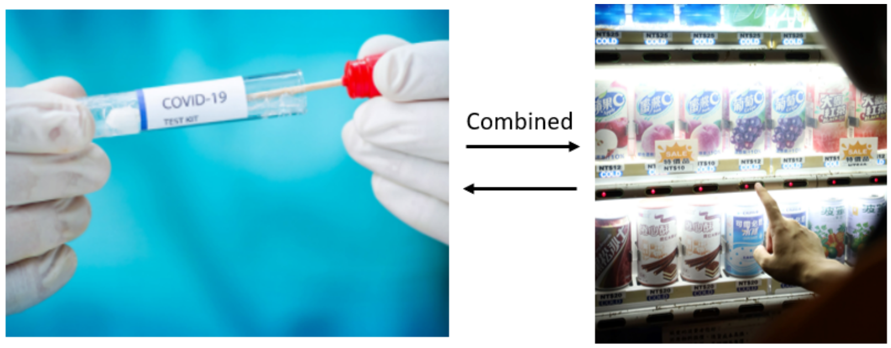

Fig 1. Visualization the goal of ECE445 Covid-19 Convenience Locker

2. Design Procedure and Details

Covid-19 Convenience Locker could be split into 4 different sections. The Mechanical System Section is composed of a Rotator and Sanitizer. Rotator is responsible for distributing/collecting the testing tubes with a capacity of 7 tubes. Thel mechanical sanitizer is integrated in this section to regularly clean the mechanical system. The Processing Section consists of Microcontroller and Motor Driver, which handles all the software automation and data transmission. The Environment Control section will monitor the temperature and control the temperature to avoid high temperature situations. The identification section is responsible for reading the student's I-Card and printing out the testing sticker with the student's information. The block diagram of Covid-19 Convenience Locker is shown in Fig 2.

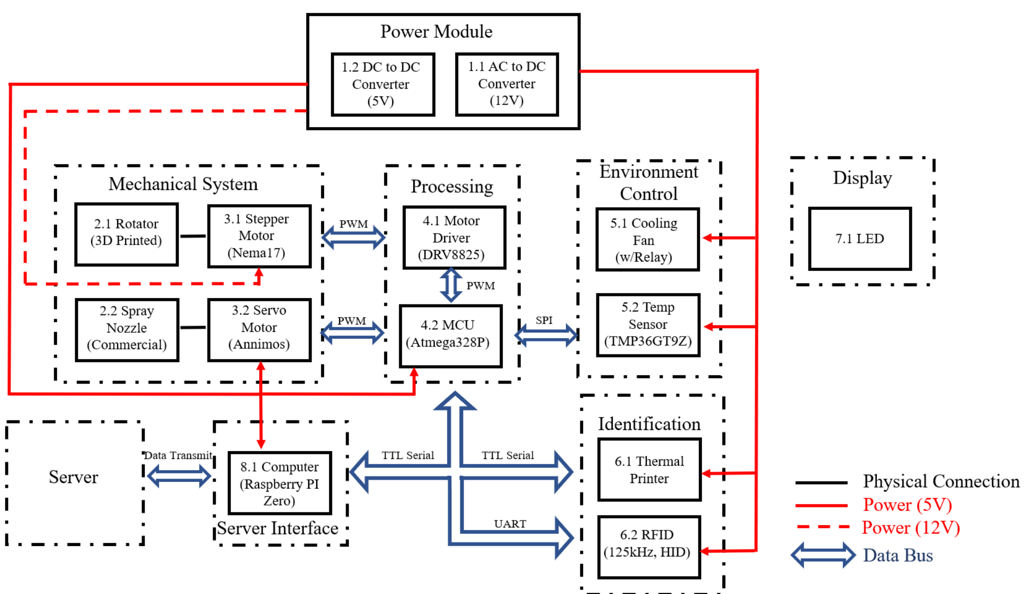

Fig 2. Block diagram of Covid-19 Convenience Locker

2.1. Mechanical System

2.1.A Mechanical Rotator

The rotator component is composed of a mechanical rotator design and a stepper motor. The mechanical rotator is prototyped using 3D-printing due to the design complicity. The 3D-printing could greatly accelerate the iteration process, and bring us the optimized mechanical structure. The mechanical rotator design has two different layers: Top rotator and bottom rotator. The bottom is used to distribute the testing tubes, while the top one is used to collect the tubes. Each layer of rotator contains 7 extruded holes, which has the capability of holding 7 tubes. Compared with cartridge-like design, the choice of rotator design is to minimize the risk of jamming the testing tubes. At the same time, this greatly utilizes the advantage of rotation motion brought by the stepper motor. In other words, the stepper motor could easily control the motion of the rotator. The groove design on the top rotator is used to allow bulk transfer for testing center staff. The groove design allows only one degree of freedom, which is the vertical motion. Thus, when the top layer is housed with the whole device, it will rotate together. The shaft coupling installed at the bottom rotator will fix the rotator on the D-shaft of the motor. The choice of the metal coupling is to increase the durability of the device. Moverover, the connection between bottom rotator and rotator connector uses M4 screws to increase the overall strength and durability. The detailed design figure is shown in Fig 3.

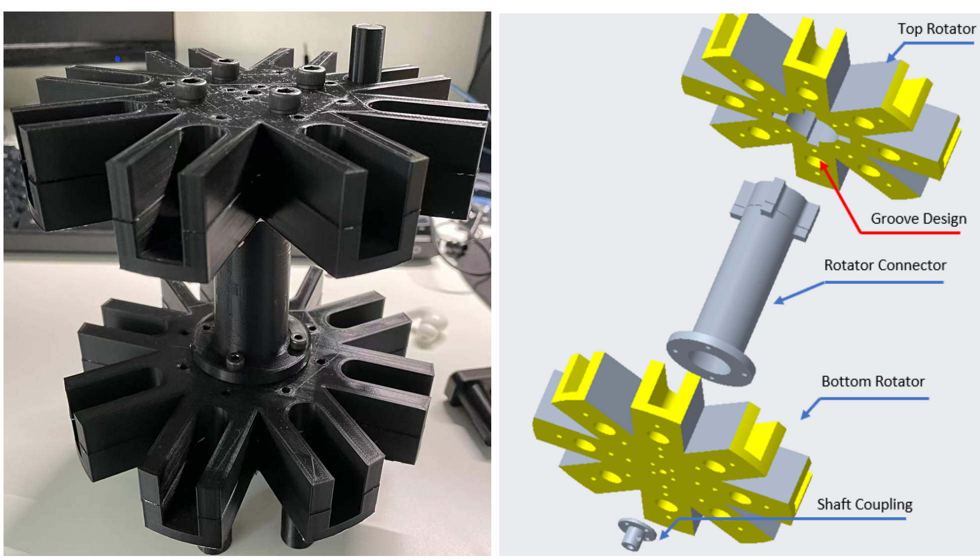

Fig 3. Mechanical Rotator System a.) Physical b.) CAD Illustration

The stepper motor is chosen using a 12V bipolar stepper motor. The choice of 12V motor instead of low voltage is to increase the torque capacity of the motor. Although the rotator design represents the mechanism that all the gravity adds to the center of the motor shaft, which will not create additional torque, choosing a high torque motor is a safe choice in case of unexpected scenarios such as friction. Also, the step angle size of the motor has to be a factor of the rotation angle. In our case, the rotation angle is 45° and motor step angle is 1.8°. The stepper motor is connected to a Motor driver so that the microcontroller could directly control the behavior of the motor.

2.1.B Mechanical Sanitizer

The mechanical sanitizer system is to utilize a servo motor to control the motion of the commercial spray bottle. In our design, the servo motor is fixed at the back of the spray bottle, and a 3D printed spray linkage is used to connect the servo motor shaft and spray bottle trigger. There are two common sanitizer spray bottles available, one is manually pressing type and the other is pneumatic type. The pneumatic type spray bottle could provide more constant pressure during each trigger, but the cost is higher than the manually pressing type. Also, to automate the pneumatic type, an electric pump needs to be directly connected to the spray nozzle, which requires larger power input. With the reasons above, our project choses manually pressing the spray bottle. The two-bar linkage is used in this system to transfer the torque into the force adding on the spray bottle trigger. Four different available holes on one of the linkages are used to represent different extent of pre-stretch adding on the spray bottle. For durability consideration, we eventually use the last hole, which will decrease the pressure on the nozzle, and in turns amount of sanitizer, but will increase the durability of the design. Furthermore, the chamfer at the front corner of the linkage is to decrease the material stress point during the operation.The linkage design is shown in Fig 4.

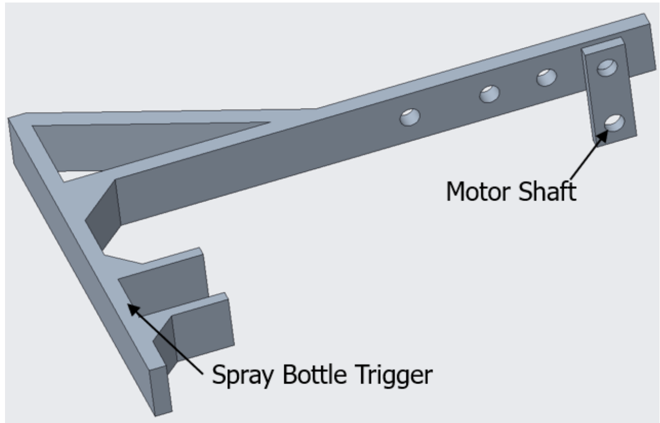

Fig 4. Mechanical Spray Linkage CAD Illustration

2.2 Processing System

The processing system consists of a microcontroller and a motor driver. The microcontroller integrates the IC chip Atmega328P with an external 16Mhz clock on the PCB. The detailed PCB schematic is shown in the Appendix. The reason for choosing Atmega328P is due to its compatibility with abundant Arduino peripherals and software libraries. For example, to control all the servo motors, Servo2 arduino online library is used. [4] Another advantage of Atmega328P is that it could be bootloaded from an comercial arduino board as an in-system program (ISP), which is shown in Fig 5. Moreover, a large number of digit I/O pins is sufficient to satisfy large quantities of devices. The commercial arduino board will transfer the program to the stand-alone Atmega328P chip, which can be operated using the external circuit.

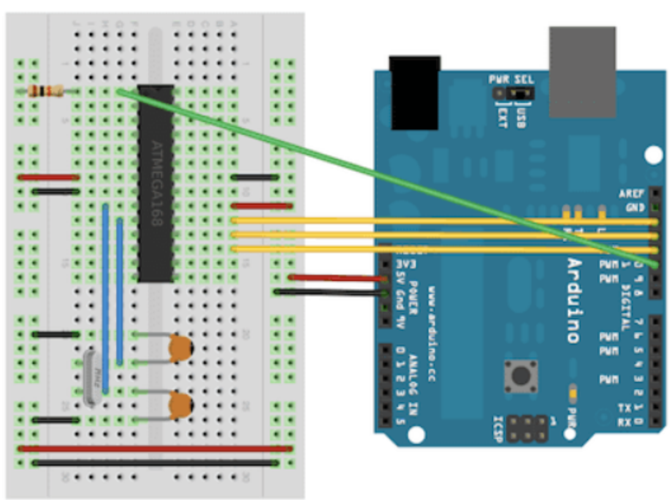

Fig 5. Circuit of Burning Bootloader [5]

The motor driver integrated the DRV8825 IC chip with a rheostat to control the behavior of the stepper motor. The motor driver will take 12V as operating voltage, and change the output current to 1.5A by adjusting the rheostat. 12V and 1.5A are chosen based on the datasheet of the stepper motor. Then, the motor driver will generate the Pulse Width Modulation (PWM) signal into the four leads of the motor based on the input signal from the microcontroller. The decision of using DRV8825 as driver is because it could control a high power motor (45V/2.2A), and it has the capability of dissipating progressively by connecting the metal layer of the chip with the ground layer of the PCB. The detailed motor driver wiring diagram is shown in Fig 6.

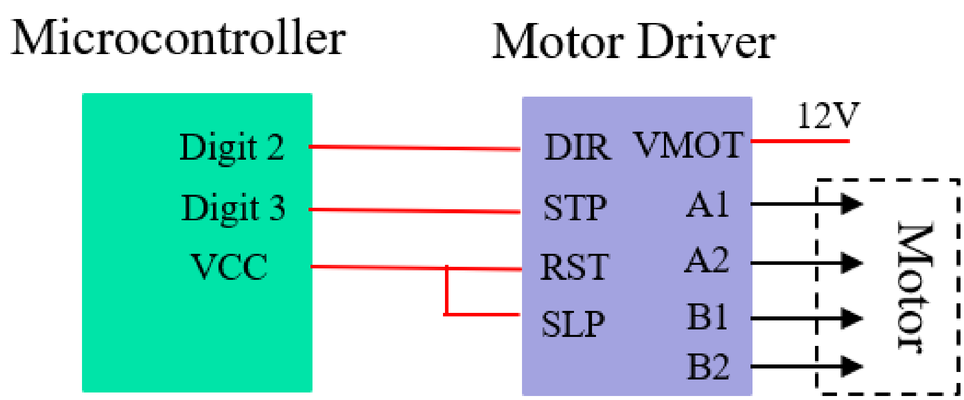

Fig 6. Circuit of Motor Driver

2.3 Information Identification System

The information identification system consists of a RFID reader and a thermal printer. The RFID reader uses HID 5455BkN00 in our project. The reason for using this RFID reader is due to the requirement of I-Card Protocol. UIUC I-card utilizes a low frequency (125kHz) portion of radio frequency and HID company encoder standard. The HID reader chosen in this project met the requirement above. Besides, the operating temperature is -30°C to 65°C, which is suitable to operate during the several weather conditions in the Illinois area. And the device size is 127mm*127mm so it could perfectly fit into our locker.

The RFID reader is used to identify the person who will use the locker. This device could read 35 bits of information under 125 kHz frequency. The first 14 bits are identified as the facility code while the last 21 bits is the student or staff’s information. Depending on the facility code, the microcontroller can identify the person as a student, staff or someone who is not allowed to use the locker. When we are doing the real tests of the RFID reader, we program the microcontroller such that the RFID reader could read the I-card information and compare the facility code with the UIUC facility code. The RFID reader transmits data to the microcontroller through the Data0 and Data1 pin and the beeper will beep when someone is using the RFID reader. We recorded data from digit pin 4 and digit pin 5 and then compared it with personal information which has been stored in the microcontroller.

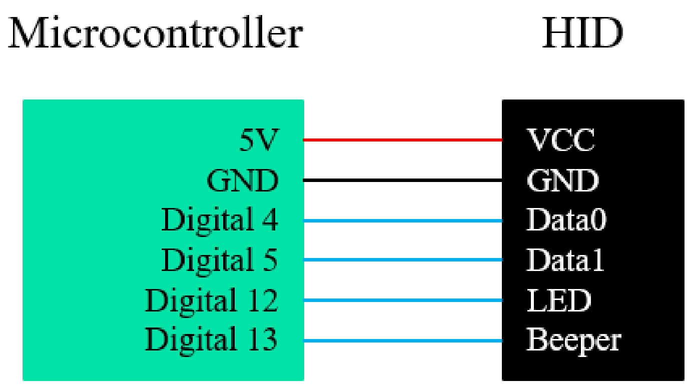

Fig 7. Circuit of HID

The thermal printer ADA597 has an operating voltage ranging from 5V to 9V and an operating current of 1.5A, which satisfy the power input of the PCB. Also the thermal printer only requires one digital input and one digital output to transmit the data, which is arduino software friendly. The RFID reader will send information to the microcontroller and the thermal printer will receive the information from the microcontroller. The thermal printer will print out the corresponding student's information. The challenge is that we have to manually type the personal information for comparison since we do not have access to the database storing campus ID information. Future groups may also think of the 2FA system and facial recognition for information verification.

2.4 Environment Control System

The environment control system consists of a temperature sensor and a fan/relay subsystem. This system is designed to adjust the temperature inside the locker, specifically cooling the temperature down when it is above the threshold temperature

The TMP36 is the temperature sensor in our design. When the temperature is too hot, it should send commands to the microcontroller and the microcontroller will send commands to the relay. We use this temperature sensor since it has a self-heating temperature as low as 0.1°C and it provides typical accuracies of ±1°C at +25°C and ±2°C over the −40°C to +125°C which fits our needs. The TMP36 has an operating voltage ranging from 2.7V to 5.5V. It also has a 10 mV/°C scale factor and it provides a 750 mV output at 25°C. The temperature sensor will keep sending voltage information to the microcontroller and the microcontroller needs to identify the temperature and send start or close signal to the relay/fan.

According to Fig. 8, it is investigated that 25°C is the right temperature to keep the sample fresh. To help the users roughly identify the temperature, several LEDs are used to display the temperature. A green LED was set for displaying temperature from 20°C to 30°C, a yellow LED was set for temperature from 30°C to 40°C and a blue LED was set for temperature from 10°C to 30°C. There could be severe circumstances. and a red LED was set from temperature larger than 40°C. Most COVID convenience lockers will be put inside the apartments, so we assume severe circumstances will never happen and the temperature is always around 25°C. The detailed thermal analysis is attached in Appendix B.2.In case of an outside convenience locker, we design a fan/relay system for cooling purposes.

We use two DC fans for cooling purposes. The reason for using this is that they are cheap and reliable. The microcontroller will compare the real-time temperature with the setting threshold temperature (25°C)all the time. When above threshold temperature, the microcontroller will enable the relay, which effectively turns on the cooling system.

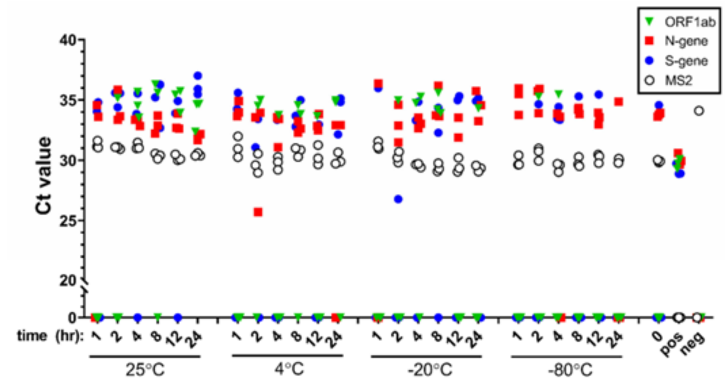

Fig 8. Stability of saliva samples [6]

2.5. Software System

The Atmega328P is used as the microcontroller in our project. Since it is directly the same chip as the arduino, we use arduino IDE for coding. The software block diagram and the flowchart are attached as below.

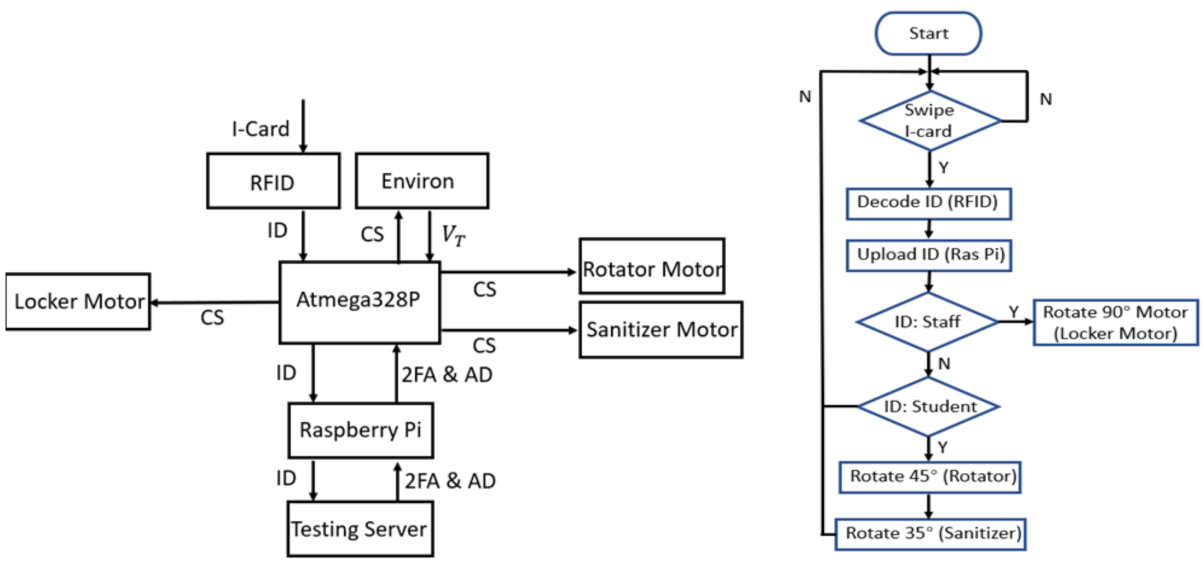

Fig 9. Software a.) Block Diagram b.)Software Flowchart

We use two microcontrollers for the whole project since the number of I/O pins on one microcontroller is not sufficient to functionalize all the arduino devices. The whole procedure of the software flowchart is divided into two parts. The first microcontroller controls the RFID reader, servo motor and sanitizer motor. The second microcontroller controls the thermal printer, environment system and the rotator. Two signals will be used as the start/finish signals between two microcontrollers. As the flowchart shows above, the whole process starts when someone uses the RFID reader to swipe their I-card. The first microcontroller will identify whether the user is a staff or a student. If the user is a staff, the locker servo motor will rotate 90 degrees to unlock the top cover, so that staff can pick up all testing tubes. When the user is a student, the first microcontroller will send a start signal to the second microcontroller. When there is no start signal from the first microcontroller, the second microcontroller will keep monitoring the temperature. It will check whether the temperature is above the threshold and control the relay to start the fan if it is above. If the second microcontroller receives the start signal from the first microcontroller. It will jump out of the loop, the thermal printer will then start and print the data. The stepper motor will rotate 45 degree for the first student, 45*2 degrees for the second student and 45*n degrees for the n student who used the locker. The student can now pick up the testing tube. When the student finishes the testing, he or she should use the RFID reader again. The first microcontroller will receive this signal and send the second signal (finish signal) to the second microcontroller. When the second microcontroller receives the signal 2. It will rotate 22.5 degrees (due to mechanical design) to let the student put back the testing tube. Wait several seconds, and rotate 45*n+22.5 degrees back. This will complete all the processes.

3. System Verification

3.1 Mechanical System

3.1.A Mechanical Rotator

To verify the mechanical rotator can successfully rotate to the desired angle we want, we put a protractor beneath the rotator to measure the angle of degrees it rotates each time. The results are shown in the table below.

Trial #	1	2	3	4	5	6
Biased Angle [Degree]	10.5	6.2	-7.9	12.2	-8.6	-9.2

Table 1. Angle error measurement for six trials when rotating 135 degrees

During the testing, we choose 135 degrees as our testing angle because if we choose 45 or 90 degrees, the biased angle will not be easily noticed. We expect that the larger the angle, the larger the error will be. The results show that it is unavoidable to have some random errors each time because of the closed loop motor we choose. So it is possible that after the rotator works for several rounds, the error will accumulate and will cause some issues when the tester wants to return or grab the tubes.

3.1.B Mechanical Sanitizer

All we need to check in the mechanical sanitizer is to make sure the sprary linkage can successfully trigger misting. The figure above shows that liquid can be spraried. During testing, the only thing we keep changing is the acceleration of the servo motor. It is possible that it may not have large enough force to spray liquid. The calculation is done in Appendix B.1.

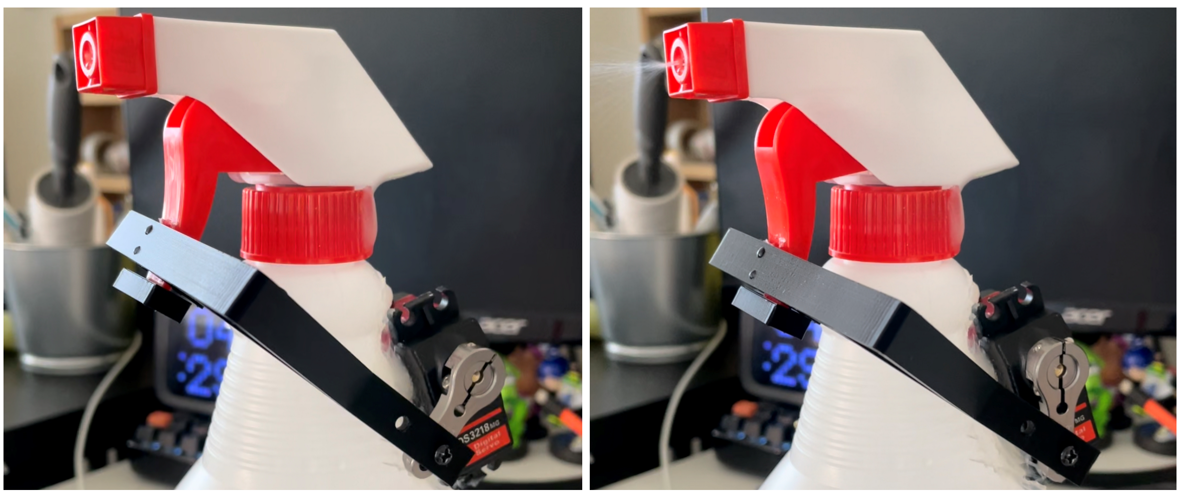

Fig 10. Sanitizer Verification a.) Resting Position b.) Triggering Position

3.2 Information Identification System

To test whether HID works properly, we swiped our own ID card to check whether the serial monitor correctly displayed the bit number.

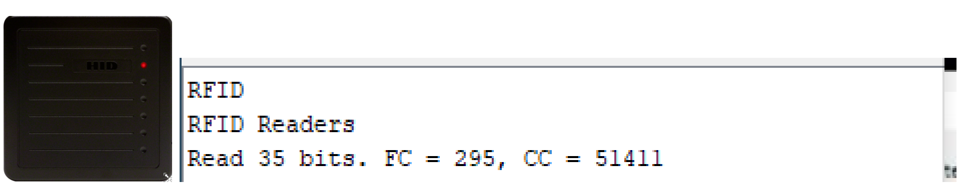

Fig 11. HID reader and bits read on serial monitor

Each I-card has a unique CC number, so we decide to use this number for the purpose of identity recognition. This unique CC number will be matched to all the information of the owner. The information will then be printed out by the thermal printer.

The second testing part is the thermal printer. When connected to 5v, it should print the information correctly and readable as soon as it receives the signal from HID reader

Fig 12. Thermal printer and example of printed information

One more thing we need to test from the requirement is the successful rate of swiping cards on the HID reader. We swiped the cards until the reader successfully read the bits and repeated this step for six times. We finally get the following results.

Trial #	1	2	3	4	5	6	AVG	SD
Swipe Time	1	1	3	2	2	3	2	0.82

Table 2. Number of times we need to swipe to be successfully read

Obviously, it is very difficult to assure a successful rate higher than 95% we mentioned in the requirement because the HID reader itself is not very sensitive. The best way to solve this issue is to replace a more sensitive HID reader.

Another minor issue we faced when connecting the Information Identification System is that it is possible thermal printers can not reach 5V, which leads to the issue that some information is not clear to see.

We measured the voltage across the thermal printer and found that it is around 4.5V, which means it can not have enough power to print clear words. The reason we believe is that other devices may utilize some of the voltage. To solve this problem, we simply disconnect the thermal printer with our PCB Vout and use an external power source 5V battery to power the thermal printer.

3.3 Environmental control system

The TMP36 temperature sensor we choose reads an analog value and then converts it to the corresponding temperature. To find the relationship between analog reading and the temperature. We used Arduino to test and record the analog reading displayed in the serial monitor at different temperatures. The circuits for testing and the resulting graph are shown below.

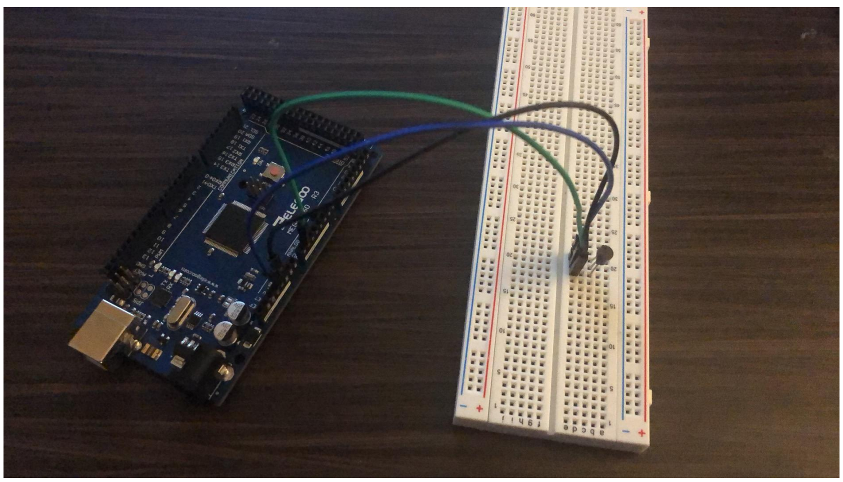

Fig 13. Circuits for test the relationship between Analog read and temperature

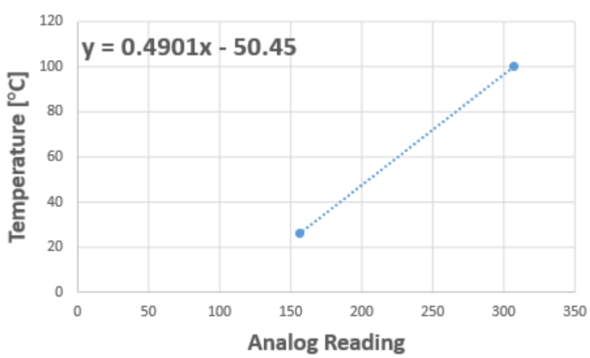

Fig 14. Graph for Analog reading and temperature

By calculating the gradient of the line, we get the linear relationship between Analog reading and temperature. To confirm this equation is correct, we need to check whether TMP36 correctly outputs 750mv at 25°C. To convert from analog read to the voltage across the sensor, we need to calculate as follows:

Step 1: read the graph we find the analog reading is 157 when temperature is at 25°C.

Step 2: 157 / 1023 = 0.153 = 15.3% percentage # 1023 the bound of analog read

Step 3: Use 5V to multiply the percentage in step 2. We get 0.76, which is about 760mv.

The value we calculated is very close to 750mv. The small difference is possibly caused by some offsets. But we can at least use TMP36 to monitor the temperature around the locker. We also put some LEDs to display the different ranges of temperatures(20-30, 30-40, etc).

One other part of the environmental control system is the cooling fan controlled by relay. However, during testing, the power of the cooling fan we bought is so small that it is possible to achieve the functionality to change the temperature. Therefore,what we tested is just to make sure when temperature is above 25°C relay will functionalize the cooling fan.

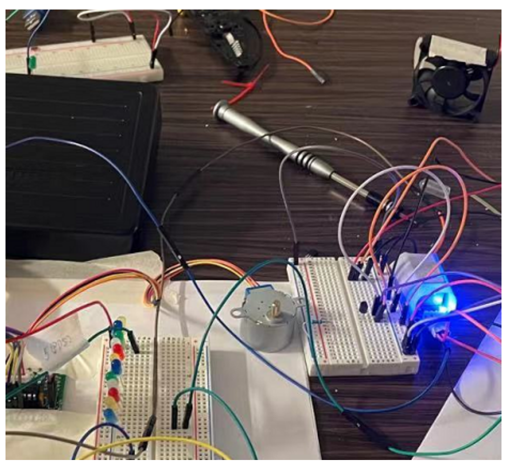

Fig 15. Configuration of environmental control system

By the figure above, LEDs, temperature sensors, cooling fans and relay(blue light) can be seen clearly and the result is satisfied.

3.4 Processing System

The microcontroller is programmed using the external circuit including capacitor and external clock via Arduino ISP [7]. To verify the functionality of microcontroller, a led blink example is used. The circuit is shown in Fig 17. If the microcontroller could run the led blink example with an external circuit, the programmability could be guaranteed. Similarly, the blink example is applied to all the digital pins on the PCB. With the verification, all the digital pins could blink the led as designed.

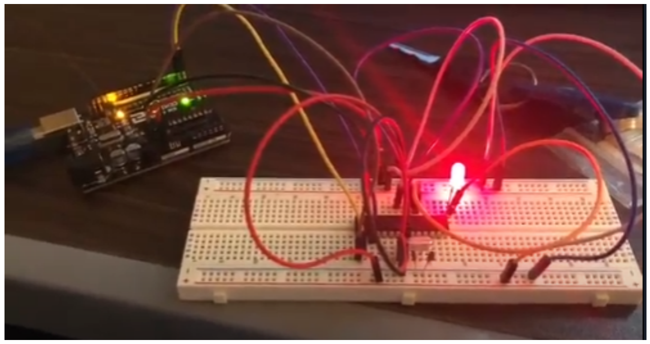

Fig 16. Configuration of bootloader microcontroller

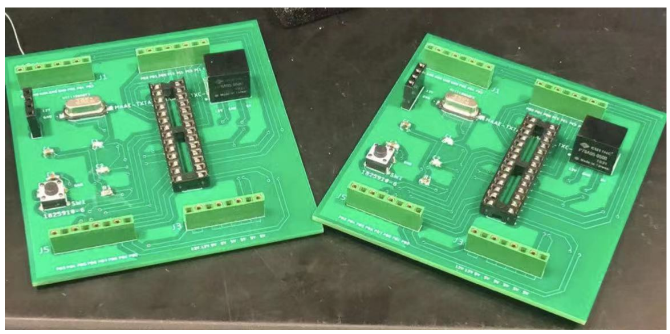

Fig 17. PCB of microcontroller (w/ DC converter)

4. Costs and Labor

An entry level electrical engineer in the U.S. has an hourly pay of $35 while the salary is $34 for an entry level software engineer. [8][9] Everyone in our project works on software and hardware parts. So, our fixed development costs are estimated to be $34.5/hour, 10 hours/week for three people. We worked for this project for 16 weeks. Also, our project is supported by the machine shop. We suppose the labor costs are 6 hours with a wage of $30/hour. We need two PCBs and they need $23 each. So, the total labor costs are in Table 1.

Labor Description	Math	Costs
Team members	34.5/hour*10hour/week*16weeks*3 people*2.5	$41400
Machine Shop	6 hours* 30/hour	$180

PCB	23*2	$43

Table 3. Total label hour and cost of ECE445 final project

We need an estimate of $195.58 for all the electronic components. This includes all the components of all subsystems in this project. Due to the limit of spaces, a detailed components price list is put in the Appendix D.

The total cost is the sum of everything above which is calculated as $41818.58. We used second-hand components and could not get a discount since we only bought 1 or 2 same components in each order. We believe that the price of electronic components could decrease if there is a signed contract with these companies.

5. Conclusion and Ethics

5.1 Conclusion

To sum up, we are able to implement all the subsystems and successfully complete this convenience locker. Since the Covid convenience locker can execute all testing procedures with one-stop services, this locker can automate the testing process and make life easier under this circumstance. Additionally, due to the low-cost design, the locker is promised to distribute widely across the campus especially inside the students' apartments. This will greatly improve the students' life quality, since students don't need to commute back and forth, and also effectively reduce the risk of being infected when using public transportation.

5.2 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.

5.3 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. [10] 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."[10] 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."[10] 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"[10]. 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.

5.4 Future work

The 2FA system was not implemented into this project since we did not have access to the UIUC database. Future work can be done in using the 2FA verification and facial recognition to prevent someone from faking the test. It is also possible that someone destroys or damages the whole locker on purpose. Putting the convenience lockers into surveillance areas and developing a system which connects to the police department may solve this problem. Due to the limitation of budgets, we used the cheapest RFID reader and motors in our project. A better RFID reader and stepper motor could also be implemented to make the process smoother since there exists cumulative error in the motor and bad reading from the RFID reader.

6. Reference

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Appendix. A Requirements & Verification

Table of Requirement, Validation and Results per Project Module		
Requirement	Verification	Result
Mechanical System-Mechanical Rotator		
1.)The stepper motor could rotate 45n+22.5° (±0.225°) each time, then rotate back to the original position, with no cumulative error.	1.a) Program the atmega328P to operate the step motor to rotate 360°. 1.b) Place a Protractor underneath to measure the corresponding error.	Generally the result is satisfied but there are cumulative errors of degrees because of closed loop motor
Mechanical System-Mechanical Sanitizer		
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.a) Check whether the spray arm can be pressed by servo motor 1.b) Testing tubes on the top should be cleaned by disinfectant successfully(check whether the tubes have liquid) 2.a) Program the Atmega328P to rotate the spray back and forth repeatedly between 20 degree and 50 degree. 2.b) Using a camera to record the motion and time interval	Satisfied

Table A.1. Requirements & Verification for mechanical system

Power System-DC to DC Converter		
1.)The device can output dc voltage 5V (± 3%). 2.) The device can provide constant current from 0-500mA.	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 every 1 second. 1.c) Record the voltage and compute the average and standard deviation of voltage measurement. 2.) Measure constant current 500mA via oscilloscope.	Satisfied

Table A.2. Requirements & Verification for power system

Identification - Thermal Printer		
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.) The printer will be connected to two pins on the microcontroller and Vcc, gnd will be connected to a 5V battery. 2.) Check whether the printer can correctly print all required information after reading the logical bit signal from HID.	Satisfied
Identification - RFID Reader		
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.) Program the Atmega328 such that HID reader could read the I-card information, and compare the first 4 characters (facility code) with UIUC I-card manufacturer code. 2.) Repeat step 1.) and record the detection rate.	Requirement is satisfied but for Requirement two the successful rate is lower than 95% because of the cheap HID reader we choose.

Table A.3. Requirements & Verification for identification system

Environmental Control-Temperature Sensor		
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. 2.) Increase the environment to determine the conversion factor of the temperature sensor.	Satisfied
Environmental Control- Cooling fan		
1.) The fan should start when it is above 25°C. Testing the functionality of Relay.	1.a) After connection, send a signal towards the relay. Check whether the relay functions the cooling fan. 1.b) Monitor the fan status when the temperature is higher than 25°C.	Satisfied

Table A.4. Requirements & Verification for environmental control system

Processing-Microcontroller		
1.) Transmit the data via SPI/I2C/TTL Serial/UART. 2.) Digital pins are programmable with desired functionality	1.) For each transmit protocol, an oscilloscope is used to test the behavior of dataline to prove the functionality. 2.) Program each digit pin with a Blink LED example, and check the behavior.	Satisfied

Table A.5. Requirements & Verification for processing system

Appendix. B Tolerance Analysis

B.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 [13] Eqn.1 could be simplified to Eqn.2.

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

(1)

$$\Delta P = \rho g H \tag{2}$$

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.

$$F = \Delta P \cdot A \tag{3}$$

$$\tau = F \cdot L \tag{4}$$

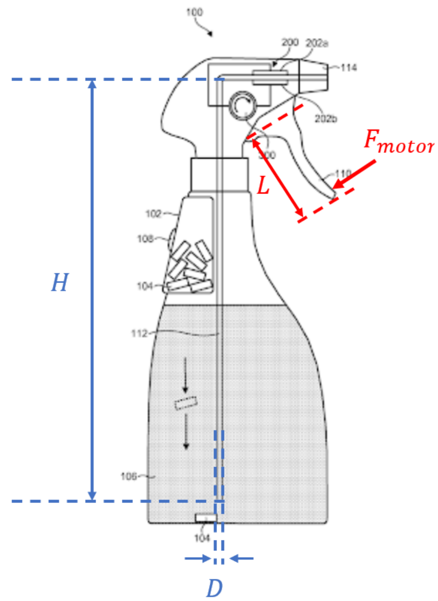


Fig B.1. Typical Schematic of a Commercial Spray Bottle

B.2 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 [11], the USA resident hall's average temperature is 75F, which is 24 $^{\circ}C$. The three dimensional laplace heat transfer equation [12] 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)

$$T(x) = T_r \quad (7)$$

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,

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

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

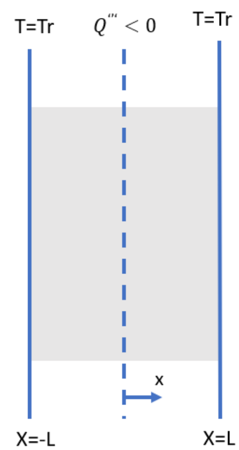
$$T(x) = T_r - \frac{Q'''L^2}{2k}(1 - (\frac{x}{L})^2)$$

(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 B.2. Temperature Analysis Theoretical Model

Appendix. C Mechanical CAD File

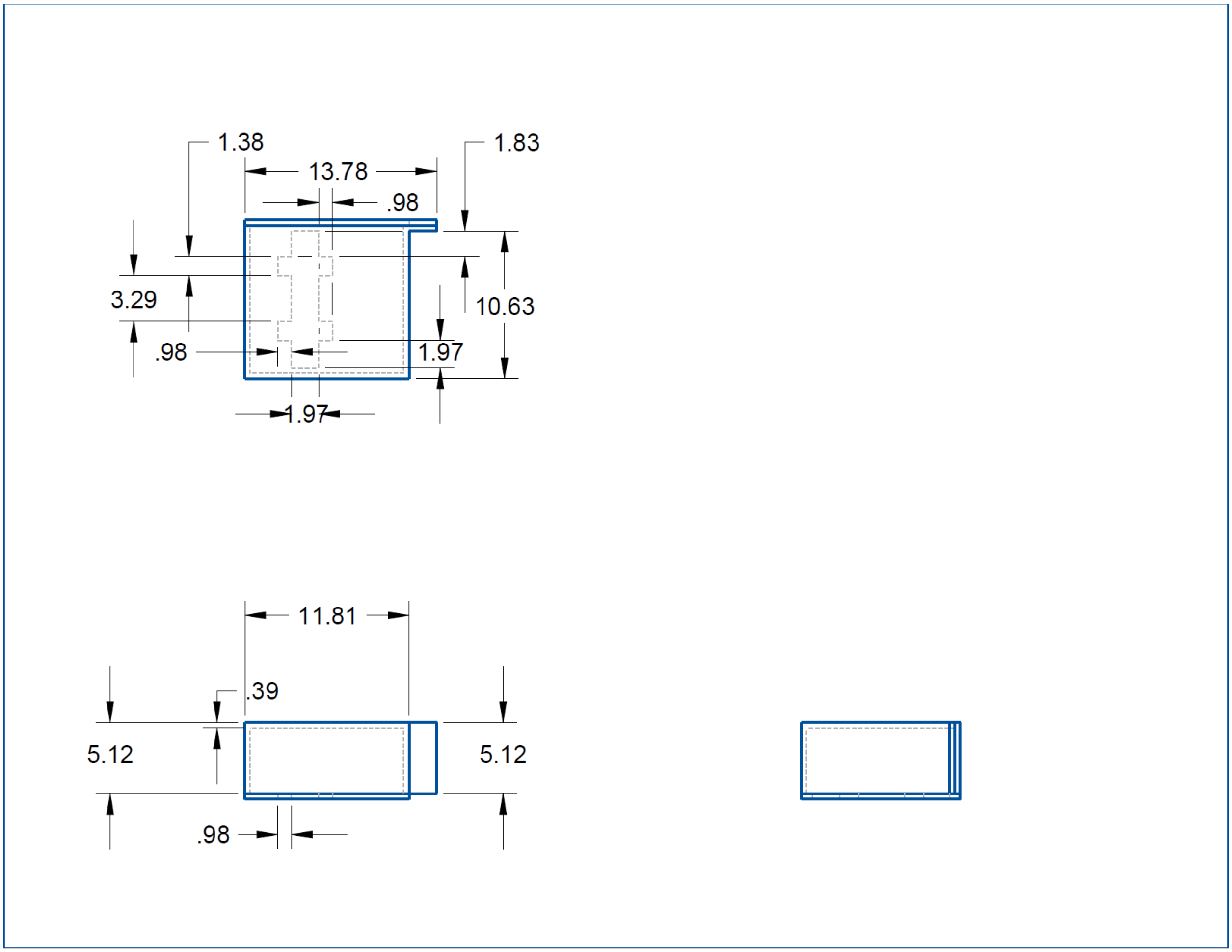


Fig C.1 Locker Mechanical Drawing

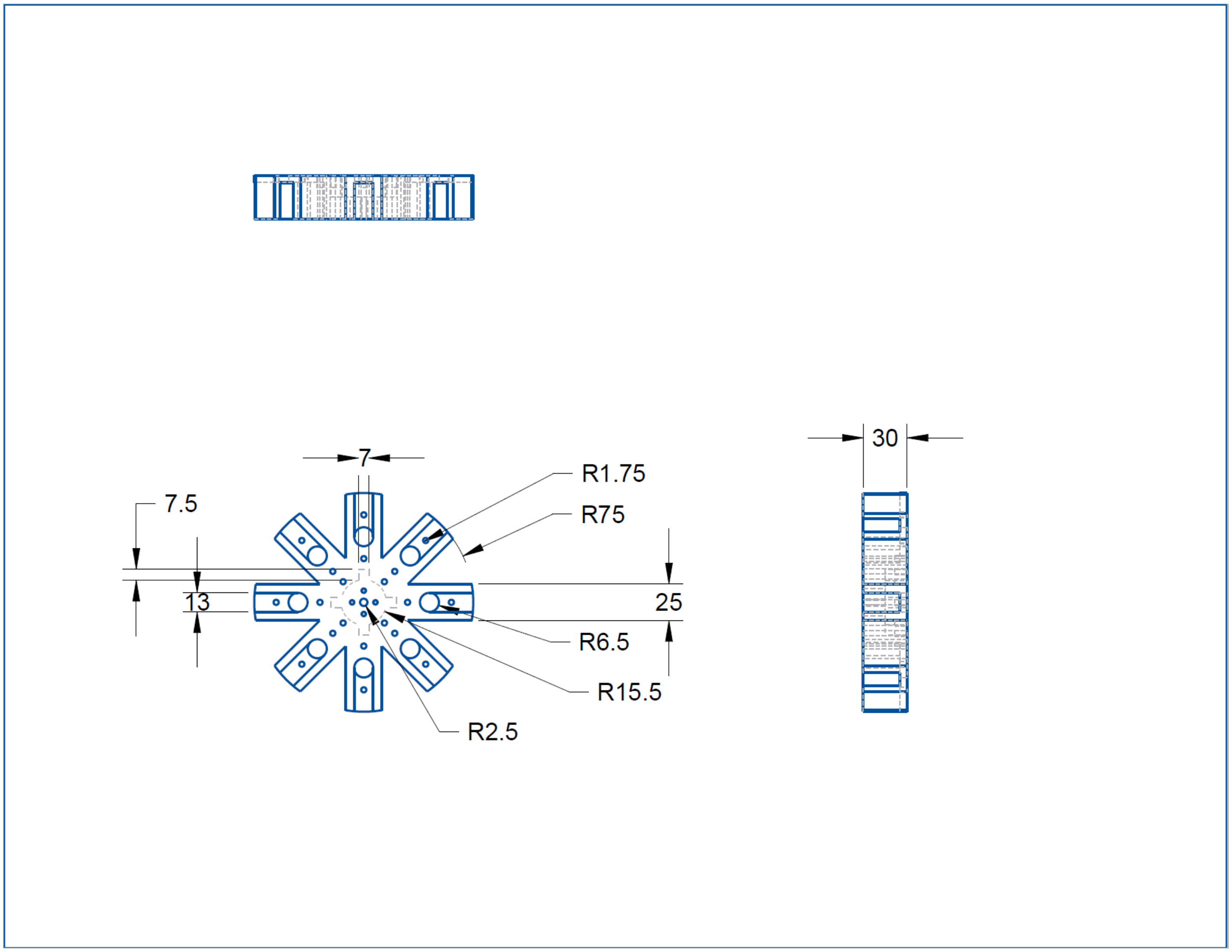


Fig C.2 Top Rotator Mechanical Drawing

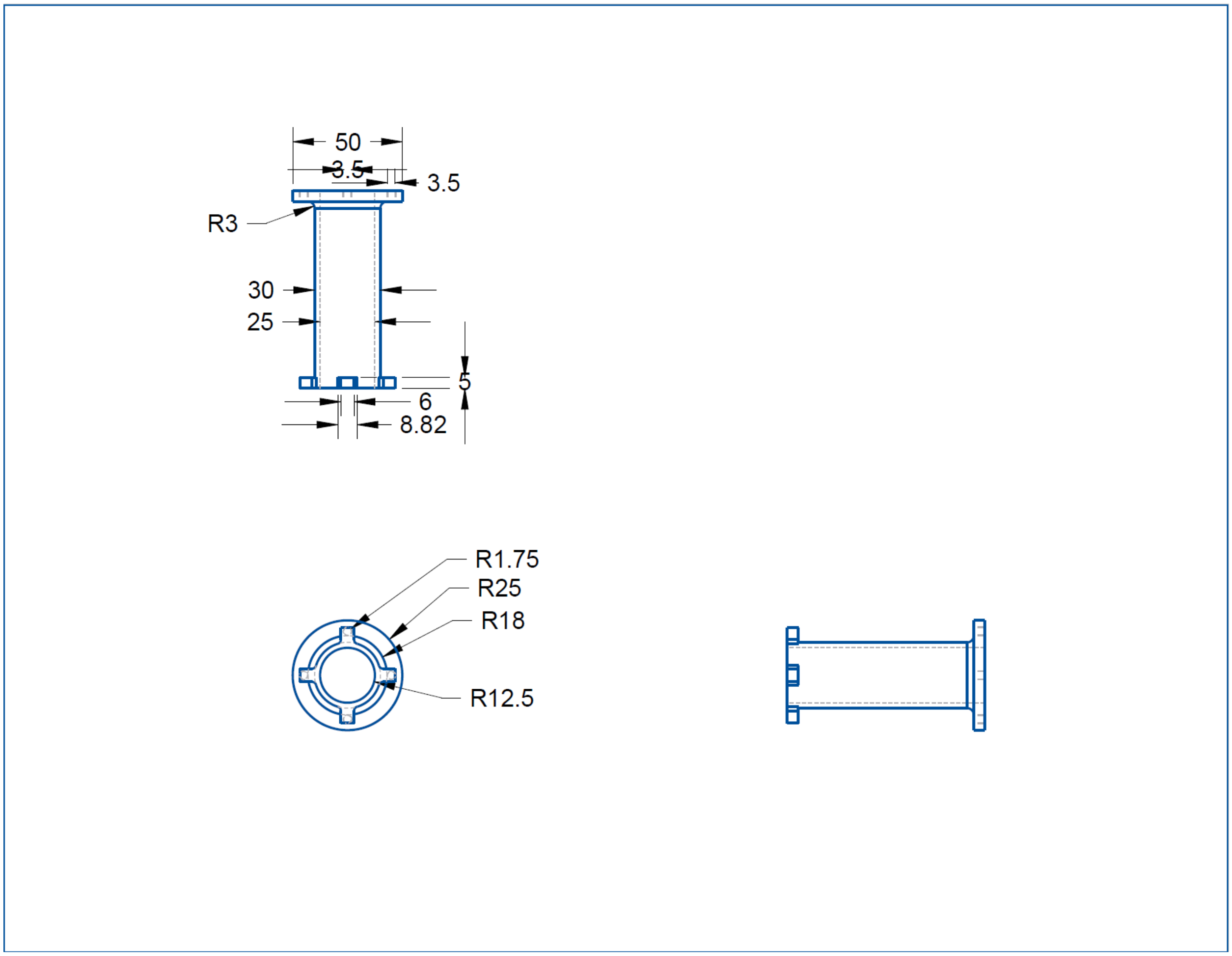


Fig C.3 Rotator Connector Mechanical Drawing

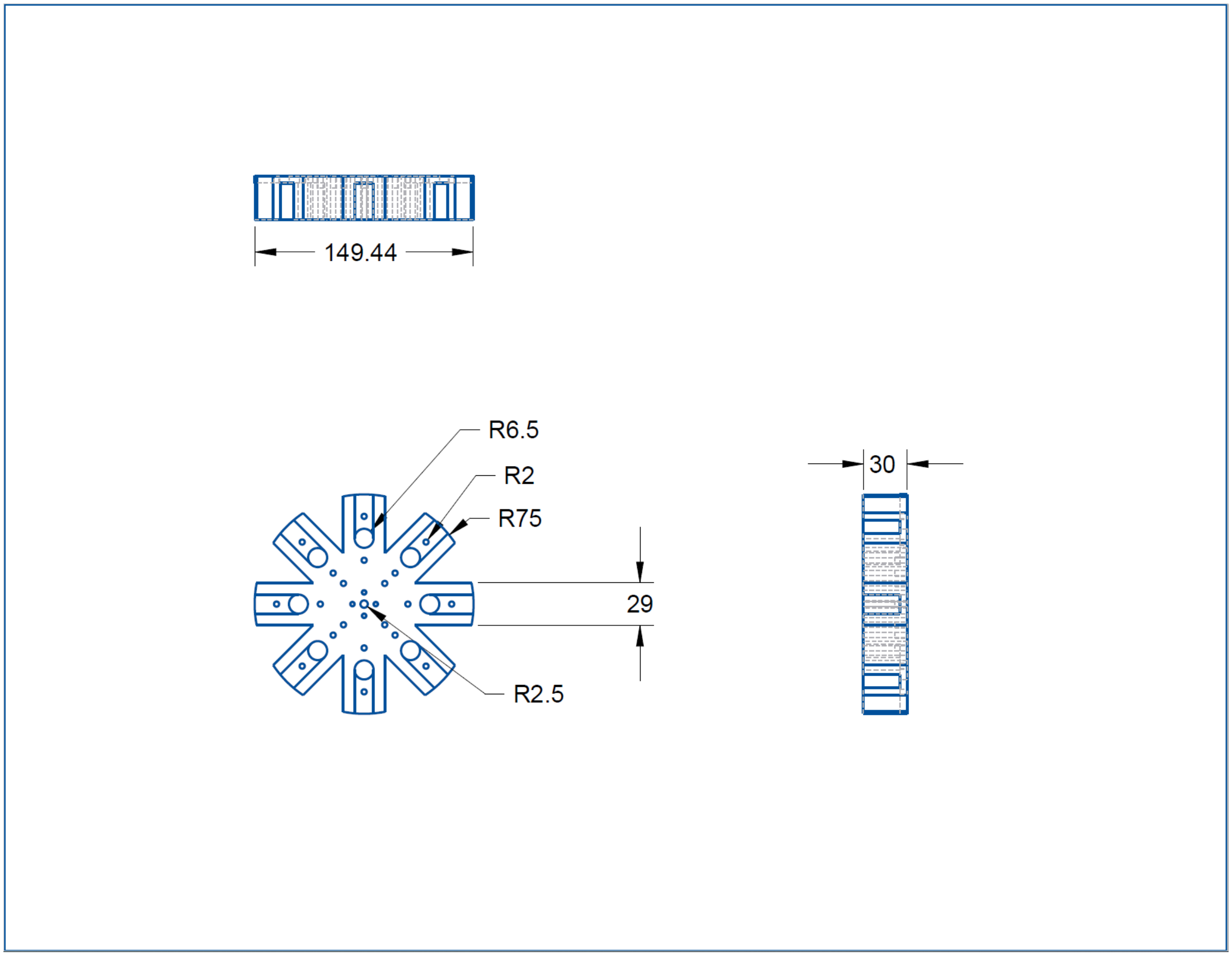


Fig C.4 Bottom Rotator Mechanical Drawing

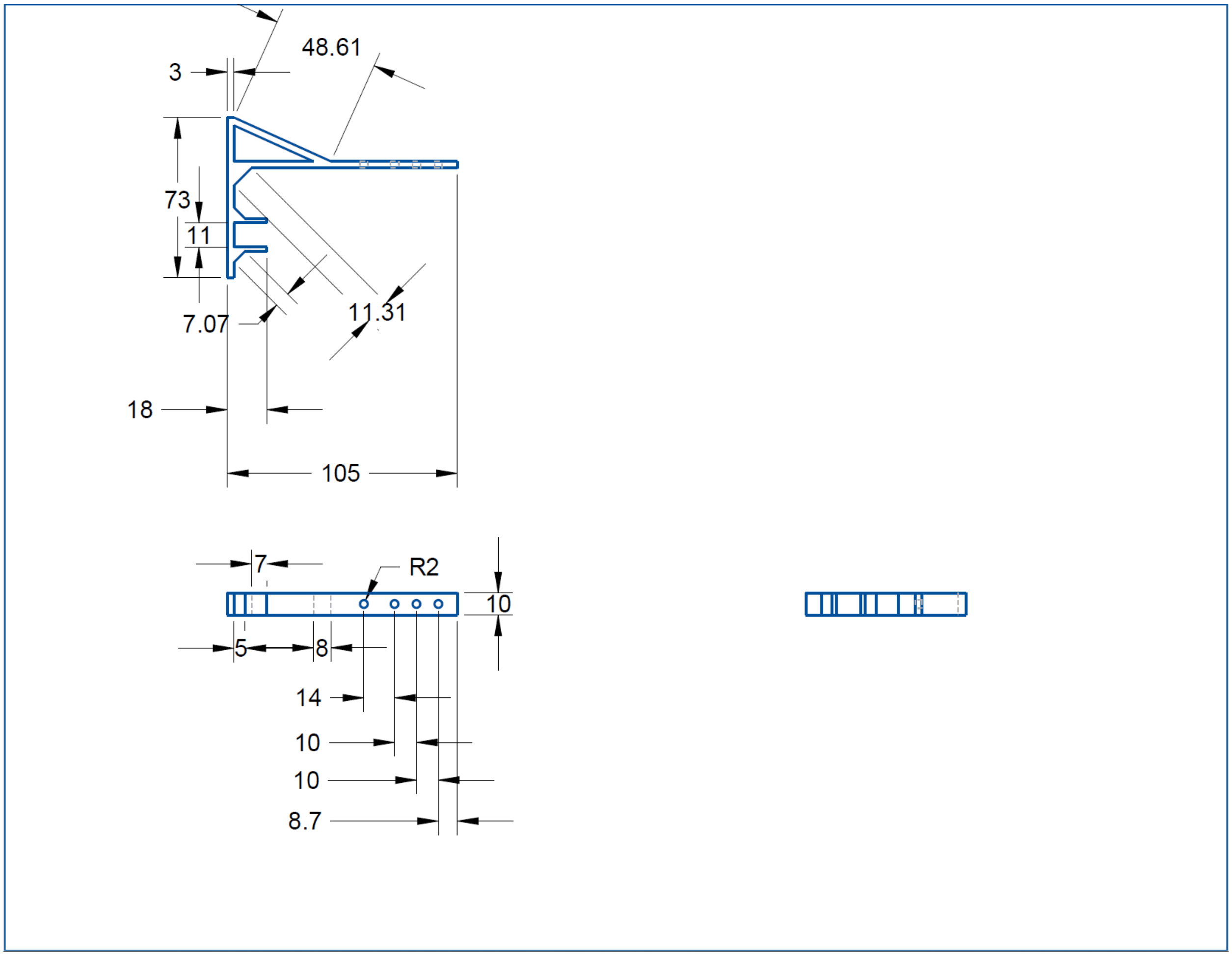


Fig C5 Sanitizer Arm Mechanical Drawing

Appendix D: Detailed Components Costs

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