COVID-19 Test Kit Distribution Machine

ECE 445, Final Report

By

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Abstract

COVID-19 is turning out to be a great challenge for humanity and there are many innovative ways coming out to combat it. Here at UIUC we use spit tests and a methodology that involves widespread testing that happens often. To supplement this system, our team developed the COVID 19 Spit Test Vending Machine. The machine is intended to be used by any organization that wants to dispense tests to a large population, namely governments or large corporations. The machine has authentication capabilities so it can link back specific tests to specific users for easy results management. The machines are cheap, can be easily deployed, and are designed to be used anywhere. We make improvements over the current system of setting up test locations in several ways: we are cheaper, take up less space, and allow more convenient access to tests with less hassle.

Contents

1. Introduction

1.1 Objective

In the last 6 months, everything changed and we now live in a new reality where a viral pandemic dictates the world in the form of Covid-19. One of the problems that people face in the pandemic is the issue of testing, namely in the United States. Many people in the scientific community have cited mass testing as a critical part of combating the pandemic and leaders are scrambling for a solution [1]. [2]. Usually to get tested a person must get the approval of a healthcare provider and go to a designated site: this presents ongoing problems. First, the location of the testing site may be a large distance from the person in need and results in inconvenience. This is especially true if the recipient has symptoms that render them unable to travel. People who have no personal vehicles may resort to using public transportation. This creates a high risk of them potentially infecting others and spreading the disease. Though mail-in test kits can rectify the need for transportation to a test site, that too also has a key problem: time. For Covid-19, time is of the essence and recipients of mail-in kits may need to wait days for their package to arrive. Including the return trip, time for processing, and other miscellaneous delays, the results become less relevant. Some communities, namely hard-hit counties and several cities, can suffer from backlogs, especially if not enough people are getting tested.

Our goal is to create a COVID Test Vending Machine that ultimately increases access to tests for more people which is critical to slowing or stopping the spread of COVID-19. The machine builds on the idea that originated here at University of Illinois at Urbana-Champaign: test early, test often, and maintain close to real-time information on the spread of the disease [2].

1.2 Background

In the current model here at University of Illinois at Urbana-Champaign, COVID-19 testing sites were set up and are used as centers for administering tests. The school is relying on students to test twice a week to maintain accurate case data. If this system is ultimately expanded, it is infeasible to locate them everywhere due to the costs and need for people to maintain those sites. Our solution would be to set up COVID-19 Test Dispensing machines in areas where testing may not always be available or in places where a full testing site cannot be set up to help deliver test kits in a quick and efficient manner. Part of our idea is that the kits would come with return postage for the test, so we can use existing infrastructure - the mail system - to ensure accessibility to our idea.

Our idea is intended primarily for governments and corporations large enough to have dedicated Corporate Campuses. It can be used by any organization that has to manage a lot of people and wants to securely and efficiently distribute COVID tests throughout a population. For corporations or other organizations that want to keep track of who is taking spit tests, we have an authentication system. In the context of our project this system is RFID. In the context of UIUC this system would be based on I-Cards. For a company like Walgreens, this system may be based on the IDs they issue to employees. This way a corporation can ensure that people are taking the tests and keep track of positive cases. We anticipate that governments would use the machine without the authentication subsystem. While there is a need to know who tests positive, requiring an ID is a barrier to entry for the machine.

1.3 Physical Design

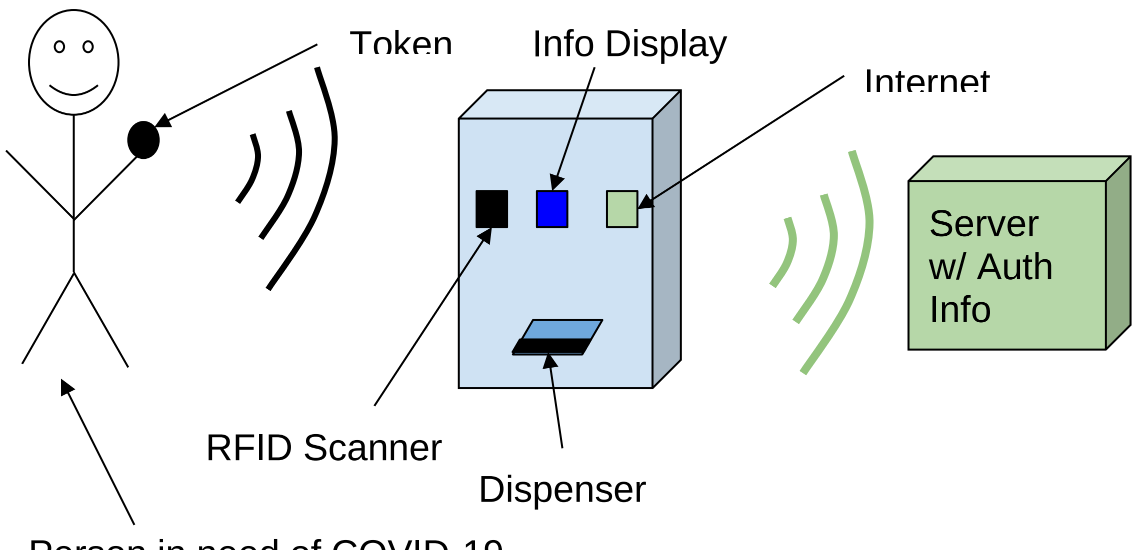

Figure 1: Visual of the Machine and Operation

1.4 High-Level Requirements

- Machine must be able to dispense 1 test kit upon 1 RFID being scanned and 1 authentication token confirmed. Each user can try to authenticate no more than 3 times.
- Machine has to be able to identify and link a test taker to the test kit for verification. This is also the mechanism that would allow the test taker to receive their results. The process should only take approximately 20 seconds if not less.
- Machine must be easy to use and accessible. The whole distribution process should take no more than 1 minute for each user.
- For the purposes of this project and scope, the final product machine must be able to carry at least 5 test kits and 10 at most.

2 Design

2.1 Block Diagram

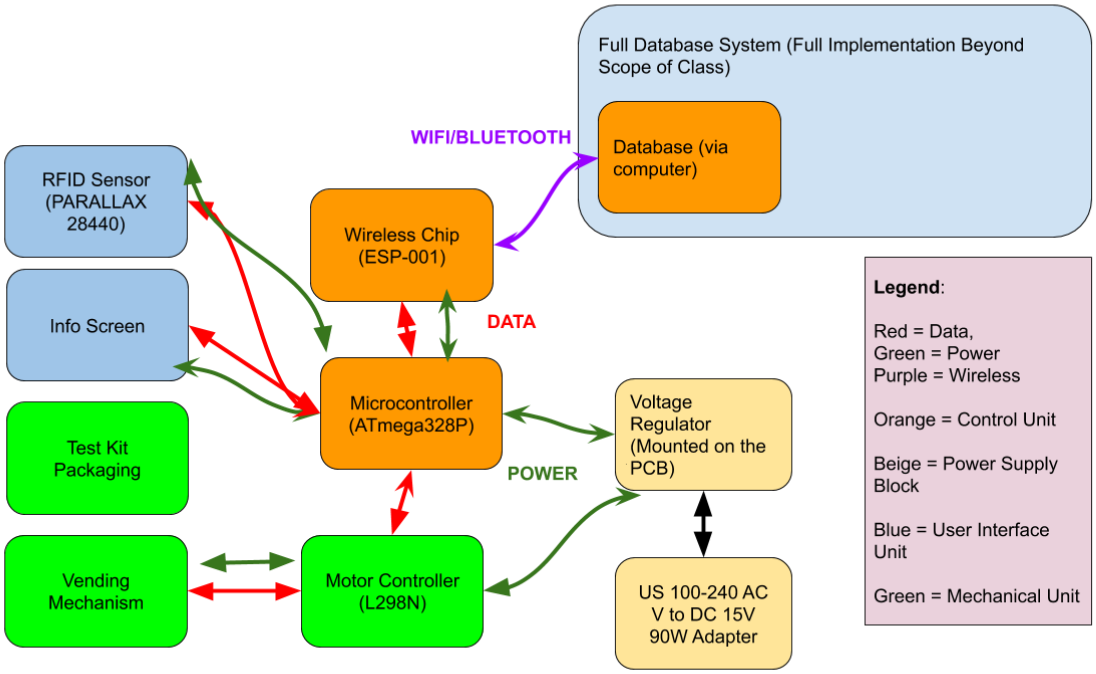

Figure 2: Component Block Diagram

2.2 Design Procedure and Details

2.2.1 Control Unit Subsystem

The microcontroller which acts as the center control unit was the first component determined by our group. We considered Raspberry PI and an Arduino board initially because we expected this project to be heavily based on software programming. However, after we digged deeper into the class, we chose to switch to a customized PCB because it would exclude unnecessary electrical components on Raspberry PI or Redboard and meet the course requirements. With this change, the ATmega328P-PU microcontroller was chosen due to strong familiarity with Arduino's programming interface, the wide-spread usage and availability of information pertaining to the microcontroller, and the power and capability of the chip being able to meet the needs of the project.

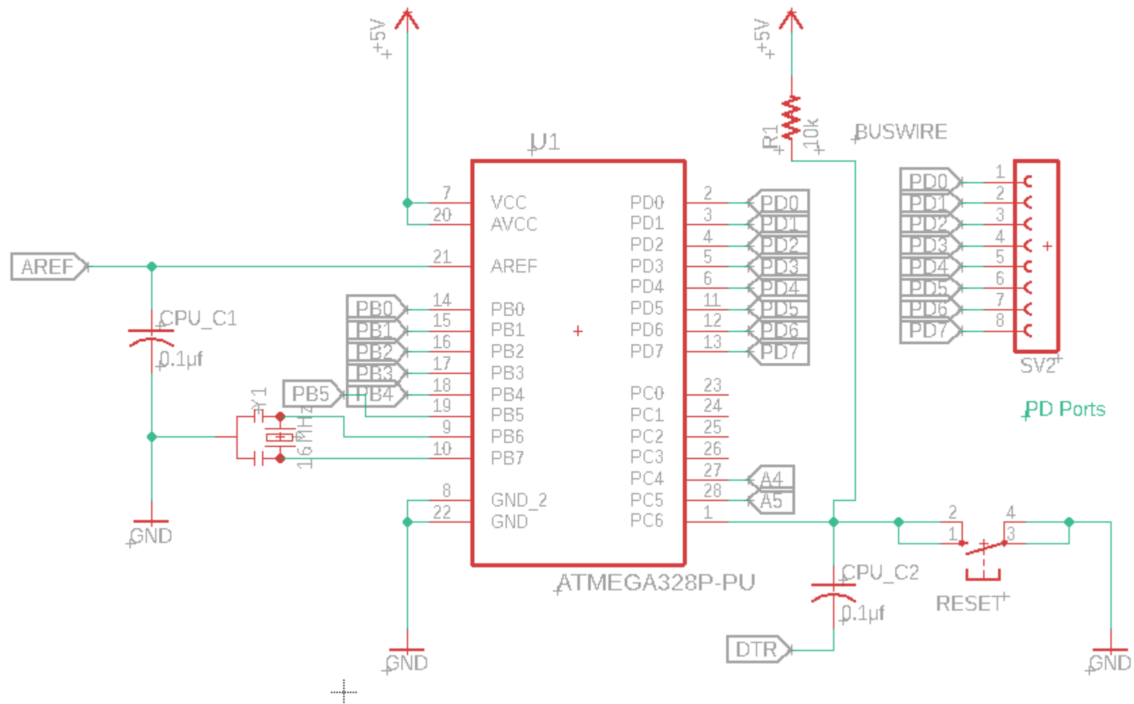

Figure 3: Schematic diagram of ATMega328-P-PU

The ESP-001 Wi-Fi Chip was chosen because we found that it fit our requirements and had a SOC that we could directly program with. Due to widespread availability and ease-of-use of the ESP-001, a standard serial interface was used for the ESP-001 to interface with the chip.

2.2.2 Power subsystem

Our power system consists of three primary components. We have the unit that supplies 12 V DC from the outlet AC. This voltage supplies the motor and motor controller. The PCB on the circuit converts theIt also gets converted to 5 V and 3.3V to supply various other components.

The AC to DC converter utilized in this project is a LEDMO 100/240V AC to DC 12V 10A 120W converter. An external AC to DC converter was utilized in our design due to the

The 12V DC to 5 V DC converter was designed using a Texas Instruments LM1117-5V converter. Using a DC port plug that was connected to the LEDMO, the converter would receive power directly from the system, and convert the power to the direct voltage. Figure 4 shows the layout of the converter and the required components needed. This converter was used to power the ATMega328P-PU chip and the PITTMAN motor’s 5V encoder.

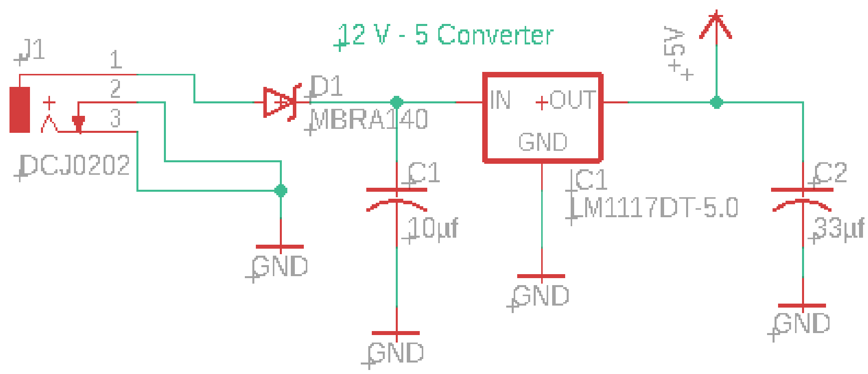

Figure 4: Schematic diagram of the 12 V to 5 V converter

The 5V DC to 3.3 V DC converter was designed using a Microchip Technology MIC5205-3.3YM5-TR converter, which was used to deliver the voltage required for the ESP-001 Wi-FI Chip. Figure 5 below shows the layout of the converter.

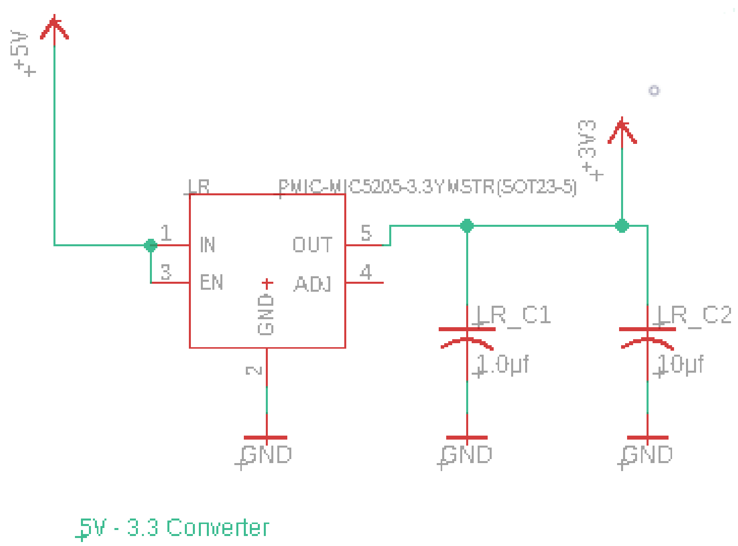

Figure 5: Schematic diagram of the 5V to 3.3 V converter

2.2.3 Mechanical subsystem

Our motor controller is a L298N motor controller with a typical interface that's controlled by the ATmega. It is being powered at 12 V by the AC/DC converter that functions as the power supply for the machine.

Our motor is a PITTMAN GM9413J820 motor with an Encoder attached to it. The Encoder sends signals back to the ATMEGA which allows the microcontroller to accurately turn the motor off. This particular motor for the built-in encoder and because we needed a motor powerful enough to to turn our spiral with all of the tubes in them.

The spiral we use is the same as any spiral you can find in a vending machine. We chose a spiral that was appropriately sized for our tubes and that could fit at least 5 of the tubes. We consulted with the machine shop on the approximate length of the spiral as we had to be mindful of the physical restraints they were dealing with. The spiral has a

2.2.4 User interface subsystem

We used the SunFounder 1602 Serial LCD Display to give feedback to the user about what's going on in the machine. The display will update if a valid RFID token is scanned in or if a result is returned from the server. It will tell the user if they have a valid or invalid token. It generally fulfils our requirements of having some feedback to the user for ease of use.

The Parallax RFID Read/Write Module is used to scan authentication from the users. The module operates on a standard serial port and is a low cost solution to reading or writing RFIDs. It scans RFIDs quickly, but is slightly inconsistent and at times may read in a blank RFID. There is code on the ATmega to manage this and the software implementation makes it easy.

2.3 Final Design Appearance

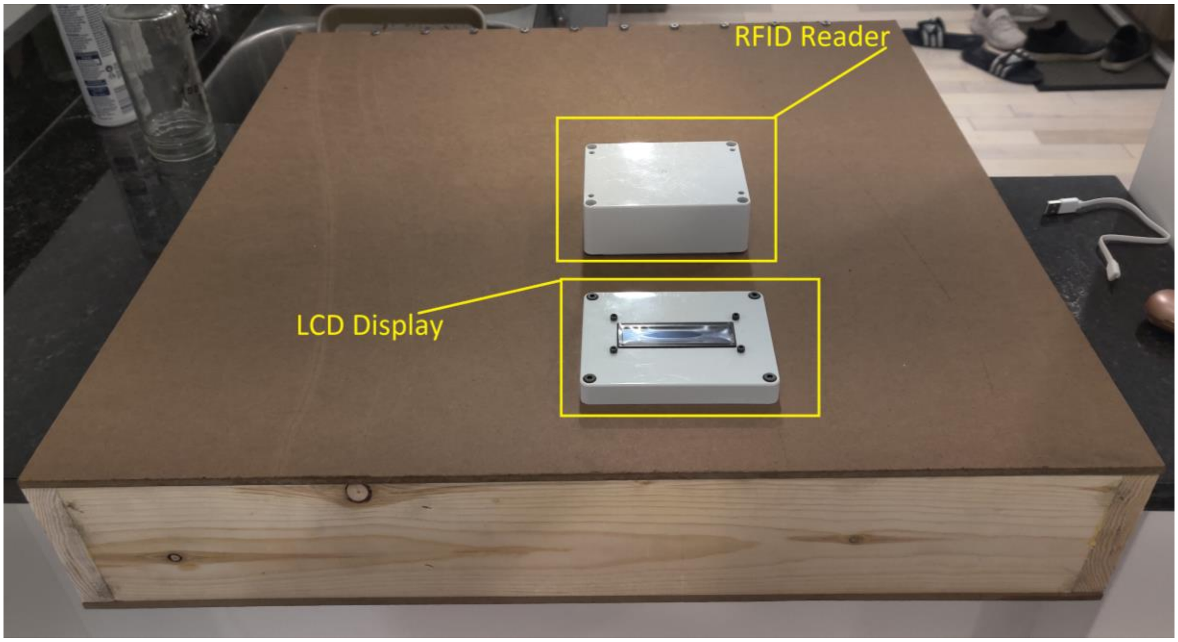

Figure 6: Outer view of the design

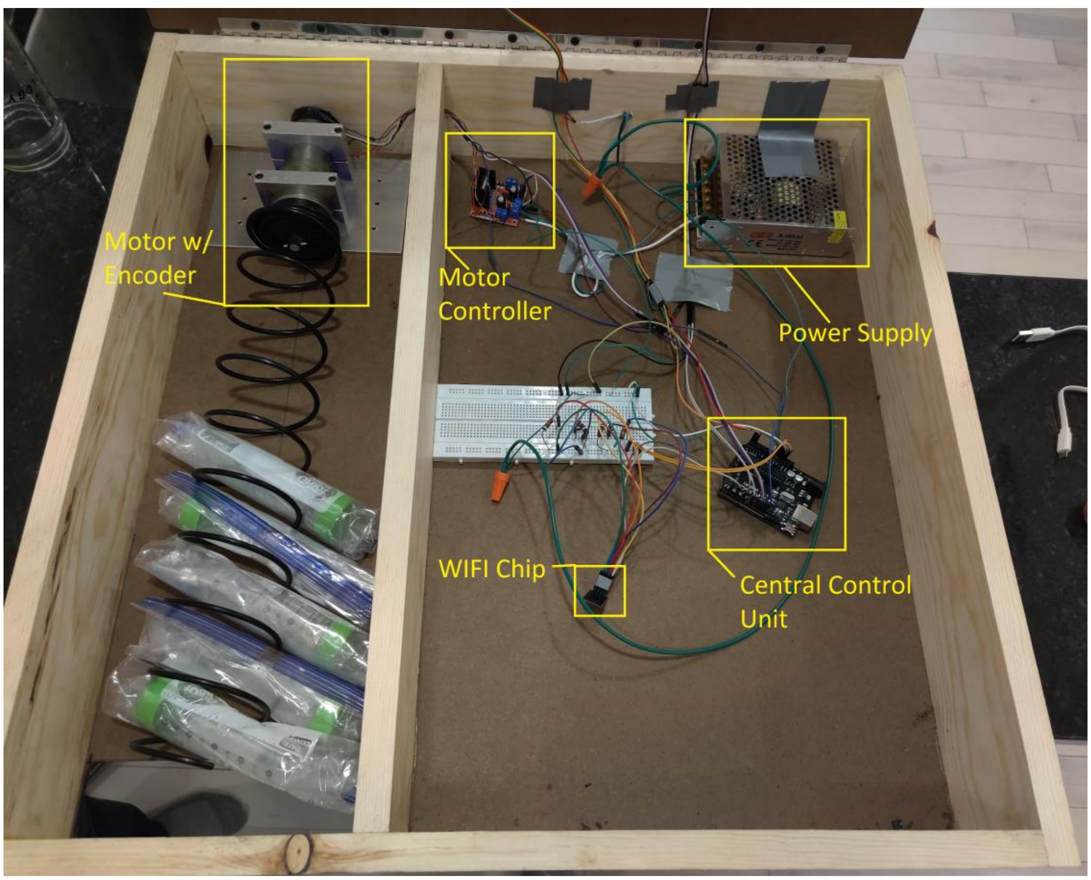

Figure 7: Inner view of the design

3. Verification

The requirements and verification table for the components can be found in Appendix A.

3.1 Power Supply Unit

The LEDMO power supply unit was verified by making sure that it could properly output the required 12 V needed for the motor controller and the PCB. This was done by measuring the output of it to the system via an oscilloscope.

For the LM117 and MIC5205 converters, the components were first simulated via LTSpice and to ensure that we would receive the proper output. Figure X below shows the LM117's simulated output, where a 12V input would still yield the calculated output of 5 V. The converters were tested manually on the PCB to ensure they could properly convert the power. The power components worked as our requirements had outlined.

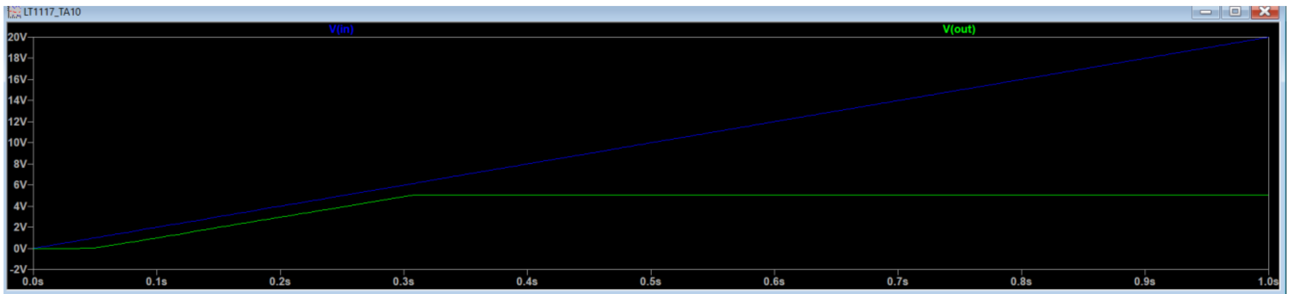

Figure 8: Simulation of the LM1117 Output Done In LTSpice

3.2 User Interface Unit

3.2.1 PARALLAX 28440 RFID Scanner

The Parallax 28440 RFID Scanner was tested by first programming the system to make sure that the RFID could be read. Using a Breakout Board, we ran code on the PARALLAX to make sure that the RFID tag we were using could be read successfully. The RFID scanner was tested in conjunction with the ESP-001, to make sure that the data on the RFID could be transferred over via the Wi-Fi chip. We were able to successfully get the RFID working.

3.2.2 LCD

To test the LCD, we attached the Sunfounder LCD to a Breakout Board to test it. We ran basic code on it to make sure that the LCD could print the intended RFID lines and display the status of the machine. The LCD worked as our requirements had outlined.

3.3 Control Unit

3.3.1 ATMega328P-PU Microcontroller

To ensure that the ATMega328P-PU Microcontroller would be able to run on our PCB, we attached the microcontroller on the breadboard and used a USB FTDI stick to upload a code into the microcontroller. This was done before the PCB was delivered to us to ensure that the code could be uploaded with no problem.

Unfortunately, even though we did this, we discovered that we were not able to upload the code onto the PCB. Attempts were made to debug the microcontroller, USB FTDI, and the PCB in an attempt to find out the cause of the error. Upon checking the microcontroller's pins, we had discovered that the ATMega's pins that were attached to the 16 MHZ crystal were shorted. This was complicated by the small size of the crystal, which had made soldering the crystal difficult. Although we attempted to re-solder and desolder the crystal to correct the error, we were not able to fix the upload error.

3.3.2 ESP-01 Wi-Fi Chip

To verify that the ESP-01 Wi-Fi chip could run, we set up a server in Java Springboot that could interface with the chip. Said chip was attached to a Breakout board to ensure that the code could run. We needed to verify that the Breakout Board, via the ESP-01, could be located and detected by the computer. The ESP-01 Wi-Fi chip was tested in conjunction with the We were able to meet the requirements, as we were able to get the breakout board to successfully communicate with the server setup in Springboot and ultimately the final project.

3.4 Mechanical Unit

3.4.1 Motor Controller (L298N)

To verify that the L298N motor controller could work, we set up a 12V input to the machine to see if it can be directly driven by such voltage input. In addition, we also attached active inputs to the motor controller's left and right enable pins to make sure both of them were working. We were successful in getting the output of the motor controller working correctly.

3.4.2 Vending Mechanism

To verify that the PITTMAN motor could work as intended, we would need to test out the timing and the position of the motor. As data for this particular motor model was unavailable, much of the values on the motor encoder, namely the pulses, had to be measured by hand in order to determine the necessary values needed to program the motor.

$$Encoder\ PPR = \frac{60\ seconds}{rpm} \times pulse\ per\ second$$

Figure 9: Equation for the PITTMAN Motor Encoder’s Pulses Per Revolution

Figure X shows the equation to determine the encoder’s pulse per revolution value. The pulses per revolution is the value required for the motor to complete one revolution. Time cannot be used as a reliable measurement as it fails to account for numerous factors in the system including friction, the weight and size of objects, and the stability of the current driven through the motor. The pulses per revolution needed to be measured by hand, which was done by running a motor and outputting its encoder pins to an oscilloscope.

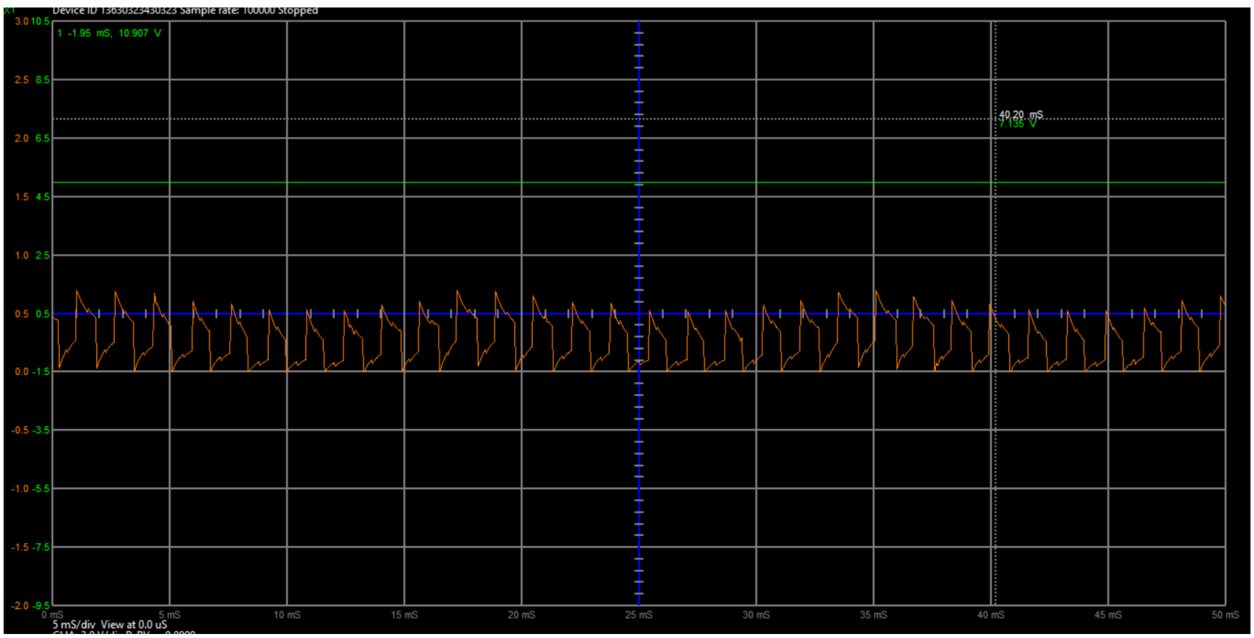

Figure 10: Output of the Encoder As Measured Through An Oscilloscope

Figure 10 shows the encoder’s output for the system, represented by the orange curve on the screen. Using calculations we were able to determine that there were 30 pulses in 50 mS (or 600 pulses in 1 second). In measuring the rotations per minute of the motor, we determined that the machine performed 30.6 rotations in a minute. By using the equation in Figure 9, we were able to determine that the total number of pulses needed was 1176 pulses per revolution. Dividing 360 degrees by 1176 yields that the motor turns .3 degrees per pulse. We were able to fulfill the requirements for the motor as intended, though sometimes we had to adjust the pulses in our code to make sure it could work.

3.5 Software

Our project design also included a software component whose full capability was not able to be implemented due to time and limitations of the course. The machine will have to communicate with a server so we can authenticate RFID tags and link up which label goes to which RFID. Since RFIDs are user specific, this is also the mechanism that will allow us to match test results to test takers.

If the semester was to go fully online, we can expect to fully implement this part of the project. Currently, our plan is to use Java's Spring Boot framework to set up a mysql database and RESTful api endpoints that can be queried by the microcontroller. This also involves writing some code that sits on the microcontroller to allow it to talk to the server. Raspberry Pi has the capability to run Python 3 on it so we can use this to run GET and POST requests.

Since the data we are transmitting is confidential - we do not want anyone but us to know which RFID corresponds to which test - we will need to use HTTPS or something of that nature to ensure our data is not being transmitted plain text across the internet. An extremely simplified version of this without security is possible on a local network for demo purposes. We were able to get the basic software side of this project to work in the final prototype.

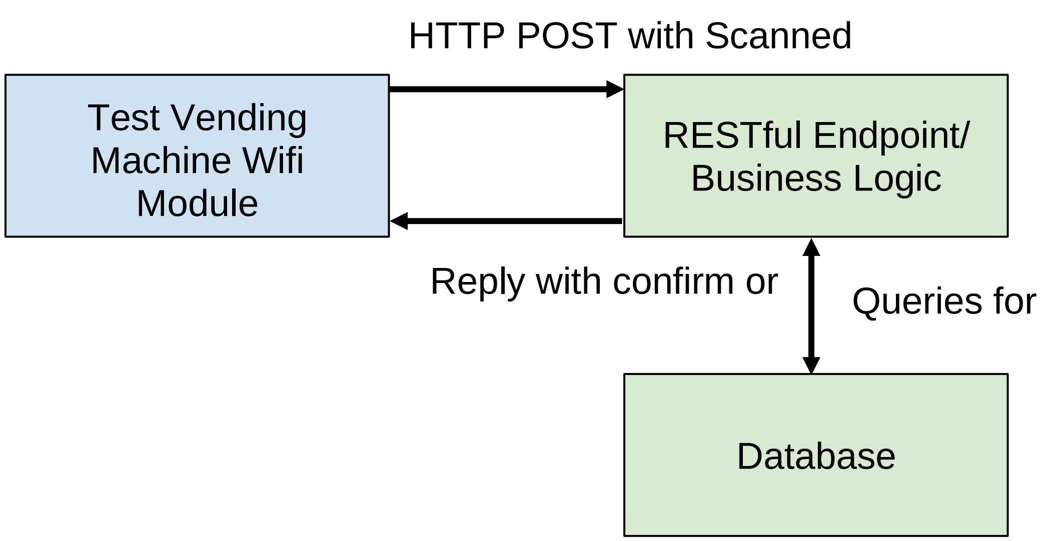

Figure 11: High-level Software Diagram

4. Cost

4.1 Labor

Only one person will be working on setting up the physical components of the machine. However, the labor cost will be calculated assuming three people are working on the project 6 hours a day, 5 days a week for 8 weeks and an hourly salary of $35 per person.

Total Labor Cost for each partner is:

Ideal salary (hourly rate) × actual hours spent × 2.5 (4.1)

Where the ideal salary is the hourly wage a team member expects to gain, actual hours spent is the total hours each partner expects to spend on this project.

By using formula (4.1), we get 14400 USD for each partner with an ideal salary being 30 USD per hour and time spent being 6 hours per day, 4 days per week and totally 8 weeks to complete the project.

4.2 Parts List

Table 1: Components list and price

Part	Cost($)	Parts needed	Sourced from
ATmega328P Microprocessor	2	1	Internet
Motor Controller (L298N)	7	1	Internet
120 V Plug	6.47	1	Internet
12 V Motor (Tower Pro MG996R)	11	1	Checkout from lab
LCD Screen (HD44780U)	8	1	Internet
RFID Sensor (PARALLAX 28440)	49.99	1	Checkout from lab
RFID Tag (World Titan Tag)	3	1	Checkout from lab
120 V/240 V (LEDMO 100V/240V -> 12 V DC)	16.99	1	Internet
.1 uF Ceramic Capacitors (C0805C104K5RAC7411)	.25	2	Internet
Reset Button (B3F-1000)	.28	1	Internet

12 V-> 5V Voltage Regulator (Texas Instruments LM1117DT-5.0)	1.48	1	Internet
5V-> 3V Voltage Regulator (MIC5205-3.3YM5)	.40	1	Internet
Diode (MBRA140)	.41	1	Internet
1 uF Ceramic Capacitors (C0805C105M8RACAUTO)	.31	1	Internet
10 uF Ceramic Capacitors (C0805X106K8RACAUTO)	.85	1	Internet
1x5 Female Pin Header	.44	1	Internet
1x6 Female Pin Header	.49	2	Internet
1x8 Female Pin Header	.59	1	Internet
2x5 Female Pin Header	.59	1	Internet
1x2 Female Pin Header	.29	1	Internet
Crystal 16MHZ (Murata Electronics CSTNE16M0V530000R0)	.27	1	Internet
DC Barrel Power Jack	.85	1	Internet
Total:	$112.20	24	

5. Conclusions

5.1 Accomplishment

With all parts integrated and software being tested, a prototype of our project can work as we expected in the end. A user can successfully use a verified RFID token and get one test tube at a time and it does not require more than one minute. An unverified RFID token is successfully denied. This process is based on connecting to a local server and a database via the Wi-Fi chip instead of doing a local logic control via the microcontroller alone. Therefore, in spite of the fact that our prototype has not reached to a proper scale an industry product should have since the storage of the machine is too small and database is not as complete as ones that companies already have for themselves, we succeeded in fulfilling all requirements and implementing expected functionality for the machine.

5.2 Challenges

During this special time of pandemic, there are several challenges that we had to overcome while working on the project. First, our group has two online students and only one in-person student. Therefore, we have to walk through all the work with online communication. A lot of work has to be divided into each person, and we need to conquer the problems first and then contact each other for more opinions. Second, a lot of components were purchased by each group member separately. Therefore, we can only test components one by one and then send them to our in-person student. All the tests over the whole circuit and system would have to depend on the only in-person student which increases a lot of extra work and difficulty to solve problems. Finally, our PCB debugging was another challenge for us. Before this class, all three of us were in a lack of PCB design knowledge. In addition, we encountered part of the circuit not functioning properly and it was really hard to debug and solve the issue since we have to test from pin to pin because of lack of experience.

5.3 Ethics

Due to privacy and ethical concerns, we have to keep the authentication data confidential as medical information falls under the Health Insurance Portability and Accountability Act (HIPAA) and should be handled with the highest degree of care. HIPAA maintains that test takers medical information and records must be kept under confidentiality and cannot be accessed without the consent of the individuals involved [6]. Because of this regulation, we have to provide a secure and private way for test takers to access their results.

5.4 Future Expectations

We also expect a more complete design for this project before it can become a weapon that the government, schools and companies can use to deal with pandemic. A larger size of storage, an software App that can act as a health care record with a more useful and practical database, or even a direct integration of the sample testing machine that can return the result of the test at the scene can all be the future potential which makes the project more powerful and useful. With help of our project, a lot of society entities can re-open during the pandemic and test all workers with higher efficiency and control the virus spread more effectively. And more people’s lives can be saved without the devastating damage to the economy which might hurt some people even more than the virus.

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Appendix A: Requirements & Verification Table

Table 2: Components Requirement and Verification Table

Part:	Requirements	Verification	Results (Y/N)
Parallax Scanner	1. The RFID Scanner must be placed in a proximity where it can read verification from a user. 2. The RFID Scanner must be able read the information from the identification correctly.	1. Measure the distance of the RFID scanner's proximity and verify that certain physical objects do not block or interfere with its reading. 2. A. Program the ATMEGA328 PPU to read data off a card scanned from the RFID B. Via its internet connection, the machine will send the code that is uploaded from the RFID scanner to the database it is connected to. C. Review the data and verify that the database has received the identification.	Y
LEDMO 100/240 V -> 12 V 10A Power Unit	1. The Power Supply must be able to safely provide 12 V +- .5 V and 5V +- .5 V separately at the same time.	1. Verify that the power supply provided matches the intended values via an oscilloscope.	Y
LCD	1. The LCD must be able to show the status of the machine including the token identification.	1. Within the code that is run on the microprocessor, program checks are designed to change	Y

		the Info Display to show which state the machine is running in.	
ESP-001 Wi-Fi Chip	1. The Wi-Fi Chip must be able to connect with a local server which is no more than 12 feet remotely. 2. The Wi-Fi Chip must be able to receive and broadcast information. 3. The Wi-Fi Chip must receive a 3.3 V intake, per device information.	1. Make sure that the local server can detect the machine wirelessly and generate a stable connection. 2. Use a PC to send code to the machine and also let the machine generate a fixed test signal to the PC and see if both can work. 3. Create the voltage regulator to regulate power coming from the PCB to that range.	Y
ATMEGA328-PPU	1. The microcontroller must be able to run the code needed to operate the machine. 2. The processor must be capable of running constantly. 3. Must operate at 5 V input.	1. The code will be implemented and read via a USB FTDI implemented on the PCB. 2. Run the chip with testing codes to make sure no failure occurs. 3. Use a multimeter to test input voltage.	N for 1 and 2, Y for 3
L298N Motor Controller	1. The motor controller must be able to take in the 12 V as intended 2. The motor controller must be able to keep stable	1. Using an oscilloscope, check to make sure that the motor controller is receiving the 12 V. 2. Measure the responsiveness time	Y

	rotation speed.	between the microcontroller and the motor controller	
PITTMAN MOTOR	1. The vending mechanism must be able to dispense only one test kit at a time.	1. Check the timing of the motor and operation for the spiral to dispense at least one test kit. This will be dependent on many factors: A. The size of the test kits when dispensed. B. The speed and power of the motor C. The response time between the motor controller (including from the microprocessor) to the motor.	Y
Test-Kits	1. The package should be held in a bag. 2. The package should contain a test tube for spit.	1. Make sure the vending coil can hold the kits.	Y

Appendix B: Printed Circuit Board