Smart Health Pill Dispenser
Detailed Design Report

Author:	*Student Number:*
Dana Ding	20606931
Pranav Sharma	20613086
Kelvin Tezinde	20619069

ECE 493

Otman Basir

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1 Introduction

1.1 Background

Due to several studies showing that persistence with treatment decreases over time, several methods for measuring adherence have been developed [1]. Adherence, in the context of the project, is a patient's consistency to adhere to their recommended medication doses consistently and timely. Unfortunately, none of the existing methods can completely do valid adherence methods, either failing to track if a patient takes it at the right time or failing to check if a user actually consumed their pills (through user interaction/input).

1.2 Problem Statement

Due to current pill adherence measurement systems lacking a way to measure all necessary adherence metrics, a tool is required that can successfully read all such metrics for a user. To avoid the potential of decreased treatment, via infrequent/poor consumption of their medication, a tool that helps patients track, remember and record their intake is required.

1.3 Objectives

The objectives of the solution are as follows:

- The solution must leverage IOT technologies
- The solution must be portable so the patient can carry the pills if they travel
- The solution should include the ability to alert to patient when it is time to take their dosage
- The solution must track the dosage that the patient needs
- The solution should dispense the required dosage automatically
- The solution must have security measures to ensure only the patient is accessing the medication
- The solution should keep track of the total number of pills stored
- The solution must be reasonable to implement in 1 month
- The solution should be cost effective

1.4 Constraints

The constraints of any proposed solution are as follows:

- The solution must be an IOT device
- The solution must be less than 8 inches in height
- The solution must have a base dimension of 1.5 inches or less
- The solution must use authentication to dispense pills to ensure the patient is the only one who can access them
- The system must have a level of complexity that allows for it to be implemented within one month

1.5 Criteria

The criteria of the solution are listed below:

- The solution should give the user access to see the total number of pill stored
- The solution should dispense only the amount of pills that need to be taken automatically
- The solution should restrict access to pills until the scheduled time of dosage
- The solution should include communication with a device to notify the patient when it is time to take their dosage
- The solution should have a one step method for authentication
- The solution should cost less than $50 to implement

2 Proposed Solution

2.1 Solution 1: Single Pill Dispenser

The first solution is a Pez like dispenser that can only dispense single pills at a time. This design is slender and tall to fit all of the pills on a stack. An actuator from the bottom of the design will push the pill bottle up and a PIR (passive infrared) sensor to detect the motion of the actuated pill exiting the bottle.

The design will also feature a PC dashboard that allows the patient to view the number of pills in the bottle, the time of their next dosage, the number of pills in their dosage and the current time left in their prescription cycle. These metrics are entered during the bottle setup and care calculated by the bottle and synchronized to the application periodically.

The application will send emails to the user to alert them that it is time to take their dosage. The solution will use the maximum constraints of 8 inches in height and 1 inch in diameter to store up to 120 pills. The solution will use a RFID tag to restrict access to the pill bottle to the patient. The dispenser will only dispense one pill at a time, however it will dispense up to the number required in the dosage with only one touch of the RFID security key. The pills are loaded in by configuring the bottle using a PC and the RFID security key to unlock the physical bottle.

The communication from the smart Pez like pill dispenser and the patient's PC will be Wifi. This ensures that the pill bottle can communicate long ranges and throughout the whole home of the user. If Wifi is not connected the pill bottle can also be connected to the PC via USB to view all of the necessary metrics offline. Figure 1 shows an initial sketch of this design.

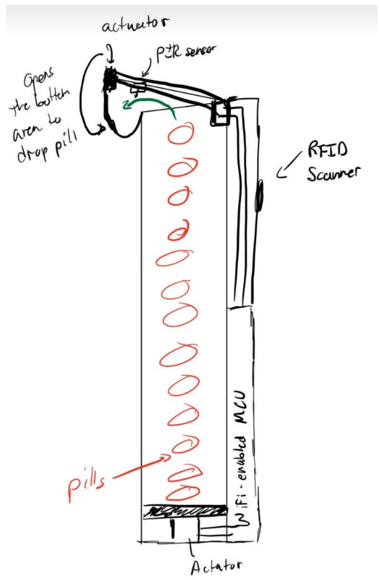


Figure 1: Smart single pill dispenser

2.2 Solution 2: Smart Blister Pack

The second solution is a smart blister packet for monitoring medication adherence. Every time a patient pops open a pill from the blister packet, a signal will be sent to an NFC device which will upload the data to a database. This allows caregivers to ensure that the patient is on track and that the pills are taken at the right time.

The smart blister packet will use conductive tape that is connected to a small NFC enabled micro-controller that detects and records the time and date of opening for each pill. This data is then sent to the server to allow caregivers to receive emails about the status of their patients medication. The solution will include a small case to access the blister pack that will only open when an RFID badge given to the patient is tapped. This meets the constraint that authentication is required for the solution. The solution will be quite small and only hold the pills that the original blister pack for the respective medication uses. This means that there the blister pack or case will not violate any of the size constraints. Figure 2 shows a high level diagram of the solution.

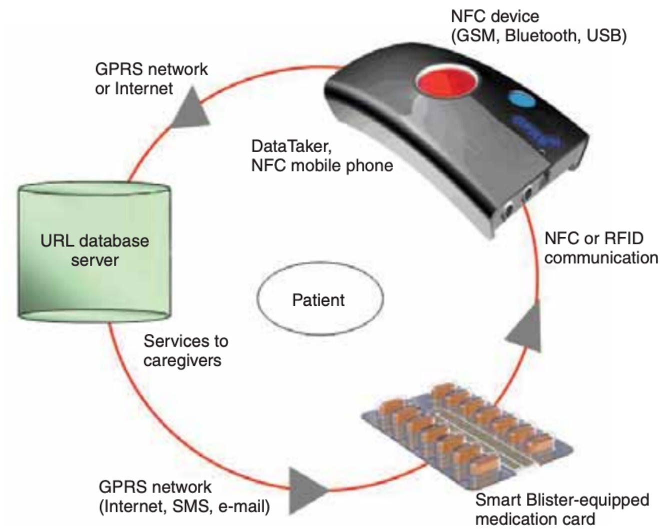


Figure 2: High level data flow of smart blister pack

2.3 Solution 3: Smart Pill Bottle

The third solution is a cylindrical pill bottle that will be 4-6 inches in height depending on selection of electronic components and have a diameter of 1.5 inches. This pill bottle will use a solenoid, an electromagnetic lock and a combination of an LED and photodiode will be used to track when a pill exits the dispenser by reading the voltage change into the microcontroller. The photodiode and LED will be on separate sides of the end of the dispenser. When a pill exits the dispenser, the photodiode will be blocked from the LED causing the voltage to drop and signal and then unblocked when the pill exits causing the voltage to go back up. These changes in voltage will signal the microcontroller to update the number of pills in the bottle.

The tool would alert users when they need to take their pills through an app with push notifications, track the number of remaining pills in the dispenser and track times and dates that a user removes a pill from the dispenser. Users can also configure the app to include data such as how often they should consume their pills. The tool would communicate with the app via BLE. The electromagnetic lock on the bottle will also be unlocked using the application to satisfy the constraint of authentication to dispense the pills from the bottom of the bottle. The pill bottle should hold at least 60 pills, but possibly more if the pills are smaller.

The pill bottle will automatically dispense a pill at the time of dosage by activating the solenoid. If multiple pills are to be dispensed the solenoid will activate again once the patient removes the first pill from the bottle to dispense the required number of pills for the dosage. The pills are loaded in through configuration with the mobile application before the bottle is locked, which can be performed by the patient or the caregiver. Figure 3 shows an initial sketch of the following design.

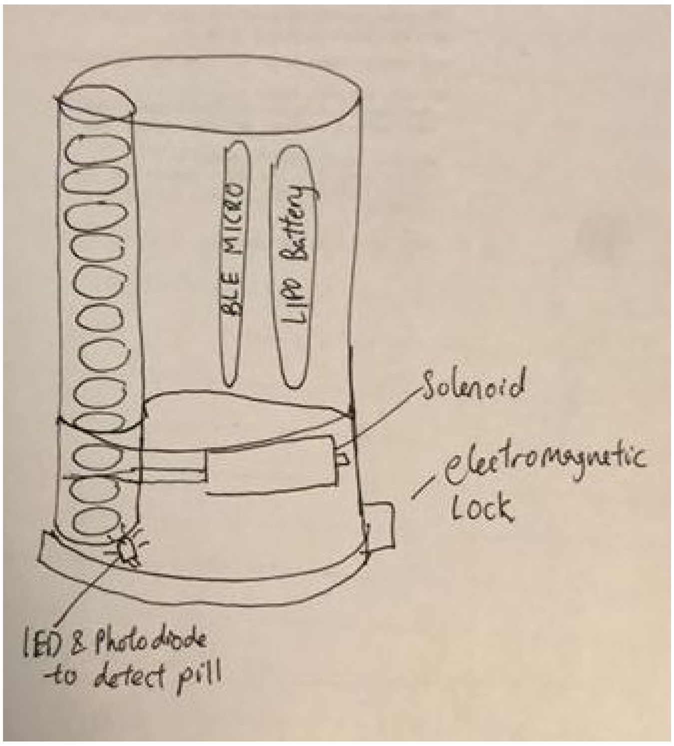


Figure 3: Initial sketch of smart pill bottle

2.4 Design Selection

To evaluate the three designs using the constraint and criteria defined, the solutions are evaluated under broader categories such as cost effectiveness, portability, security, feasibility, and simplicity.

Cost effectiveness is important since the budget for the mechanical design of this project is out of pocket with no reimbursement and therefore costs come out of pocket. When looking at the design from a mass market standpoint, cost effectiveness is also important. Portability is a key feature since pill bottles usually need to be transported to different locations and pills are not always taken in the same place. Security is important for the smart pill bottle so it ensures only the patient can access their medication and all data recorded is accurate to only actions of the patient or caregiver in some cases. Feasibility is one of the categories of evaluation because the project only has a timeline of 1 month without all working hours of that month dedicated to the project. Due to the circumstances, feasibility of the designs must be evaluated to ensure success. Simplicity is the final category used to evaluate the designs and evaluates how simple the design is from the user perspective. A smart pill bottle should be just as accessible to patients and caregivers as a regular pill bottle so this metric is a good measure of if the design could be easily adopted by users.

For cost effectiveness the first design and the third design are comparable in terms of components, however the first design requires an RFID scanner whereas the third design uses the users mobile phone as a means of authentication. In comparison, the third design is more cost effective than the first. When comparing the second design in this manner it is the smallest design but will require conductive tape and wiring for every pill. Although it seems that this should be the most cost effective, the cost scales up and it therefore a tie with design two and design three in this aspect.

For portability, all of the designs are strong. In terms of size, design one is the largest of the three proposed solutions. The next biggest design is the third design while the smallest will be the second design. However, the authentication and usage of the solutions plays a role in the portability. For design one, the dispenser can only be effectively used with the RFID card for authentication and a Wifi connection for data access. These two conditions make it the least portable option. For the second solution, the RFID tag and the reliance on Wifi to update a server also limit portability, however the solution is still able to record data over BLE or NFC so it is still more portable that the first solution. The third solution does not rely on any Wifi connection; authentication is provided via app and therefore, it is the most portable option.

Security is pretty much the same throughout the three designs with a slight advantage to design one and two. The first and second design both use an RFID security key for authentication which is physical. This means the only way that security can be compromised is through someone physically stealing the security key and the pill bottle which would be hard to do. Slightly worse in this area is the third solution which is authenticated through the mobile application. Since the authentication occurs through the mobile application, this means that bad actors could hack into a patients account or use other means of software attacks to access the pill bottle if needed.

The fourth category of evaluation is feasibility. Every project is feasible within the given timeline but the third solution matches closest to the skill set of the group. In addition to this, the first solution involves more moving components and more complex mechanical design which is not the main goal of the project, making it less feasible in this metric. The second solution involves further development on the web end and less development in the area of embedded systems, which makes it slightly less feasible than the third solution.

The final category the design is evaluated under is simplicity. Solution one is simplistic, however the way the pill is meant to drop into the user's hand may be less intuitive from the shape than the other designs. The third design is the next best in simplicity. The bottle will unlock when requested from the mobile app and only the single pill will be in the lid that comes off. The mobile app will feature a clear button for this feature which should make it very intuitive for patients and caregivers. The most intuitive is the second design since usage is exactly that of a normal blister pack. Since no change is made and it follows the current convention, it is the most simplistic design.

After evaluating every design, the third solution is selected as it is the best solution when considering cost effectiveness, portability, security, feasibility and simplicity.

3 Design

3.1 Feature Summary

The selected design will include the following features:

- Automatic dispensing of number of pills dosage
- Track the number of pills left using the amount entered as the start as reference
- Tracks the time a pill exits the bottle
- Push notification alert at dosage time
- Companion mobile app to view number of pills in bottle, next dosage time, how many pills per dosage, time of last pill taken and current prescription cycle via Bluetooth
- Authentication to open pill bottle will be done through mobile app
- Access to pills is limited to set dosage time, but can be overridden in app

3.2 Mechanical Design

Figure 4, 5, 6 show the front, top and side views of the pill bottle respectively.

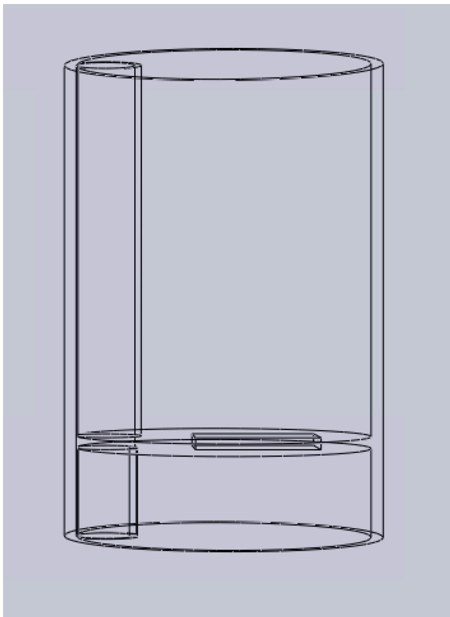


Figure 4: Side view of smart pill bottle

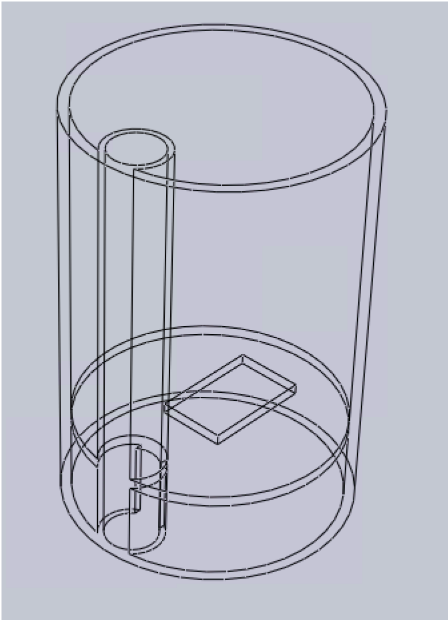


Figure 5: Top view of smart pill bottle

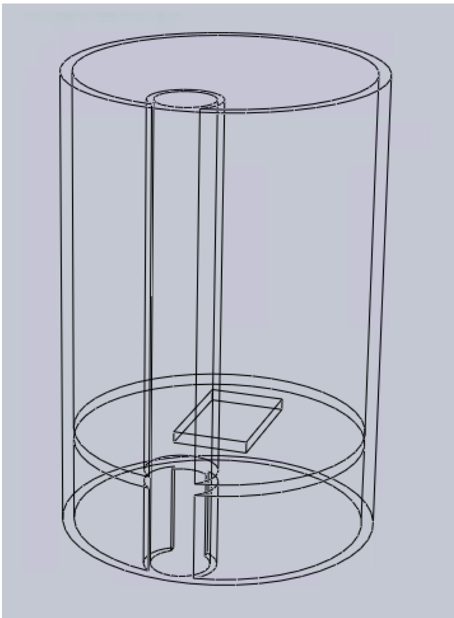


Figure 6: Side view of smart pill bottle

The mechanical design of the pill bottle is simple, the pills are loaded by the pharmacist into the container at the top where there is a slot of the perfect size. The pills are blocked by a solenoid with a custom tip attachment which releases pills at an appropriate time. The solenoid is designed to slot into the middle slice of the pill bottle. The bottom cover is controlled with an electromagnetic lock that unlocks over Bluetooth on the mobile app only for the individual patient. A piece of metal is attached to the bottom cover and the 5V electromagnet with 2.5kg of holding force is placed beside the solenoid. These actuators need to be controlled by a micro controller and powered through a battery that will be fixed into the main storage area of the device right next to the pills.

3.3 Electrical Design

For the electrical design, the chosen micro-controller can be powered directly with a 3.7V lipo battery. The micro-controller also has an integrated NRF52 bluetooth low energy chip which talks to the mobile app.

Referencing the wiring diagram shown in Figure 7, The solenoid and electromagnet are both going to be powered off the micro-controller. Since a solenoid is an inductive load, a snubber diode is required across the contacts which help eliminate transient voltages caused when a magnetic coil suddenly loses power. Without this diode in place, the transient voltage spikes can damage other elements of the circuit. The yellow wire is the control pin of the arduino going to a base resistor through to a transistor which switches the solenoid on and off.

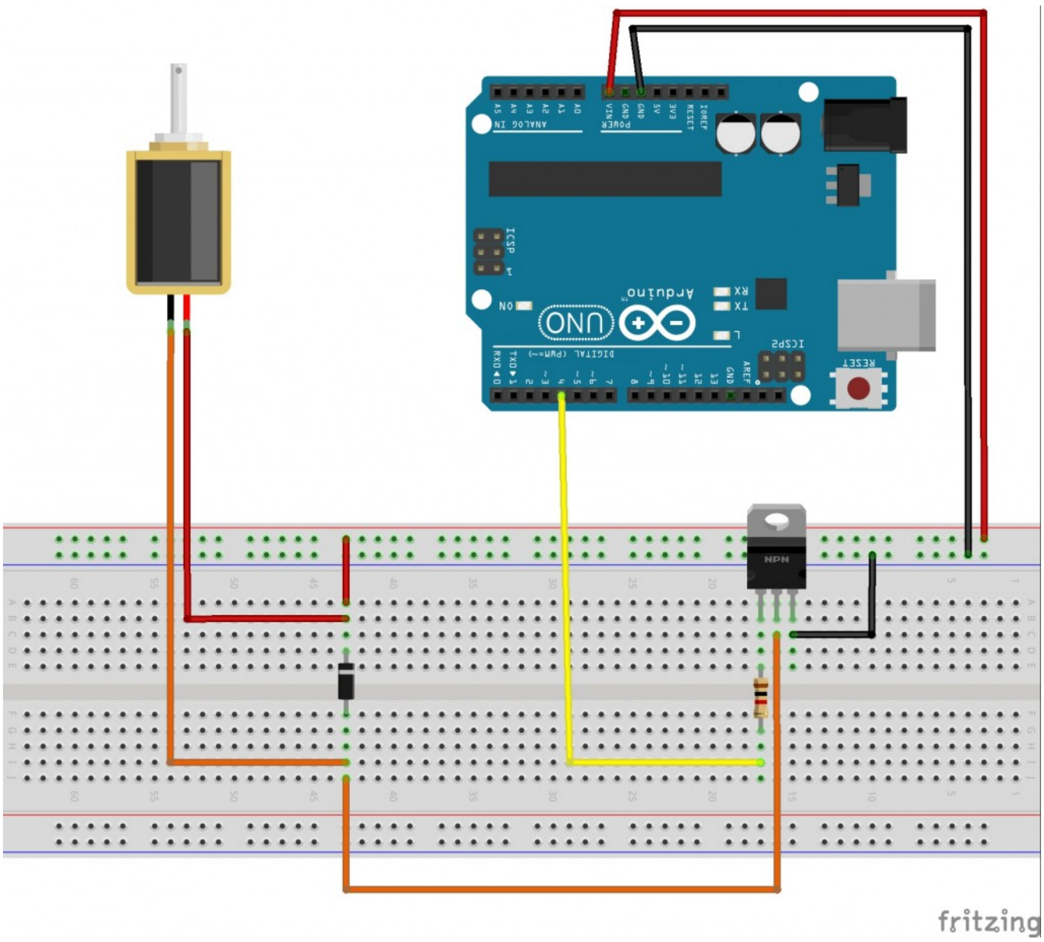


Figure 7: Solenoid wiring diagram

The photodiode and LED that are used for pill detection are connected directly to and powered by the micro controller. Figure 8 shows the photodiode and LED wiring diagram.

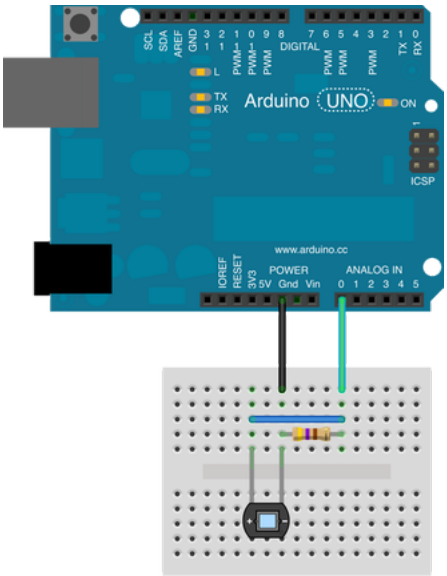


Figure 8: Photodiode and LED sensor wiring diagram

3.4 Software Design

3.4.1 Embedded Software

The software design will be broken up into two components. The first component is the embedded software which will run on the micro-controller selected. The embedded software will cover the control of the pill bottle automatic dispensing and well as the sensing, recording and communication of data to and from the mobile application.

Automatic pill dispensing will be done through receiving a bluetooth message from the mobile application when the time of dosage comes. Once the time of dosage is reached, the micro-controller will toggle the control pin of the solenoid and cause it to open. At this point, the photodiode and LED will be used to sense when a pill is taken out of the bottle, since the pill will cover it when the dosage is ready. Upon the controller receiving the authentication signal, the electromagnet will be shut off using a control signal and the bottle will be allowed to be opened.

Once the micro-controller reads the voltage of the photodiode circuit increase, the internal count of pills dispensed per dosage is decremented. The process will go back to the step of automatically dispensing a pill by activating the solenoid once the pill bottle is closed. Once the pills per dosage count is decremented to zero, the micro-controller stores the date and time in a DD:MM:YYYY-hh:mm:ss format. The micro-controller will then listen for the next dosage time over Bluetooth. The counter that stores the number of pills in the bottle is also decremented at this time. All of this data will then be sent to the mobile app for view of the patient or caregiver over Bluetooth from the micro-controller. Figure 9 displays the embedded software logic visually using a flowchart.

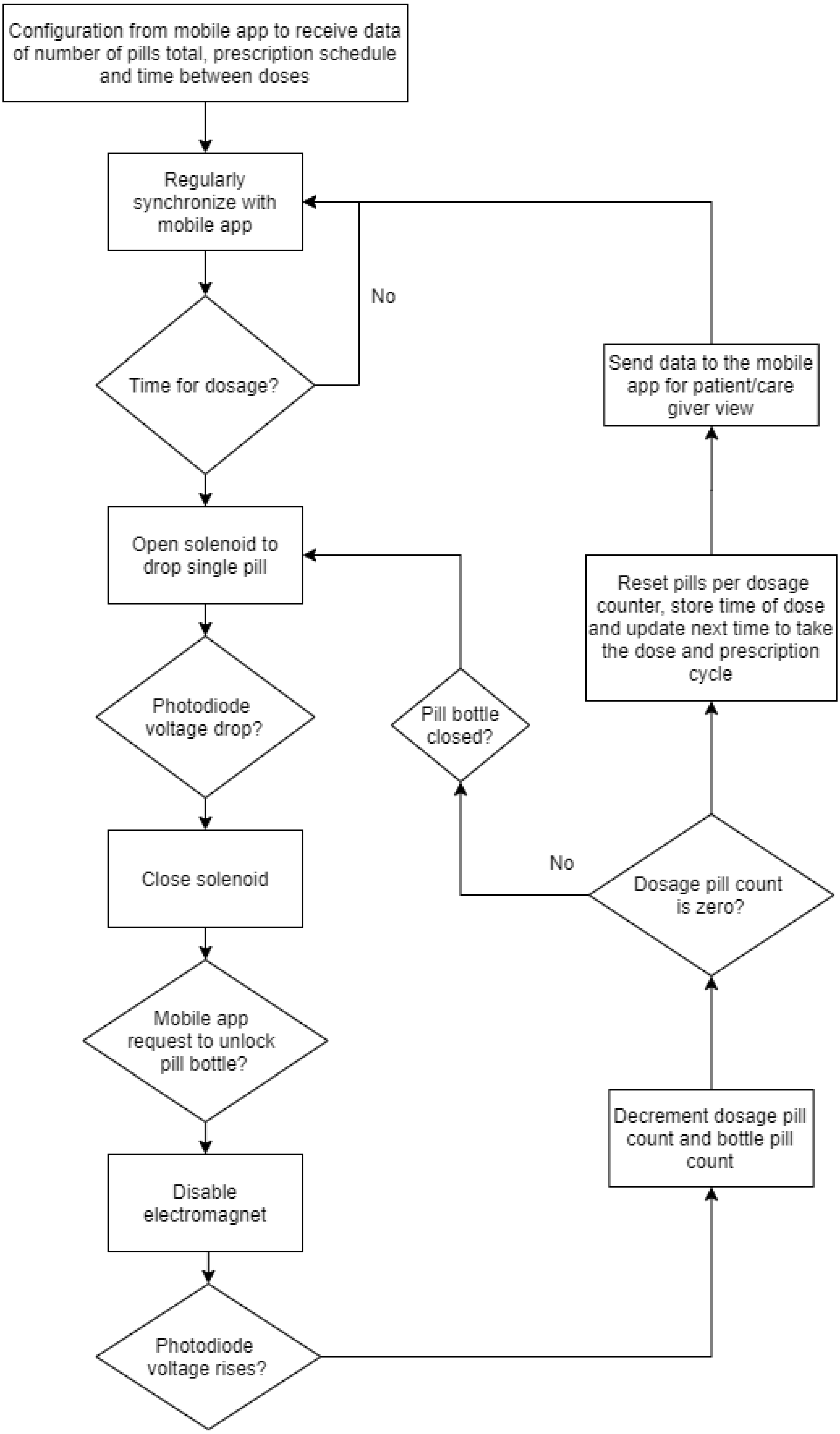


Figure 9: Embedded software logic flowchart

3.4.2 Mobile Companion App Software

The second software component for the IoT project would be the companion application that users of the pill dispenser would use. The purpose of the app is twofold; used as a visualization tool for users to view multiple pieces of data such as the time they extracted their last pill, and it is used as an alarm/reminder for patients to take their medication.

When a user first opens the app, they are taken to a Bluetooth scanning page, which can be seen Figure 10. Before they can proceed any further, the user must connect their device to the pill dispenser via the application and once they do that, they can be taken to the main page of the application. When a user first goes into the main page (part of which can be observed in Figure 11), there will be no data regarding the users configurations. To configure the app, then, the user must click on the 'configurations page', seen on Figure 12.

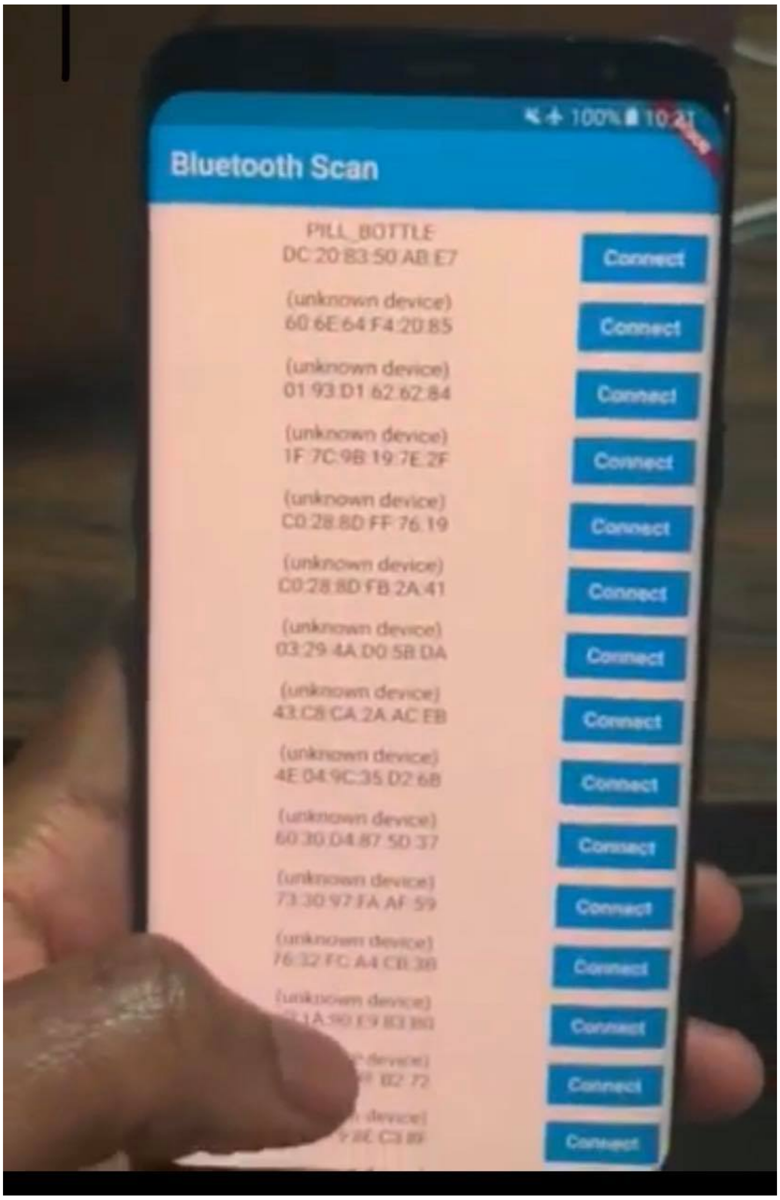


Figure 10: Bluetooth scan page

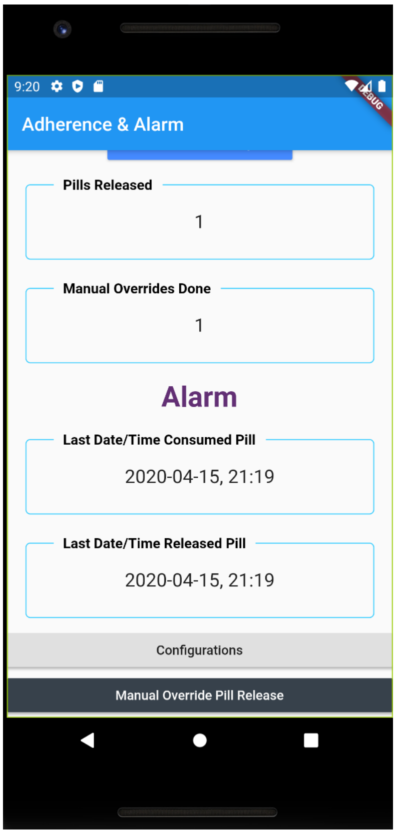


Figure 11: Section of the main page showing alarms and configurations

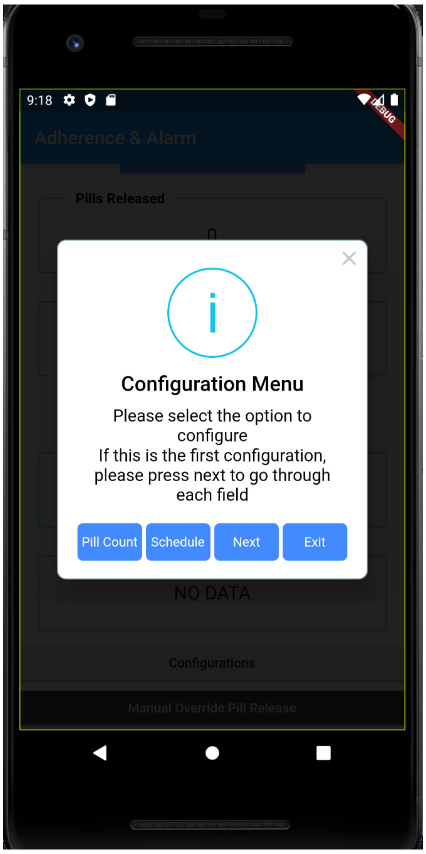


Figure 12: Configurations for the app

Configurations include the amount of pills in the pill bottle (for device purposes) and picking a schedule of consumption to meet the customers medical needs. Choosing a schedule causes the app to create an alarm that will signal to the user whenever their consumption time arrives. The user would signal the app to close the alarm, then a new alarm object is created in the background that will again signal the user once their duration is met. When the user dismisses the alarm, the pill bottle shall dispense a pill. For example, If a user set their adherence to every 8 hours, then every 8 hours, an alarm would play from their mobile devices.

As a final note, the app also has a 'manual override' button, where the user may dispense a pill before their alarm has actually rung, or directly after. This was implemented because the device may dispense a pill, but said pill may fall on the ground or be slightly damaged, making the user unwilling to consume it. Furthermore, to properly track adherence and ensure that the user is also active during their own tracking, the user shall manually increment the amount of pills they consume. Currently, the app tracks when a pill is released and when a user initiates a manual override, but the user themselves increment consumption values, again, because automatic adherence is extremely difficult (as pills released != pills consumed). To ensure that users increase the consumption value at a rate that makes sense, when the consumption value will exceed the 'pills released' value, a warning pop-up shall appear asking the user if they want to proceed with the action, as seen in Figure 13. For more details and a demo, the videos provided will go into more detail on the app.

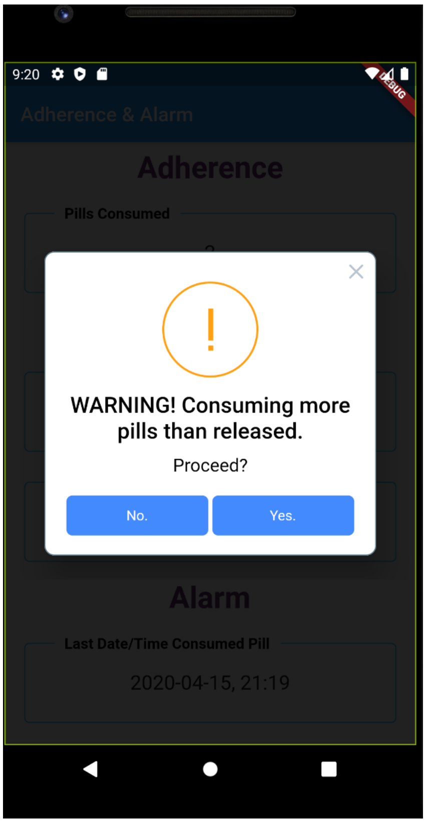


Figure 13: Warning message when consuming more than released

In terms of tools, the application communicates with the device via Bluetooth. The app is built with the help of Googles Flutter tool and dart, which is compatible with both android and IOS.

4 Implementation

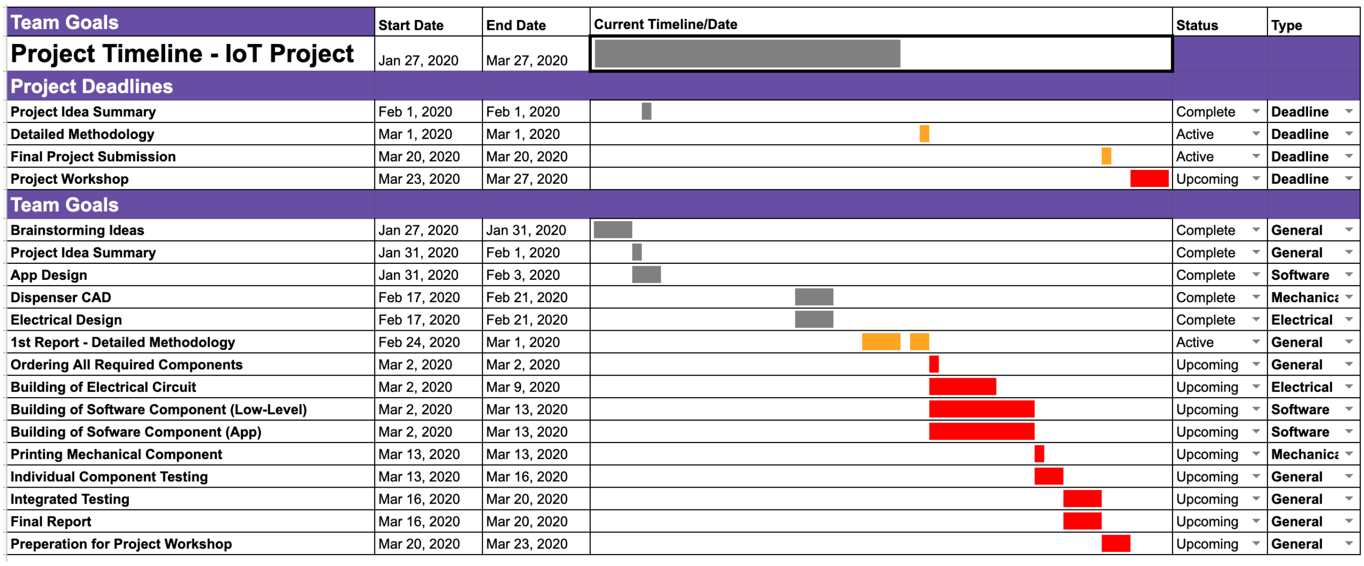
4.1 Components

The components selected are the following:

- Micro-controller - Adafruit Flutter NRF52 BLUEFRUIT LE
- Lock - 5V Electromagnet with 2.5kg holding force
- Solenoid - 5V push solenoid
- Power - 3.7V Lithium Polymer Battery
- NPN transistors
- Diodes
- LEDs
- Photodiodes
- Resistors
- Metal disk
- 3D printed enclosure

4.2 Timeline

Given the schedule of the project, a timeline was created to ensure the project would be completed successfully. A Gantt chart using excel was created and was intended to cover the teams schedule from before the initial proposal due date until the 27$^{\text{th}}$ of March. The figure below shows the Gantt chart used for planning. Details on the unique aspects of said chart will be expanded upon in Figure 14.



Team Goals	Start Date	End Date	Current Timeline/Date	Status	Type
Project Timeline - IoT Project	Jan 27, 2020	Mar 27, 2020			
Project Deadlines					
Project Idea Summary	Feb 1, 2020	Feb 1, 2020		Complete	Deadline
Detailed Methodology	Mar 1, 2020	Mar 1, 2020		Active	Deadline
Final Project Submission	Mar 20, 2020	Mar 20, 2020		Active	Deadline
Project Workshop	Mar 23, 2020	Mar 27, 2020		Upcoming	Deadline
Team Goals					
Brainstorming Ideas	Jan 27, 2020	Jan 31, 2020		Complete	General
Project Idea Summary	Jan 31, 2020	Feb 1, 2020		Complete	General
App Design	Jan 31, 2020	Feb 3, 2020		Complete	Software
Dispenser CAD	Feb 17, 2020	Feb 21, 2020		Complete	Mechanica
Electrical Design	Feb 17, 2020	Feb 21, 2020		Complete	Electrical
1st Report - Detailed Methodology	Feb 24, 2020	Mar 1, 2020		Active	General
Ordering All Required Components	Mar 2, 2020	Mar 2, 2020		Upcoming	General
Building of Electrical Circuit	Mar 2, 2020	Mar 9, 2020		Upcoming	Electrical
Building of Software Component (Low-Level)	Mar 2, 2020	Mar 13, 2020		Upcoming	Software
Building of Sofware Component (App)	Mar 2, 2020	Mar 13, 2020		Upcoming	Software
Printing Mechanical Component	Mar 13, 2020	Mar 13, 2020		Upcoming	Mechanica
Individual Component Testing	Mar 13, 2020	Mar 16, 2020		Upcoming	General
Integrated Testing	Mar 16, 2020	Mar 20, 2020		Upcoming	General
Final Report	Mar 16, 2020	Mar 20, 2020		Upcoming	General
Preperation for Project Workshop	Mar 20, 2020	Mar 23, 2020		Upcoming	General

Figure 14: Project timeline

The chart above is broadly composed of three parts; the project goals, team deadlines and finally, the timeline section that both parts have. The large, gray bar found at the top of the chart is used to visualize the elapsed time since the defined beginning of the project (in this case, the 'beginning' is January 27th). Completed tasks are shown in grey, active in orange, and upcoming in red. The 'Type' column is purely used for specific team members to see what they need to work on, ex: the mechanical team member knows what mechanical aspects of the project are due. Note that this is a dynamic chart, meaning that as time goes on, the state of the gray bar changes, and if tasks are deemed active even after their due date, their timeline status turns red.

The Gantt chart above shows the intended schedule the project would follow back in late February, but due to the current situation, many timelines were shifted, including the due date of this project. Most deadlines pre March 13 were met, save for the mobile application, with the mobile app being completed April 13th after a lot of testing. Due to the shift of deadlines, the previous Gantt chart shown in the figure above is not completely accurate, but it shows the teams intended goals before school closure.

4.3 Prototype Build

Due to extenuating circumstances the custom housing was unable to be 3D printed, instead a temporary one was made with cardboard. A picture of the unit can be seen in figure 14. Attempts were made to try to replicate the 3D model in figure 6, the entire assembly fits inside a cylinder enclosure, the wires that connect the solenoid slides through the disk to connect to the micro controller along with the appropriate transistors and resistors.

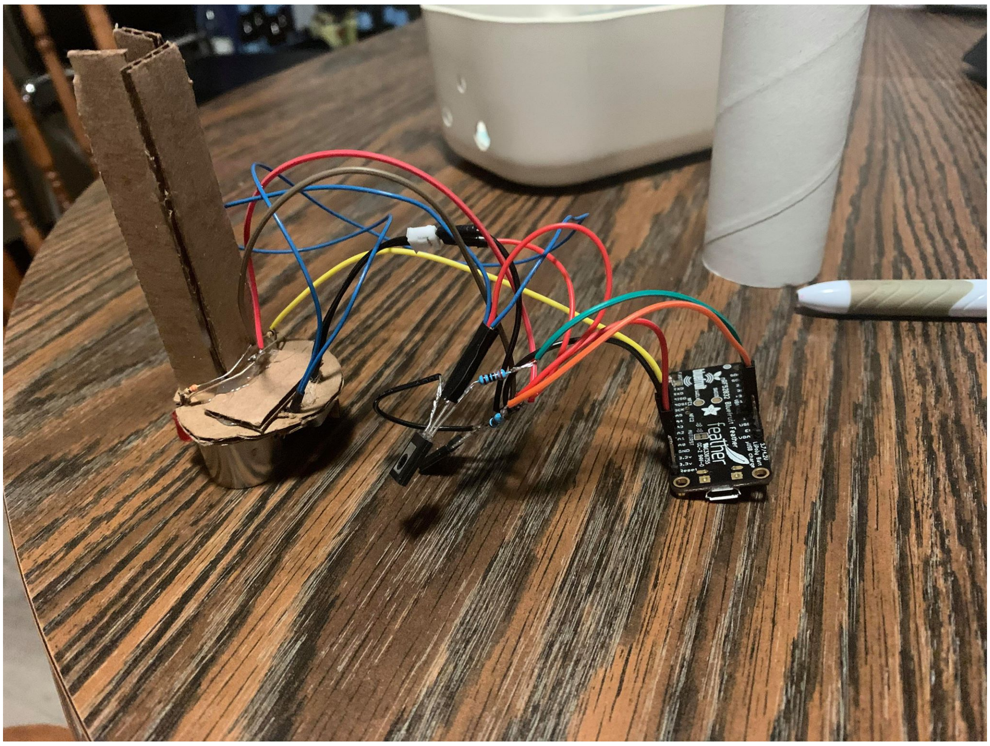


Figure 15: Pill Dispenser Prototype

The solenoid that controls the releasing of pills is affixed to the bottom of inside of the pill bottle along with the electromagnetic lock mechanism. Both components are wired to the micro controller as shown in the schematic in figure 7. A lid was made from cardboard and a metal disk is glue on, this allows the electromagnetic lock to fasten the pill bottle.

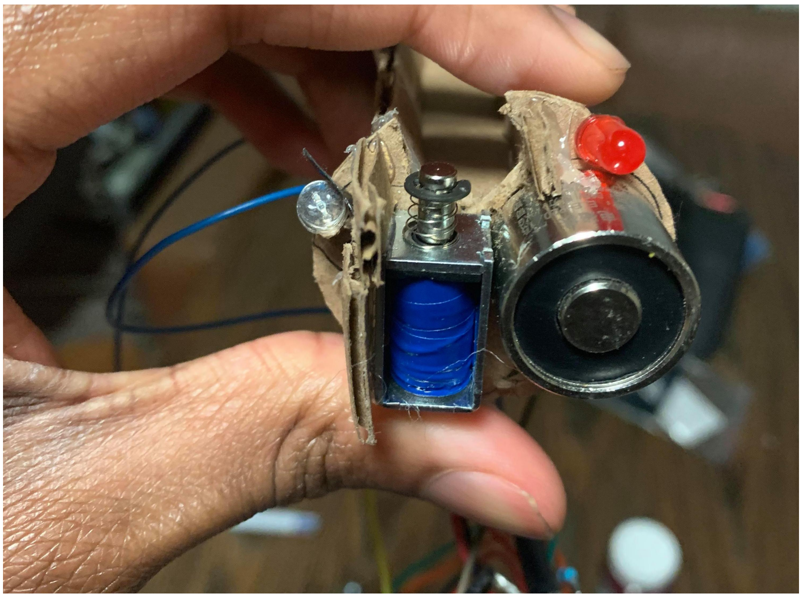


Figure 16: Solenoid and Electromagnetic Lock arrangement

The photo diode and LED responsible for pill detection are wired according to figure 11 and are placed on either side of the pill shaft, this allows the movement of the pill to be captured as a disturbance in the photo diode analog signal.

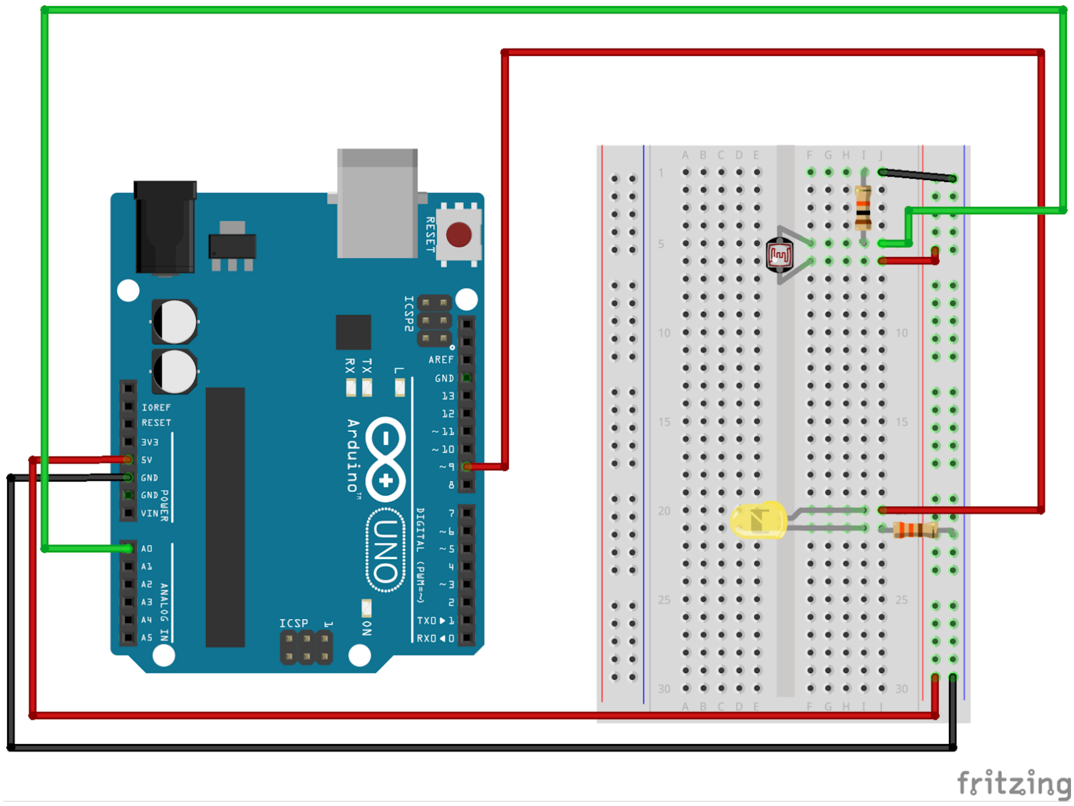


Figure 17: Photodiode and LED wiring

5 Testing

The full system is tested in two parts. The first part is subsystem tests which involved testing the standalone parts of the firmware and the application. This encompasses most of the functionality of the system, with the Bluetooth communication being the only major feature left off the subsystem testing plan. The first test conducted is testing the firmware standalone to ensure that the solenoid and photodiode sensor worked effectively to detect pill dispensing and that the solenoid is able to be opened and closed from the firmware. The pill used for these tests is a small piece of paper to avoid wasting real pills. The test is considered complete on the successful detection of a pill being released, by printing if the pill is released and comparing that to the results of the test. This test is a success and allows continued development of the system.

The next subsystem tests occur on the mobile application and involve testing configurations and alarms. The tests are conducted by setting the configurations to simulate a prescription cycle that has a dosage every minute. The alarm functionality is then tested in three states. The first state is with the application open, and success in this case is if an alert message pops up on the application accompanied by a notification and an alarm. Both the notification and the dismiss button on the alert message should stop the alarm and this is the condition that marks this test successful. The next test of this feature includes testing when the app is still open but not active. The alarm still plays and can be turned off with the notification. The final test is if the notification sent by the application still appears when the app is closed and it is time to take a dosage. This test is also successful, with the background service of the mobile application sending a notification after one minute, which is the simulated prescription schedule. All in all, all of the standalone mobile application tests are a success and testing efforts proceed with integration testing.

Integration testing tests the Bluetooth communication from the smart pill bottle to the mobile application. The testing plan is split up to test that the mobile application can connect to the smart pill bottle and can only proceed into the data once connected, manual override of the pill bottle works to release a pill, the pill released count is updated through a Bluetooth message from the device and that the pill bottle is unlocked and the solenoid releases a pill when the alarm is triggered. The first test is a success, with the application not proceeding past the Bluetooth scan screen until a connection is established with the pill bottle. Furthermore, the second test is a success as when the manual override button is selected and confirmed, the pill bottle will dispense a pill to the user. The final test is also a success, as the same function to trigger the manual override is used to send a Bluetooth message to the pill bottle to unlock it whenever the dosage time in the configured prescription schedule is reached.

These tests make up the test plan of the system. The results of the test are that the system works as expected, however since the system is a prototype there are many improvements that can be conducted to the mobile application and mechanical design. Due to the the current circumstances in the world and the scope of the project these improvements could not be explored further since it is very hard to test a physical system remotely. In conclusion, the result is a working prototype of a smart pill dispenser that leverages IoT technology through Bluetooth communications with a mobile device to utilize automated dispensing and provide data metrics as well as sense when pills leave the bottle.

6 Conclusions and Recommendations

A need for a tool that can read all necessary adherence metrics for a user has been identified. Objectives, constraints, and criteria were created in order to develop multiple solutions and rank said solutions against each other. Using the engineering design process and judgements, the smart pill bottle was chosen as the best solution. The bottle will be using a solenoid and electromagnetic lock combination to actuate the mechanism that allows the pills to be dispensed. It shall use an LED and photodiode to detect when a pill is dispensed, allowing the system to detect when a pill is successfully detected. System architecture would consist of the smart bottle communicating with an app via Bluetooth, storing any configuration data unique to the user within the users' mobile device, with the app alerting the user when it is time to consume their dosage. The micro-controller to be used will be an Adafruit Flutter NRF52 BLUEFRUIT LE, powered by a 3.7 LiPo, all within the 3D printed encasing that shall be the bottle.

In a review of the detailed design, all objectives and constraints are met, such as authentication before dispensing and pill tracking. In this case authentication is implicitly done through the password on the users phone, so further authentication is deemed unnecessary.

The individual aspects of the project commenced on March 2$^{\text{nd}}$, with unit testing beginning approximately 2 weeks after, integrated testing the week after that. Due to extenuating circumstances, development proceeded into April with development concluding on April 13$^{\text{th}}$.

The team tested the smart pill bottle and saw no issues with dispensing, however since this is a prototype and due to extenuating circumstances limiting travel, the smart pill bottle is only tested with small pieces of paper instead of pills. This means that the issue of multiple pills being dispensed when the solenoid unlocks is never fully tested and is a recommendation to further develop this project. Furthermore, other recommendations are the mechanical design of the system should be made out of material that is more rigid, such as the original plan of 3D printing. The final recommendation is that the application should provide more data metrics, such as a running countdown clock to allow the user to see when their next dose is and the application user interface should be developed further to allow users to have an easier time interacting with the application and have smoother transistions between pages.

In conclusion, the smart pill bottle demonstrates IoT technology within a prototype through sensing pills exiting the bottle and communicating with the mobile application through Bluetooth.

7 References

[**1**] van Onzenoort, Hein & Neef, Cees & Verberk, Willem & Iperen, H & de Leeuw, Peter & van der Kuy, Hugo. (2012). Determining the feasibility of objective adherence measurement with blister packaging smart technology. American journal of health-system pharmacy : AJHP : official journal of the American Society of Health-System Pharmacists. 69. 872-9. 10.2146/ajhp100592.