COVID-19 Test Kit Distribution Machine

ECE 445 Design Document

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10/01/20

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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 rural areas where residents may have to travel longer distances to get medical approval then another longer distance to a testing facility. All of these trips would render someone more exposed, so decreasing their travel distance would lower the barrier for getting a test and make people safer while they are getting one. In our eyes, there is a great need for such a machine.

1.3 Physical Design

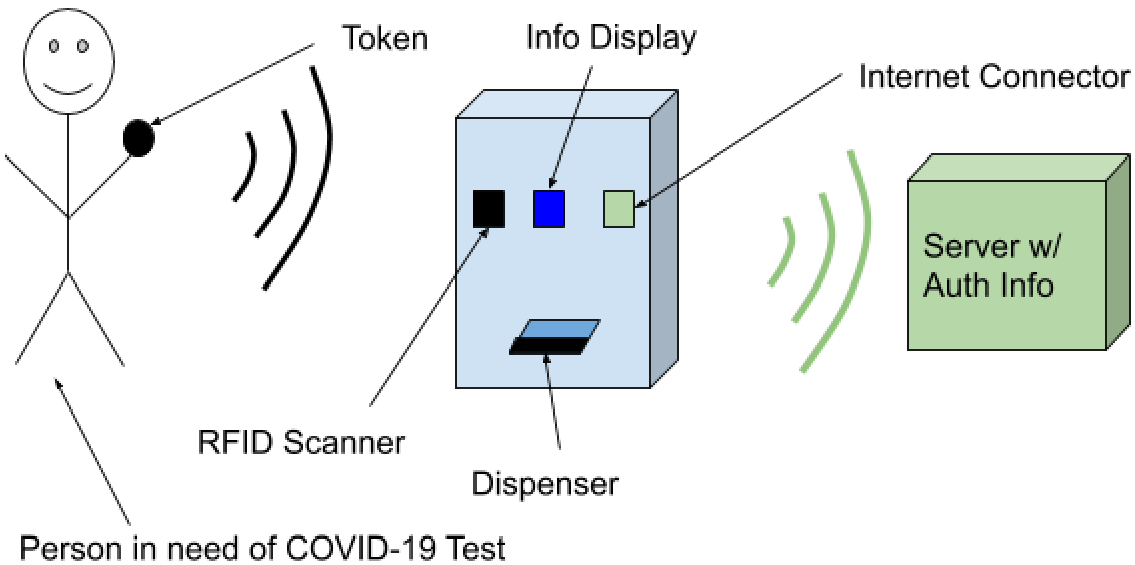

Figure 1: Visual of the Machine and Operation

1.4 High-Level Requirements

- Machine must be able to dispense a test kit upon an RFID being scanned and an authentication token confirmed. Each user can try to authenticate no more than three 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 twenty seconds if not less.
- Machine must be easy to use and accessible. The whole distribution process should take no more than one minute for each user.
- For the purposes of this project and scope, the final product machine must be able to carry at least five test kits.

2 Design

2.1 Diagrams

2.1.1 Block Diagram

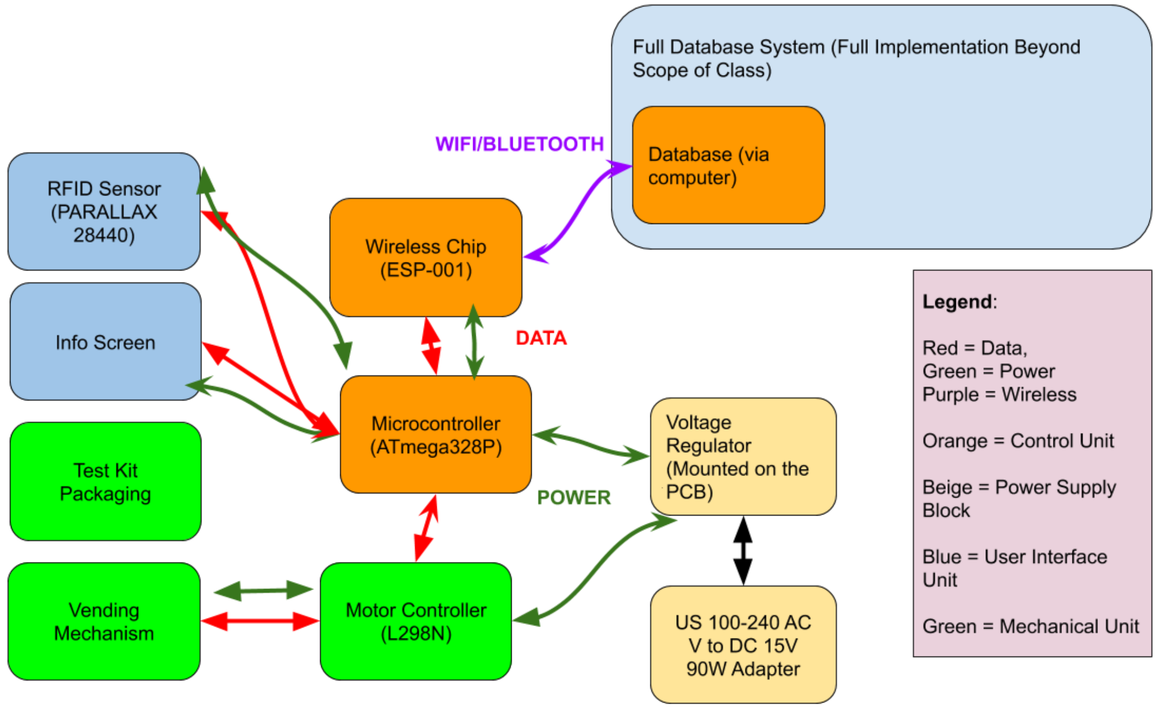

Figure 2: Component Block Diagram

2.1.2 Flow Chart

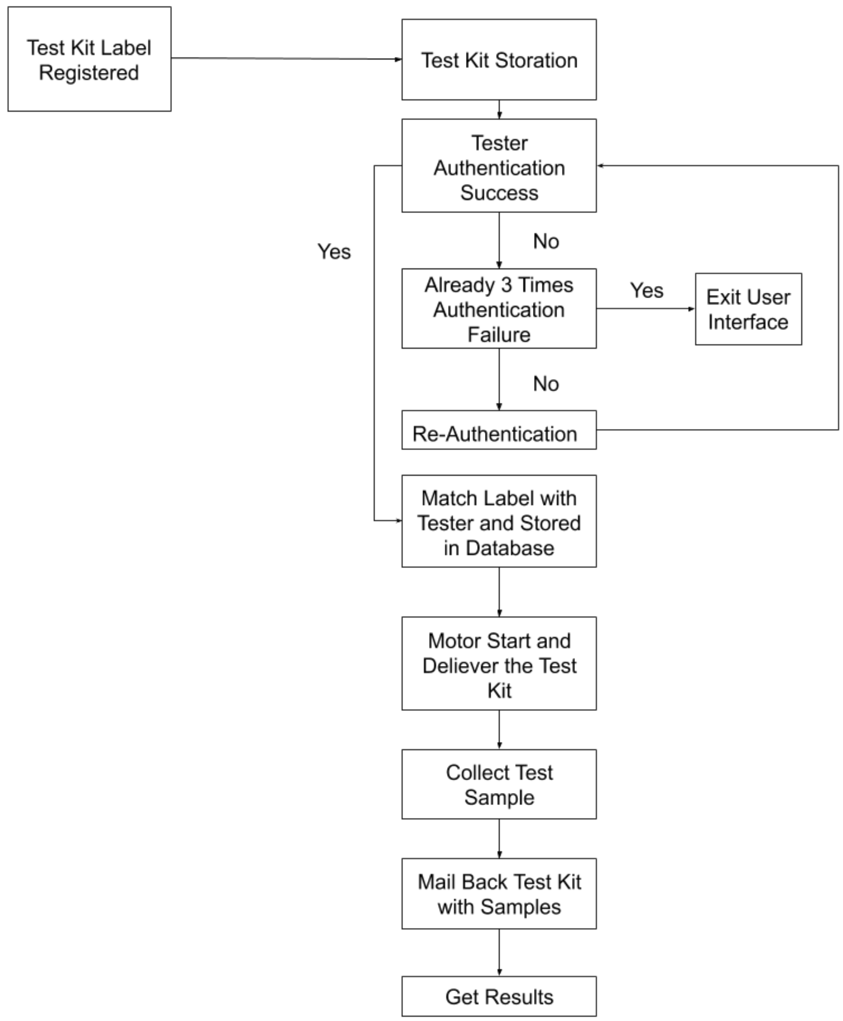

Figure 2: Testing Kit Distribution Flow Chart

2.2 Power Supply Block

2.2.1: 120 V Plug - The machine is intended to be plugged into an outlet 24/7. For the plug, we intend to use an AC/DC supply to provide 12 V and 5 V for the various components of the machine. The mechanical unit of the machine, which consists of the motor controller and the vending mechanism, will utilize the 12 V. The control unit, which consists of the microcontroller, wi-fi chip, will utilize the 5 V. In order to properly control the separate voltages, we will utilize a voltage regulator.

Requirement:	**Verification:**
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.

2.3 User Interaction Unit

2.3.1: RFID Scanner (PARALLAX 28440) - The main way for users to allow the machine to verify them. For our intended design, the user will carry a form of authentication that will allow them to be verified. In the context of the University of Illinois, a form of authentication would be an I-Card. For the purposes of this project, we have decided to use the RFID as the main method of verification. The scanner should be short range so passersby cannot accidentally activate the machine. The machine does not need the capability to sense test takers from more than a couple inches.

Requirement:	**Verification:**
1. The RFD 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 Raspberry Pi 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.

2.3.2: Info Display - The machine will use a display to notify test takers if their RFID is accepted or not and to show the current status of the machine. Displaying information to the intended user is a necessity to make the machine easy to use.

Requirement:	**Verification:**
1. The Info Display must be able to show the status of the machine. 2. The Info Display must follow the correct working process to guide testers.	1. Within the code that is run on the microprocessor, program checks are designed to change the Info Display to show which state the machine is running in. 2. Let a user completely follow the guide on the Display and see if he/she can finish the collecting process successfully.

2.4 Control Unit

2.4.1: ATMega328P Microcontroller. - The microcontroller, which will be mounted on the PCB itself, will be responsible for operating the machine and carry the code needed to operate the functions. Its high speed, various applications, and heavy documentation makes it an ideal chip to use to operate the machine. The 1 MIPS per MHz the microprocessor also achieves a balance between power and processing speed for the machine.

Requirement:	**Verification:**
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. 4. The time of responsiveness between the microcontroller and the various components must take no less than 5 ms.	1. The code will be implemented and read from a SD Card reader that will be implemented on the PCB. The design may not need a SD reader if the code can fit onto the ATMega's internal memory of 32kb. 2. Run the chip with testing codes to make sure no failure occurs. 3. Use a multimeter to test input voltage. 4. Verify the speed of the chip via recording time spent by doing a large-quantity mathematical calculation.

2.4.2: Wi-Fi Chip (ESP8266 ESP-01) - A self-contained system-on-chip (SoC), this widely-used variant of the ESP8266 allows the microprocessor to connect to wireless internet, which is necessary for maintaining communication between it and the database. It receives verification tokens through this chip as well as transmit the user's identification with the matched test kit to a mother database overseeing the machine. The low-cost, compact, yet powerful chip is a must for the machine.

Requirement:	**Verification:**
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.

2.5 Mechanical Unit

2.5.1: Motor Controller (L298N): This controller is responsible for supplying the power needed to operate the spiral vending mechanism that will be used to acquire the test kits. We determined that the motor controller needs to be operated at least 12 V in order to operate the motor needed for the machine. The device

Requirement:	**Verification:**
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 rotation speed.	1. Using an oscilloscope, check to make sure that the motor controller is receiving the 12 V. 2. Measure the responsiveness time between the microcontroller and the

2.5.2: Vending Mechanism: This arm will be responsible for fetching the test kit for the user. The vending mechanism utilized by the machine is designed to be simple. We currently plan to utilize a traditional vending machine spiral that is powered by a 12 V motor. The mechanism spiral needs to be able to house the packages between the spaces in its structure.

Requirement:	**Verification:**
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. The size of the test kits stowed in the vending mechanism must be determined early as to ensure the mechanism (and the rest of the machine) can be designed with that in mind.

2.5.3 Test Tube Packages: This will be what the vending machine dispenses.

Requirement	Verification
1. The package should be held in a bag. 2. The package should contain a test tube for spit. 3. The package should contain pre-paid return postage.	1. Manually check if the package contains required items.

2.6 Software

Our project design includes a software component that may be out of the scope of this semester to actually implement due to time constraints. 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.

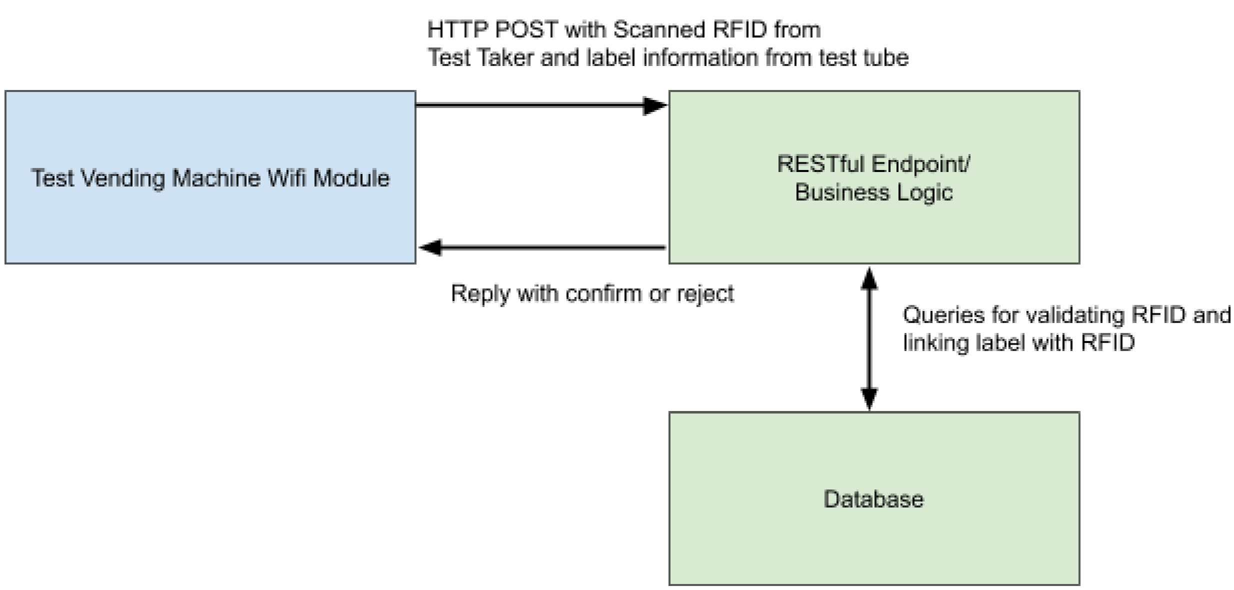

Figure 4. High-level Software Diagram

2.7 Risk Analysis

The extraordinary nature of this semester presents a unique challenge to construct a machine of this caliber. As two members out of the three will not be able to work hands-on and must conduct things remotely, we feel that the mechanical block will be the trickiest part to create this semester.

The switch to online instruction benefits the software and programming side of the project, as they can be safely done without much in-person work in a lab/workshop setting. However, the hardware block requires full construction and the need for in-person supervision as all those materials needed to construct the block must be built by hand. In particular, the Vending Mechanism component of the project requires direct in-person interaction and trial-and-error to ensure that the components can work together as intended.

2.8 Tolerance Analysis

The motor controller will be the component that requires a tolerance analysis because of its risk of failure. On one hand, the motor controller must move the vending mechanism which will carry and precisely drop one test kit for the recipient. It will only allow a tiny error on the power and activation time for the mechanical component to move and stop at the correct time and position. The spiral have to spin from around 250 degrees to 360+250 degrees to make sure one time delivery success(250 is to completely release the product but it will depend on if our box bottom will be out of the inner circle of the spiral, another 250 is for out spinning which could happen less possibly due to large error range). This means for 5 times, we can tolerate a -(360-250)/5 = -22 degrees and a + 250/5=50 degrees error (-22 to +50 degrees) for each time spin.

We calculate that each package weighs 0.8 ounces and we estimate the coil to weigh 1 lb. Our goal is to vend 5 packages for demo purposes, so the total weight we must move is:

.8 oz = .05 lbs
(.05 lbs/package * 5 packages) + 1 lb = 1.25 lbs

Our coil is going to be roughly 30 inches and the vending should take no more than 5 seconds. We need to push a 1.25 lb object over 30 inches over 5 seconds, so the power we need is 7.5(lb x in / second). We need an appropriately rated motor.

Also, the motor controller must have stable current and voltage to ensure an almost-perfect stable speed so that the test kit will not be damaged during the delivering process.

2.9 Covid-19 Contingency Plan

To account for the circumstances, we have already planned out the final design of the hardware stack to be as simple as possible in order to achieve doability with one in-person team member. In the event that Covid forces all classes online, we plan to expand the software side of the project while maintaining the simplicity of the hardware stack project. Our on-campus person is confident that we can get together a simple wooden chassis even without the help of the ECE Machine Shop.

An expansion of the software stack would incorporate an I-Card verification system and a database capable of handling at least 50 vending machines. We can emulate a vending machine in software fairly easily by querying the endpoint as many times as a vending machine would.

The Safer Illinois App is also an open source project on GitHub. Part of the software stack expansion would be to fully incorporate our database system into the Safer Illinois App. This would mean that we could create a vending machine tab on the app and be able to display to the user the label that they are associated with.

3 Cost

3.1 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: $35/hr * 6 hrs * 4 days * 3 people * 8 weeks = $20160 USD

3.2 Parts List

Part	**Cost:**	**Parts needed:**	**Sourced from**
ATmega328P Microprocessor	$2	1	Internet
Motor Controller (L298N)	$7	1	Internet

120 V Plug	$20	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
Total:	$100.99	7	

4 Schedule

Week (Mondays)	Danny (in-person)	Brian (online)	Richard (online)
October 5	Begin PCB design	Design basic chassis and finalize vending mechanism	Begin PCB design with breadboarding testing.
October 12 (first round orders due the 15th)	Begin breadboarding PCB design; Continue designing	Review PCB design and use CAD to begin working on the general structure; send designs to the PCB. Beginning working on power block	Review PCB design
October 19	Continue designing	Begin sending designs for components to in-person team member; finalize ordering components	Review components matching between PCB and other components.
October 26 (last round PCB orders due the 29th)	Finalize PCB design	Finalize power components; review design to see if anything must be changed.	Finalize working logic of machine, begin code design for working process
November 2	Set up demo server and endpoints	Finalize mechanical block; review design to see if anything needs to be changed.	Server backend implementation
November 9 (Mock Demo Week - sub systems should be done)	Get demo server and microcontroller to talk to each other	Review the design, begin bug fixes, finalize the control unit.	User interface design, help with server side
November 16	Bug fix/continue work from prev week; Finalize microcontroller-server connection	Work on bug fixes, finalize the hardware stack of the prototype.	Finalize code design with bug fix and system check

November 23	Put together mock test kits (tube+bag)	Work on final paper	Begin working on final paper; help with put things together
November 30	Work on final paper	Week of final presentations	Final presentations, Work on final paper
December 7	Finalize paper Submit lab notebooks	Finalize paper Submit lab notebooks	Finalize paper Submit lab notebooks

5 Safety and Ethics

Part of both the ACM and IEEE code of ethics is to avoid harm [3], [4]. To follow this we need to minimize the chance of the machine as a disease vector. As this machine would be potentially interacted with by people who are both positive and negative for COVID-19, there is an obvious cause for concern. In order to rectify this, we need to minimize time the machine has to be touched. The RFID would significantly assist as verification could be done without needing to touch the machine itself. The dispensation of the package could be similarly touchless with the user only needing to grab the package itself when the machine dispenses it.

Another simple and easy solution would be to attach a hand sanitizer and disinfectant wipes to the machine. This way people could wipe down the machines themselves if they touched it and would use sanitizer as needed. As any vending machine requires a person to come and restock it, we can guarantee that our machine is sanitized at least once per day or so depending on volume. The current practice at University Test Centers is to provide hand sanitizer to test takers, and we think that attaching a sanitizer dispenser would be a good bare minimum bar to meet.

Sending the tubes over mail could also be a disease vector if the tubes were to spill open in the mail. We have attempted to anticipate this issue in our design since the kits should also provide return postage, so we will be able to control the type of packaging the tubes are returned in. We attempted to find information on 23&Me or AncestryDNA spit kits spilling in the mail, but we were unable to find any information on this. We think it is safe to assume that it will happen rarely if ever, and we can make our tubes and packaging more heavy duty as a preventative measure. Not only were we unable to find information on these types of tubes spilling, but early clinical studies show that there is very little infectious form of the virus present in saliva [5]. This means that if a spill were to occur there would be little to no negative impacts.

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.

References

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