PillSafe Final Report

Team 17

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1 Introduction

1.1 Problem

The opioid epidemic has been a rising issue, and although there are some efforts to decrease this, none have been very successful. There needs to be a stricter way of informing a doctor when a patient is susceptible to addiction without taking away complete control from them. A pill cap that counts the number of pills coming from the box and sends that data to the doctor is a solution that could help greatly with this epidemic. The current design is big and simple, and we want to improve upon this by optimizing the size and functionality.

1.2 Solution

A smart medication pillbox with a built in mechanical component, wireless transmission capabilities, and an accompanying app to track the number of pills taken out of the pill box. To ensure accurate measurements of the number of pills taken out, we use a mechanical pill dispenser system to limit only one pill to be taken out at a time.

A small laser will be pointing across the opening of the pill box where pills can exit, while a photoresistor is placed on the other side of the opening, receiving the laser. The laser is blocked whenever a pill is taken out, which is sensed via the photoresistor, and this data is stored, alongside being transmitted wirelessly to a smartphone app.

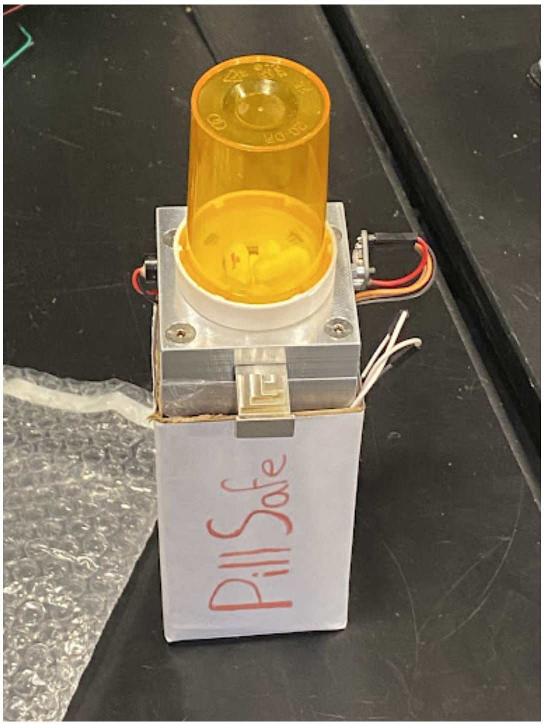


Figure 1: Final Product

1.3 High-Level Requirements List

1. Able to accurately count the number of pills dispensed
2. Able to track pill usage over time with timestamps
3. Allow only one pill to be dispensed at a time, while being easy to use
4. Have a width and depth around size of pill bottle cap

1.4 Block Diagram

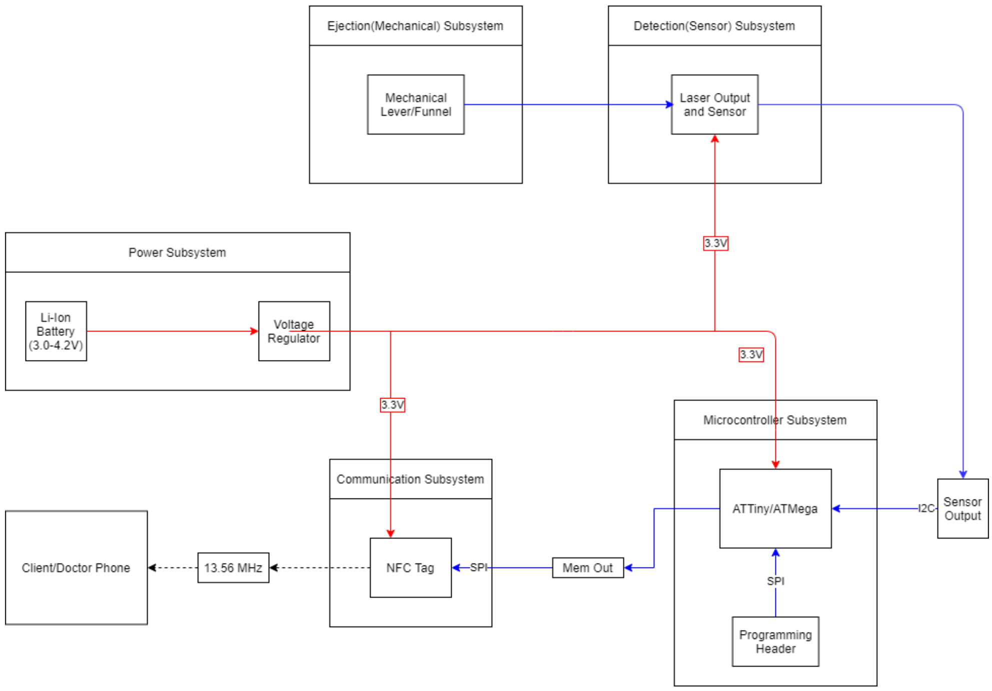


Figure 2: High Level Block Diagram

1.5 Block Descriptions

1. Power Subsystem: Battery with charging port that powers the entire circuit
2. Mechanical Subsystem: dispenses pills when user pulls lever
3. Sensor Subsystem: Detects pills being dispensed
4. Communication Subsystem: Allows communication of data stored in device to smartphone app
5. Microcontroller Subsystem: Convert sensor data and send to Communication Subsystem

1.6 Block Requirements

1. Power Subsystem:
    (a) Maintain stable 3.3 V output
    (b) Reliably recharge without compromising battery life
2. Mechanical Subsystem:
    (a) ensure only one pill is dispensed at a time, with a success rate of 90
3. Sensor Subsystem:
    (a) Accurately sense number of pills dispensed, with an accuracy of 90
4. Communication Subsystem:
    (a) Maintain fast communication between device and app, under 1 s for all transmissions
5. Microcontroller Subsystem:
    (a) Able to consistently translate sensor data into app-interpretable data

1.7 Block Level Changes

Our blocks remained the same throughout the design and implementation process, with the only major change being to use an NFC tag instead of a Bluetooth/WiFi module. This helped drastically reduce power consumption, as the NFC tag can be powered by the smartphone pulse, as well as size down the project.

2 Design

2.1 Design Procedure

2.1.1 Power Subsystem

The main objective of this subsystem is to provide the correct voltage to other subsystems as well as provide an easy way for the user to recharge this device. This was achieved by using a voltage regulator, a charge controller, and a micro-USB input. After calculating how much power the other subsystems would draw and determining how long we wanted our battery to last, we chose a 3.7V 100mAh battery.
The maximum power of the laser = Voltage * Current = 5 * 40mA = 200mAh
The maximum power of light sensor = Voltage * Current = 3.3 * 100mA = 330mAh
The total maximum power consumption is = 200 + 330 = 530 mAh
100/530 = 0.1887 hours = 11.321 minutes
Using a 100mAh battery means that our battery will last 11.321 minutes. In our original design, we wanted to have our power automatically turn on when the mechanical lever was moved, and then turn off after 30 seconds. With this in mind, our battery would have lasted at least a week. However, due to time/difficulty we were not able to implement this.

2.1.2 Mechanical Subsystem

The main objective of this subsystem is to ensure that only one pill falls out at a time. To do this, we found the following render online [1]:

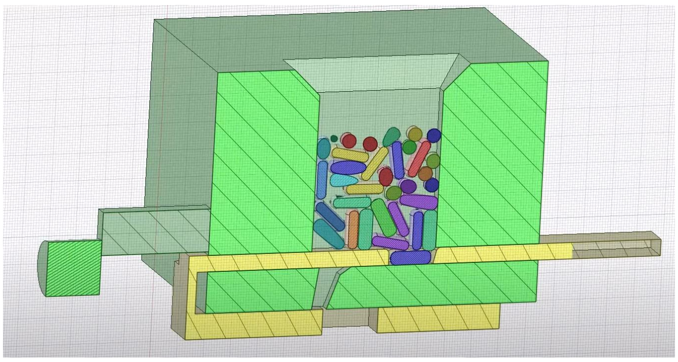


Figure 3: Mechanical Pill Dispenser System

This concept and image was handed off to the machine shop. As can be seen in the diagram above, this is made up of two openings and a small chamber. The pill first falls into the first opening of the lever and then is pushed into the chamber and then released in the opening below. The reason for this is to ensure one and only one pill gets passed through this opening at any given time. The reason why this method was chosen is because we need to ensure the user can only release one pill at a time so we can accurately track the data. Based on research, we learned that this method, although has its flaws of possible temporary jams, provides the most accurate way of releasing one and only one pill.

2.1.3 Sensor Subsystem

The main objective of this subsystem is to sense exactly when a pill is ejected from the mechanical subsystem and send a signal to the microcontroller to record this timestamp. This subsystem consists of one laser and one photodiode sensor. These two components are placed across from each other on the outside of the pill dispenser opening. So when a pill drops down from the opening, it momentarily blocks the laser light from the sensor and this drop in LUX value causes the a trigger in the sensor to let the microcontroller know that a pill has passed. The reason we chose these specific components and this method is because of the accuracy. No other method will provide just as much accuracy in such an efficient way. The laser and sensors also draw very little power so it keeps the system running longer.

2.1.4 Communication Subsystem

The main objective of this subsystem is to communicate the number of pills taken and their respective timestamps to a smartphone. Our initial design of the Communication Subsystem used a WiFi module instead of an NFC module. We envisioned that it would communicate via WiFi to a remote database. After considering the size and power draw, we then tried to use a Bluetooth module instead, deciding to pair users' phones to the device to receive information. We realized that this would be overkill for only simple data transfer, so we finally opted for a NFC tag instead.

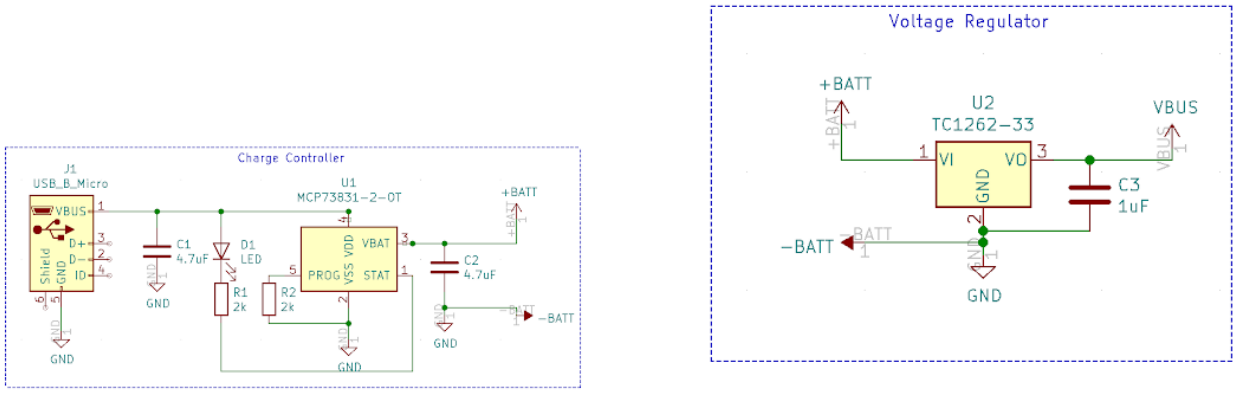
2.1.5 Microcontroller Subsystem

The main objective of this subsystem is to translate the signal output from the Sensor subsystem into app-interpretable data and send to the NFC's EEPROM. There are not amany alternative approaches, as the only difference would be firmware details and the specific chip used. We ended up with the ATTiny 1604 chip, mainly because of its cheap price and suitable flash memory size for our firmware.

2.2 Design Details

2.2.1 Power Subsystem

The power subsystem [5] provides power to all other systems of the design. It has a rechargeable 3.7 V battery and a voltage regulator to output 3.3 V. The charging system takes in a micro USB which is connected to a charge controller. The 100 mAh Li-Po battery is 20 mm x 20 mm x 4 mm which fits in the dimensions of the cap.



(a) Charge Controller

(b) Voltage Regulator

Figure 4: Power Subsystem PCB Schematics

2.2.2 Mechanical Subsystem

The machine shop took the idea we proposed with [1] and created the following contraption:

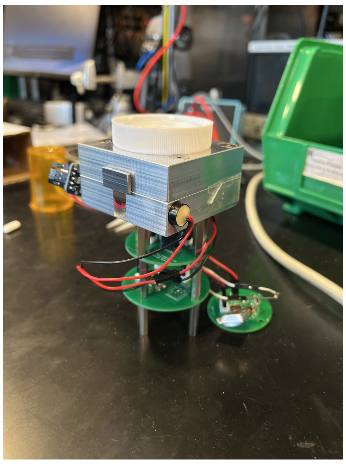


Figure 5: Mechanical Lever System

The pill falls into a slot built into a lever, which, when pushed, release the pill out through a slide. The slide's opening has the laser and photodiode placed across for detection.

2.2.3 Sensor Subsystem

We are using Adafruit VEML7700 Lux Sensor [10] as our LED Light sensor and PL 520 Laser Diode [2] as our laser transmitter. The purpose of the detection subsystem is to detect when a pill has been crossed and notify this action to the MCU.

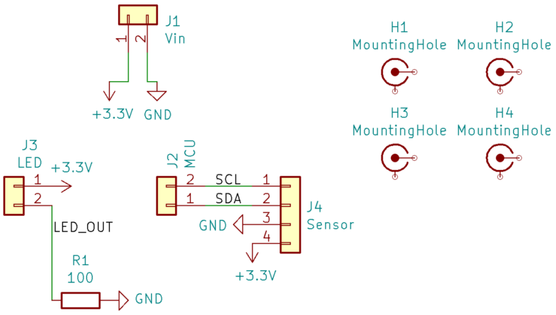


Figure 6: Photodiode + Laser Schematic and PCB

2.2.4 Communication Subsystem

The communication subsystem consists of an NFC tag [7] with a built in EEPROM for memory. It is used for easy communication of the data stored on the pillbox to users, both patients and doctors. We need the NFC EEPROM to have enough memory to store at least one week's worth of data(pill count + timestamp). Timestamp takes about 7-13 bytes, and pill count takes 4 bytes. This means a max of 17 bytes, and assuming 5 pills taken a day, that gives us 35 entries a week. This means we need storage of at least 595 bytes.

2.2.5 Microcontroller Subsystem

We are using a ATTiny1604 [6] as our microcontroller, since it has 16 KB of flash memory.

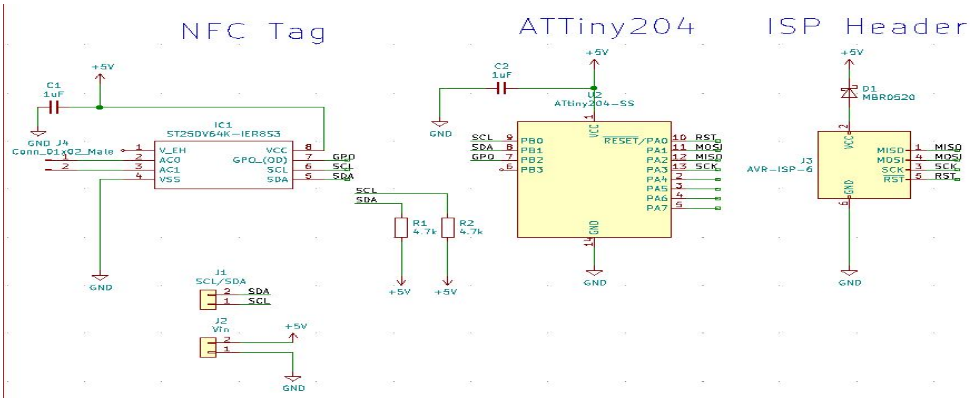


Figure 7: NFC + MCU Schematic

2.3 Verification

2.3.1 Power Subsystem

Table 1: Power Subsystem RV Table

Requirements	Verification
Voltage regulator must be able to regulate battery output voltage to 3.3V±0.5V. Microcontroller, laser, and photodiode all operate at 3.3V, with tolerances ranging of around 1.0V.	1. Measure voltage of battery input in the voltage regulator using a voltmeter which should be 3.7V. 2. Measure voltage at the end of the voltage regulator system using a voltmeter and verify it is 3.3V±0.5V.
Battery must be reliably rechargeable, so successive uses after recharging have similar battery life (within 90%)	1. Fully charge the battery. (The LED on the PCB of the power subsystem indicates when the battery is fully charged.) 2. Record voltage of battery using a voltmeter. 3. Repeat steps 1 and 2 100 times after each full charge of the battery. 4. Verify voltage does not fall under 90% of 3.7V (3.33V).

The following is the result of our verification test:

(a) Output Voltage Verification

(b) Battery Voltage Minimum Verification

Figure 8: Power Subsystem Verification

2.3.2 Mechanical Subsystem

Table 2: Mechanical Ejection Subsystem RV Table

Requirements	Verification
Be able to eject one and only one pill each time with a success rate of 90%.	1. Pull the lever 2. Check to see how many pills have been ejected by the action 3. Repeat steps a and b for a total of 10 times
Power up the entire circuit when the lever is pulled, with a 90% success rate.	1. Pull the lever 2. Check if LED/components on ALL circuit boards are powered 3. Repeat steps a and b 10 times

The following is the result of our verification test:

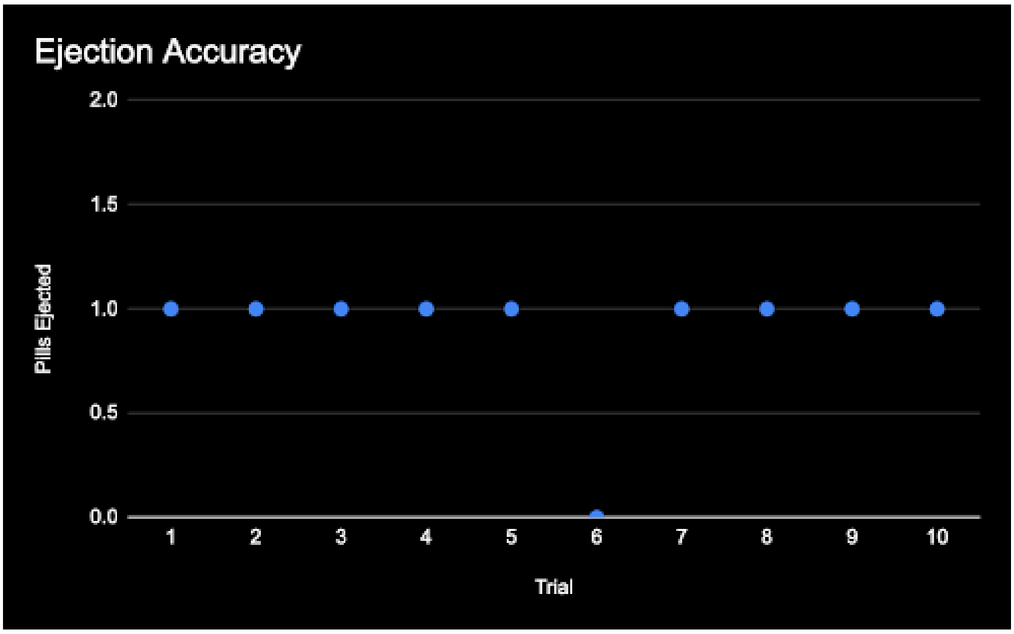


Figure 9: Ejection Accuracy Graph

2.3.3 Sensor Subsystem

Table 3: Detection Subsystem RV Table

Requirements	Verification
Be able to accurately detect when a pill has crossed, with a 90% success rate.	1. Connect LED Light Sensor to Arduino to computer to display real time data from LED Sensor 2. Eject a pill out of the container using mechanical component 3. Check if the laser beam from laser emitter to sensor was disrupted, and displayed real time on computer 4. Repeat steps a and b for a total of 10 times to see how many times laser was disrupted vs total number of times mechanical ejection was used

The following is the result of our verification test:

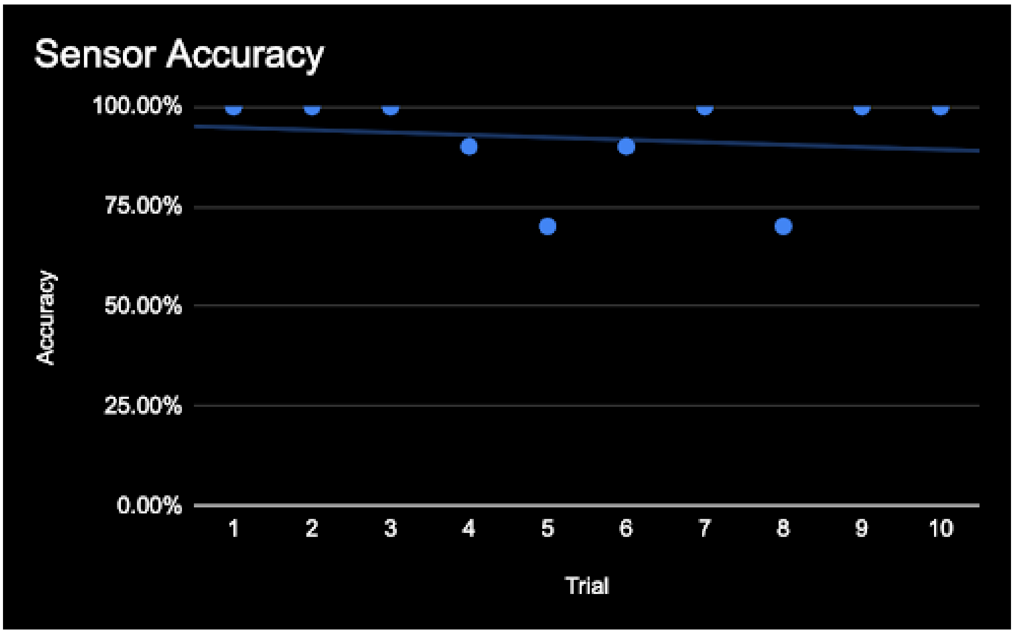


Figure 10: Sensor Accuracy Graph

2.3.4 Communication Subsystem

Table 4: Communication Subsystem RV Table

Requirements	Verification
90% successful communication rate	1. Tap surface of testing device(phone) onto lid where NFC tag resides 2. Verify on app whether a count is displayed 3. Repeat steps 1 and 2 total of 10 times, noting down times of successful communication 4. Calculate success rate
Establish connection and transmit/receive data under 1 s	1. Tap surface of testing device(phone) onto lid where NFC tag resides while starting timer 2. Record time when signal received from NFC tag on phone 3. Repeat steps 1 and 2 10 times, noting down time taken or each attempt 4. Check each communication time is under 5 s.

The following is the result of our verification test:

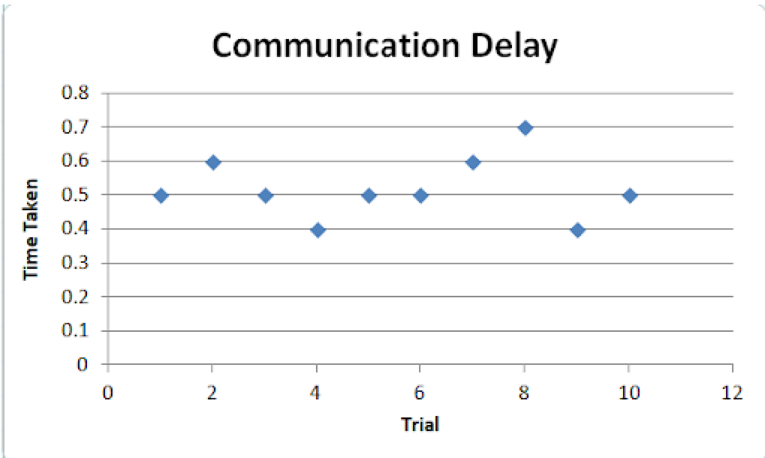


Figure 11: Communication Time Delay Graph

2.3.5 Microcontroller Subsystem

Table 5: Microcontroller Subsystem RV Table

Requirements	Verification
Process sensor data, both amount and timestamps accurately with 100% success rate.	1. Connect ATTiny1604 to laptop 2. Release one pill from the pill lid, recording the time 3. Call file.print on Arduino IDE to check data stored on ATTiny1604 4. Repeat steps a - c for 10 times, verifying each time that the amount released and time any single pill released is correct

The following is the result of our verification test:

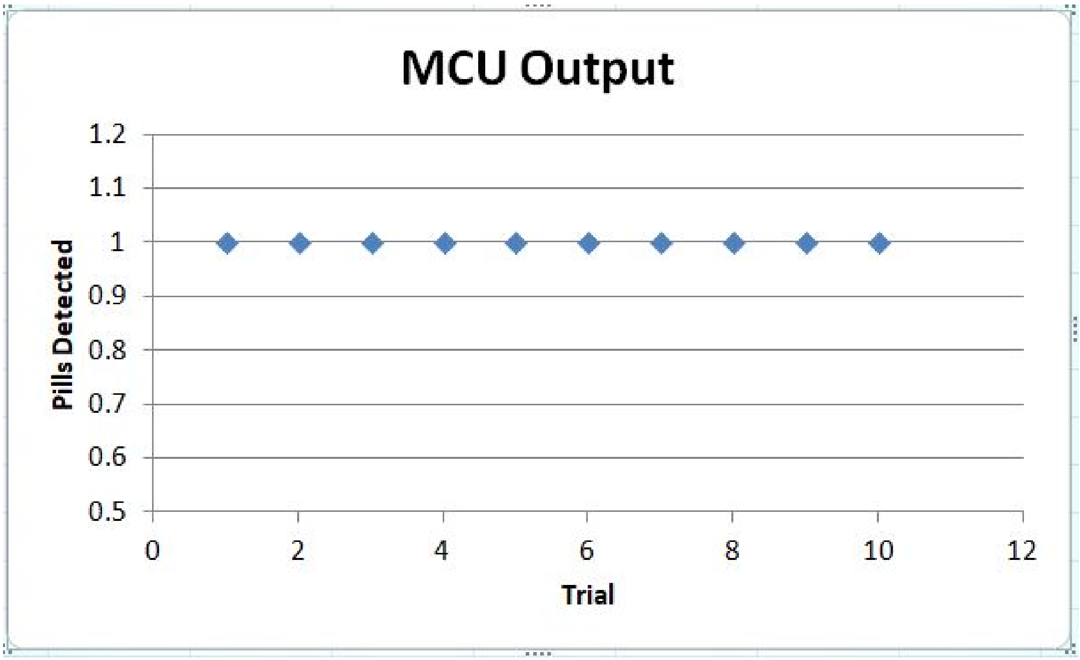


Figure 12: MCU Verification Graph

3 Cost and Schedule

3.1 Cost Analysis

1. Labor

   a. Avg UIUC EE salary: $79714. [3] Avg UIUC CE Salary: $96992. [3] Avg comes out to be $88353/yr.

   b. A 9-5 job of 52 weeks comes out to be 2080 hours, so hourly is $42.48/hr.

   c. We estimate about 50 hours for the app + NFC, 15 hours for firmware, 30 hours for PCB design, 30 hours for debugging, 15 hours for documentation + videos, 10 hours future planning, 10 hours part selection + compatibility testing + sourcing.

   d. Total hours is 160 hours, so total labor cost is $6796.38.

2. Parts

   a. Off the shelf parts generally cost less than $5.

   b. We need a laser, photodiode, microcontroller, NFC tag, NFC antenna, battery housing, battery, PCB.

   c. Assuming a higher $8 average, this comes out to $64.

3. Sum total: $6860.39.

3.2 Schedule

Table 6: Mechanical Ejection Subsystem RV Table

	Yan-Jun	Sumuk	Apoorva
Week of 10/4	Finalize list of parts to use for microcontroller subsystem and finalize layout of PCB boards inside of the cap.	Finalize list of parts to use for detection and ejection subsystem and finalize layout of PCB boards inside of the cap.	Finalize list of parts to use for power subsystem and finalize layout of PCB boards inside of the cap.
Week of 10/11	Finalize the layout of the mechanical system with the PCB boards to minimize the dimensions of the pill cap.	Finalize the layout of the mechanical system with the PCB boards to minimize the dimensions of the pill cap.	Finalize the layout of the mechanical system with the PCB boards to minimize the dimensions of the pill cap.
Week of 10/18	Start individually testing microcontroller subsystem PCB boards. Fix any errors for the second round of PCB board orders.	Start individually testing detection and ejection subsystem PCB boards. Fix any errors for the second round of PCB board orders.	Start individually testing power subsystem PCB boards. Fix any errors for the second round of PCB board orders.
Week of 10/25	Make sure the second version of microcontroller subsystem PCB boards have no errors.	Make sure the second version of detection and ejection subsystem PCB boards have no errors.	Make sure the second version of power subsystem PCB boards have no errors.
Week of 11/1	Test second round microcontroller subsystem PCB boards and fix any errors on the extra PCB boards.	Test second round detection and ejection subsystem PCB boards and fix any errors on the extra PCB boards.	Test second round power subsystem PCB boards and fix any errors on the extra PCB boards.
Week of 11/8	Test all the PCB boards working as one unit.	Test all the PCB boards working as one unit.	Test all the PCB boards working as one unit.
Week of 11/15	Construct the cap with all the working parts.	Construct the cap with all the working parts.	Construct the cap with all the working parts.

3.3 Ethics and Safety

Our main concern is violating patient confidentiality. We want to avoid this issue by making sure the patient data is only accessible to the doctor, and the patient is allowed to take the cap off when they want. We will just track when the pills are coming out of the bottle through the pill cap. We want to make sure that we do not take any control for the patient which is why we did not enforce any type of lock on the Pill Safe cap.

Since this also contains medical information we need to comply with HIPAA to make sure all medical data is stored securely so no one else but the patient and concerned doctors/pharmacists can access it [9].

One way we are looking into this is to make sure to use established and secure protocols while transferring data through software. For example, when the data goes from the phone to the database, we need to make sure it has a low chance of being intercepted. Therefore, we are looking into established platforms such as Google Firebase and other databases which ensure this form of security.

Looking into the safety concerns, there could be some minor lab safety issues. Some safety issues may arise during soldering. We will need to ensure to wear proper eye protection and solder carefully to avoid any type of burns. We also need to make sure to turn off the soldering iron and keep the station clean. Another safety concern for the product would be to make sure the electrical and mechanical components do not interfere with the actual pill product. We need to ensure all electrical components are enclosed and would not accidentally fall or cause harm to the pill themselves.

4 Conclusion

4.1 Accomplishments

We managed to create a device that does accurately track pill dispensed with a success rate of 90%, while allowing for very quick communication in a relatively small form factor. The size of the overall device fit within our high-level requirements, since the width and depth was basically the same size as the pillbox cap. Communication time was a non-issue, since all attempts to retrieve data from the NFC were under 1 s. Finally, though we did experience some bugs during development, detection success rate did eventually stable above 90%.

4.2 Uncertainties

We encountered some goals we had set out in the earlier stages of design that we could not achieve. One example is the idea of powering on the entire circuit when the lever was pulled. This proved to be too difficult to implement both in the mechanical component and circuitry. One other issue we found was the fact that the photodiode board was exposed to outside light. Originally, we had hoped to completely envelope the photodiode so that only the laser light was shining upon it. However, this was not possible under the time frame, but given a relatively constant environment light, the device still operates correctly. One last small issue was that the design of the mechanical component would sometimes lead to pills being stuck. This is easily fixed by shaking around the device, but is not ideal.

4.3 Future Work

Some steps that could be taken to improve the device overall are:

1. Add a power button
2. Enclose photodiode
3. Improve smartphone app UI and functionality
4. Improve charger port placement
5. Enhance mechanical component to minimize pills being stuck.

4.4 Ethics and Safety

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Since this also contains medical information we need to comply with HIPAA to make sure all medical data is stored securely so no one else but the patient and concerned doctors/pharmacists can access it [9].

One way we are looking into this is to make sure to use established and secure protocols while transferring data through software. For example, when the data goes from the phone to the database, we need to make sure it has a low chance of being intercepted. Therefore, we are looking into established platforms such as Google Firebase and other databases which ensure this form of security. Looking into the safety concerns, there could be some minor lab safety issues. Some safety issues may arise during soldering. We will need to ensure to wear proper eye protection and solder carefully to avoid any type of burns. We also need to make sure to turn off the soldering iron and keep the station clean. Another safety concern for the product would be to make sure the electrical and mechanical components do not interfere with the actual pill product. We need to ensure all electrical components are enclosed and would not accidentally fall or cause harm to the pill themselves.

5 Citations

References

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