

Pill Pall: A Medication Tracker and Dispenser

Team 42 — Deonna Flanagan,
Jerry Chang, Pallavi
Narayanan
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TA: William Zhang

1 Introduction

1.1 Problem and Solutions Overview

Modern medicine allows us to alleviate the ailments that come with advanced age and has consequently allowed us to extend our life expectancy well beyond limits decades ago. As expected, reaping the benefits of old age requires us to maintain regularly scheduled medication intake. Older generations have an especially difficult experience keeping track of pills taken and they may have many different pills to take at different times of the day. With growing numbers of an elderly population in the United States[2], it is anticipated that there will be more elders than caregivers in the coming years. Thus, it may be seen that overall control of specific medication taken at a time and the remembrance of taking such batches of medication proves to be a challenge for the elderly. Complications with medication, whether it be overdosing, underdosing, or mismanagement, are potentially dangerous.

Efforts by commercial manufacturers on today's market effectively dispense medication of different types with configuration options possible, but at high price points and fail to track the taking of medication. We propose an automated pill dispensing system that will inform users when to take their pills and indicate whether the pill(s) has/have been taken or not. Caregivers will be able to survey the medication intake of patients without 24/7 attention, and will free up time for greater volumes of patients or other issues, without the mundane chore of manual dose control. Additionally, to prevent overdose, the dispensing system would be able to lock and only dispense medication at the right time of day and when the single user has not already taken the pill(s). This will alleviate the need for 24/7 attention and manual dose control. There will be an interface for caregivers to configure and show the frequency of intake for specific pills. This will be configured on the interface such that pills with specific frequencies will only dispense should the time to take them be ready. Alerts and notifications should also be supplemented with the device to remind users to take the batch of medicine. Former groups implemented a number of new and related solutions without success of control over the number of pills dispensed. To circumvent this technicality, we will be working closely with the ECE Machine Shop to implement a horizontally sorting pill counter with the use of an IR sensor much like automatic pill counters seen on markets today[3]. We believe that this will be a greater improvement on a vertical gravity-based pill drop dispenser. Our project models on existing solutions, to motivate greater chances of success on dosage control.

1.2 Visual Aid

This is not to scale, but the dispenser will have an opening just for the cup that holds the pills. Below the cup is the load cell that weighs the changes in the cup to track whether the patient has taken the pills or not. The LED on the front of the dispenser will serve as an indication: green for pills taken, red for pills not taken, and yellow for pills dispensing/dispensed. The buzzer/speaker will play a noise when the pills have been dispensed in order to alert the patient to take the

medication. The phone application is for the caregiver to specify how many pills to take, at what time to take them, and any other important information. The caregiver will also be alerted about the status of the medication intake and whether or not to refill the pill dispenser.

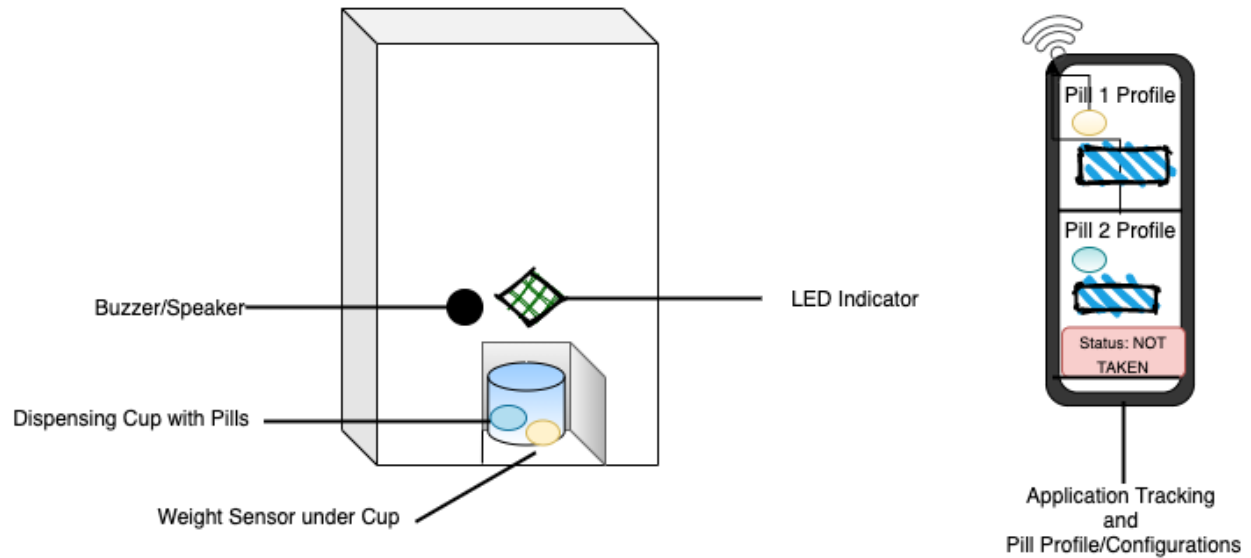


Figure 1.1.
Visual Aid

1.3 High-Level Requirements

1. Caregiver inputs the prescription specification of the medication into the mobile application. This information includes the number of pills to take and at what time of day. The dispenser should run with a scheduler and should dispense dose within a minute (60 sec) of inputted time. The dosage must be outputted based on application specifications 99% of the time.
2. Track whether the pills have been taken through application interface of caregiver. User's profile should show whether or not the medication was retrieved and receive an update on status from the retrieval site. This is maintained through a weight sensor capable of precision needed for mg weight of pills.
3. Configure dispenser remotely from mobile application by allowing caregiver to input the type of medication put into the dispenser, the number of pills to take, and at what time the pills should be dispensed. There will also be an update when the pills must be refilled on the application so the caregiver can unlock the dispenser on the app and then refill the medication.

2 Design

2.1 Physical Design

The design of our pill dispenser uses the pill counting design from modern machines to output pills based on a specified amount. There are two pill dispensing plates to allow for two separate types of medication, but both output to the same cup at the bottom of the machine. The rotating discs use the motors to turn when prompted and the pill size corridor control ensures that pills leave in a line so only one pill passes the IR sensor at a time. This allows the sensor to send the data to the control unit to track the number of pills dispensed. The weight sensor below the cup is used to track whether the pills have been taken from the dispenser or not and can be updated on the mobile application. On the front door of the dispenser, there is the EM “Fail-Secure” Lock to deter patients from breaking into the machine. The small door at the bottom allows the user to take the cup and the pills from it. The WiFi unit and control unit are placed in the bottom at the back in order to have as much space as necessary. Finally, the mobile application connects to the mechanism using the WiFi unit and can help control the machine with when to dispense the pill, if the pill has been taken, or if it is necessary to refill.

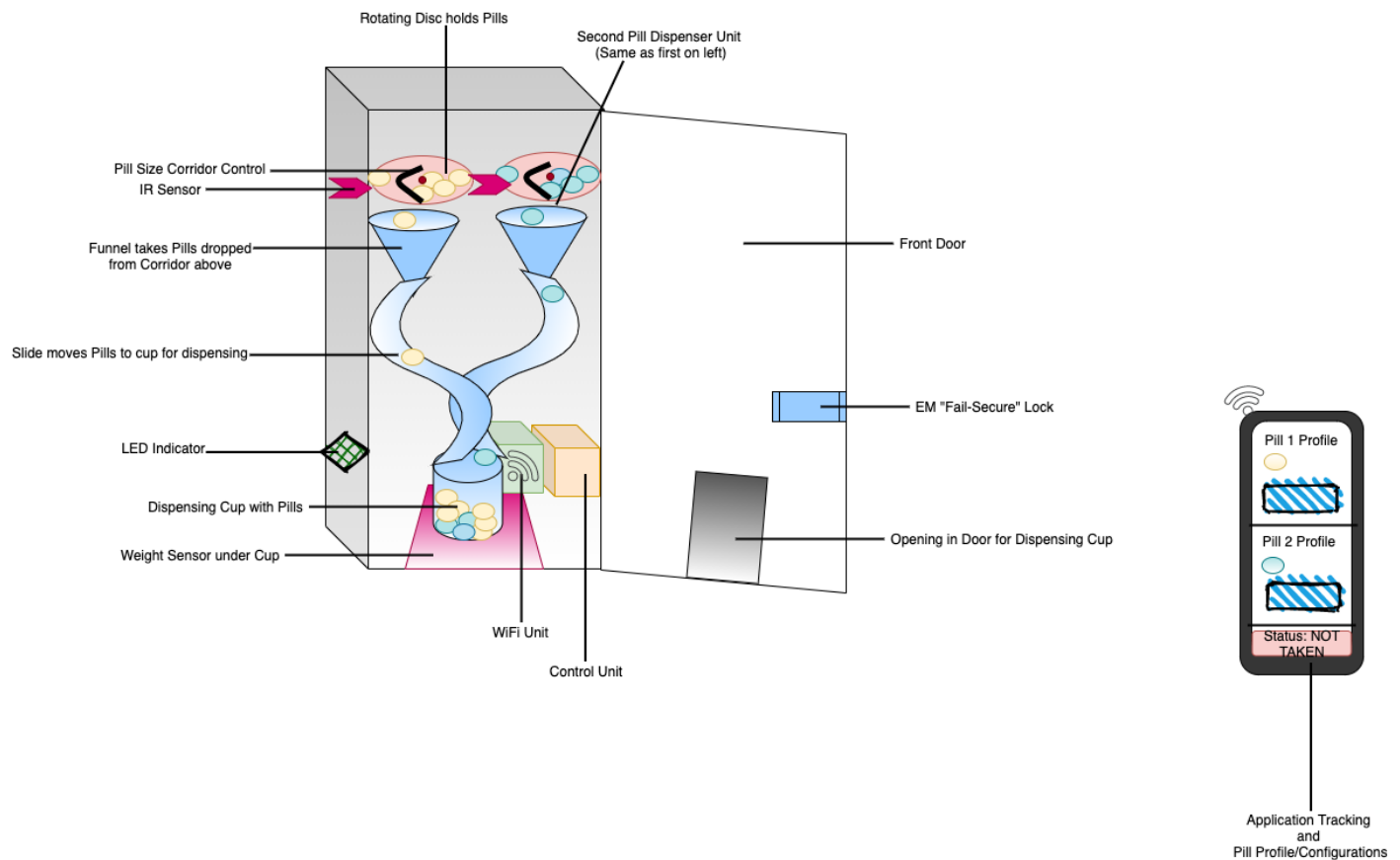


Figure 2.1.
Physical Diagram

2.2 Block Diagram

This pill dispenser requires seven sections for correct operation: power supply, microcontroller, WiFi module that connects to a server and an application, safety mechanism, sensors, motors, and an indication system. The power supply ensures that the microcontroller, sensors, lock, WiFi module, motors, LEDs, and speaker can be powered with the proper 5V. The control unit contains a microcontroller to interface with the sensors, motors, LEDs, speaker, and WiFi module. Thus allowing the microcontroller to dictate when each item's data will be used, or when it should be deployed. A WiFi module connects this control unit to a standard IEEE 802.11b/g/n WiFi network. This is so that the connected server module can interface between the mobile application and the microcontroller. The safety mechanism is connected to the microcontroller to be locked or unlocked by the microcontroller. The sensors and motors are in order to dispense a pill and are connected to the microcontroller so a specific time to run can be configured. Finally, the indication system, consisting of LEDs and a speaker, is also connected to the microcontroller to change which LED is lit and when the speaker will output noise to alert the user.

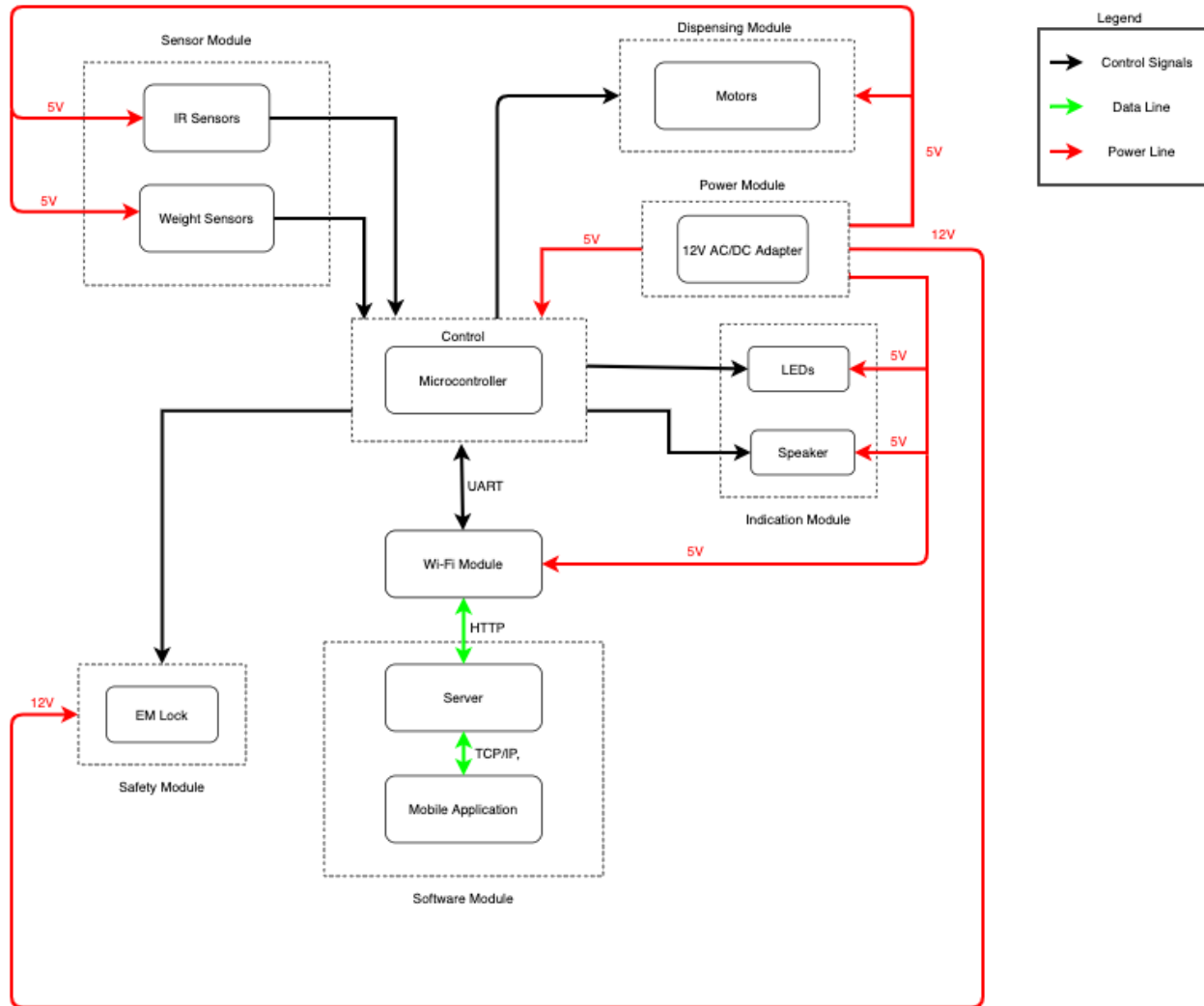


Figure 2.2.
Block Diagram

2.2.1 Power Module

A power supply is required to keep the microcontroller, sensors, motors, LEDs, speaker, EM Lock, and WiFi module working.

2.2.1.1 12V AC/DC Adapter

Power supply will be connected to the microcontroller, regulated for 5V for most of the other modules and then distributed where necessary. For the EM Lock, we will need to take the power from the microcontroller, but not regulated for 5V, instead it should stay at the 12V. The power will be plugged into an outlet for easy access and less replacement, therefore we need to convert the high power output from the outlet to the 12V that our system needs.

Requirement	Verification
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1. Must output 10.5 ± 1.5 VDC and 2.95 ± 0.05 A at an error range of 0 - 25%	1. a. Use a multimeter to check voltage drop of power supply over a $1K\Omega$ resistor to test that 10.5 ± 1.5 VDC and 2.95 ± 0.05 A is outputted using Ohm's law.
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2.2.2 Control

A control unit manages all the separate parts of the dispenser and allows them to react or deploy given specific requirements. The motor, sensors, EM lock, LEDs, and speaker need to be run at specific times to ensure that a pill is dispensed correctly and at the right time.

2.2.2.1 Microcontroller

The microcontroller, chosen to be a PIC32, handles memory allocation for the cache. It communicates with the WiFi chip via UART and reads the SD card cache through SPI (Serial Peripheral Interface).

Requirement	Verification
<ol style="list-style-type: none"> 1. Must be able to communicate over UART at speeds greater than 4.5Mbps 2. Microcontroller should take at least two analog inputs from the sensors 3. A digital output HIGH should be produced when the sensor provides a 1 and a digital output LOW should be produced when the sensor provides a 0 4. Must sink or source 10mA on each of the two GPIOs at 3.3V +/- 5% 	<ol style="list-style-type: none"> 1. Communication with the microcontroller will be verified in the wifi module 2. Test connections using driver codes <ol style="list-style-type: none"> a. Connect 3.3V to VCC to power the board b. Upload the driver code c. Set PE sensor output to 0 and check if the corresponding output pin voltage is low (approx. 0V) d. Set PE sensor output to 1 and check if the corresponding output pin voltage is high (approx. 3.3V) e. Check that the amperage can reach 10mA and expected values should be within +/- 5% of expected value

2.2.3 Dispensing Module

The dispensing module consists of the motors used to control the plates that allow only a few pills into the limited channel and to lessen the flow of pills outputted. This ensures that only the correct number of pills are dispensed.

2.2.3.1 Motors

The motor is a servo motor that will control the plate that holds a maximum of 20 pills at a time. This will interact with the microcontroller to know when to turn on to dispense the pill.

Requirements	Verifications
<ol style="list-style-type: none"> 1. Must operate at 5.0 ± 0.2 VDC 2. Must rotate 360° for a minimum of 0.07 ± 0.01 sec/60° 3. Must be able to turn 360° for a minimum of 0.07 ± 0.01 sec/60° with a load of 0.58 ± 0.05 oz attached. 	<ol style="list-style-type: none"> 1. <ol style="list-style-type: none"> a. Use a multimeter to check voltage drop over the step motor. Ensure the drop is 5.0 ± 0.2 VDC. 2. <ol style="list-style-type: none"> a. Place a plastic propellor on the motor and mark one of the propellers. Identify if the propellor passes in the same direction in the location it started at. To do this, place a marker like a piece of paper or tape in the location it started at on the motor to see if it passes by the location again. b. Test the speed of the motor somehow c. Weigh a piece of plastic or a CD such that it is 0.58 ± 0.05 oz. Attach the item to the motor and connect the motor to the power supply to see if it can still work with the additional weight.

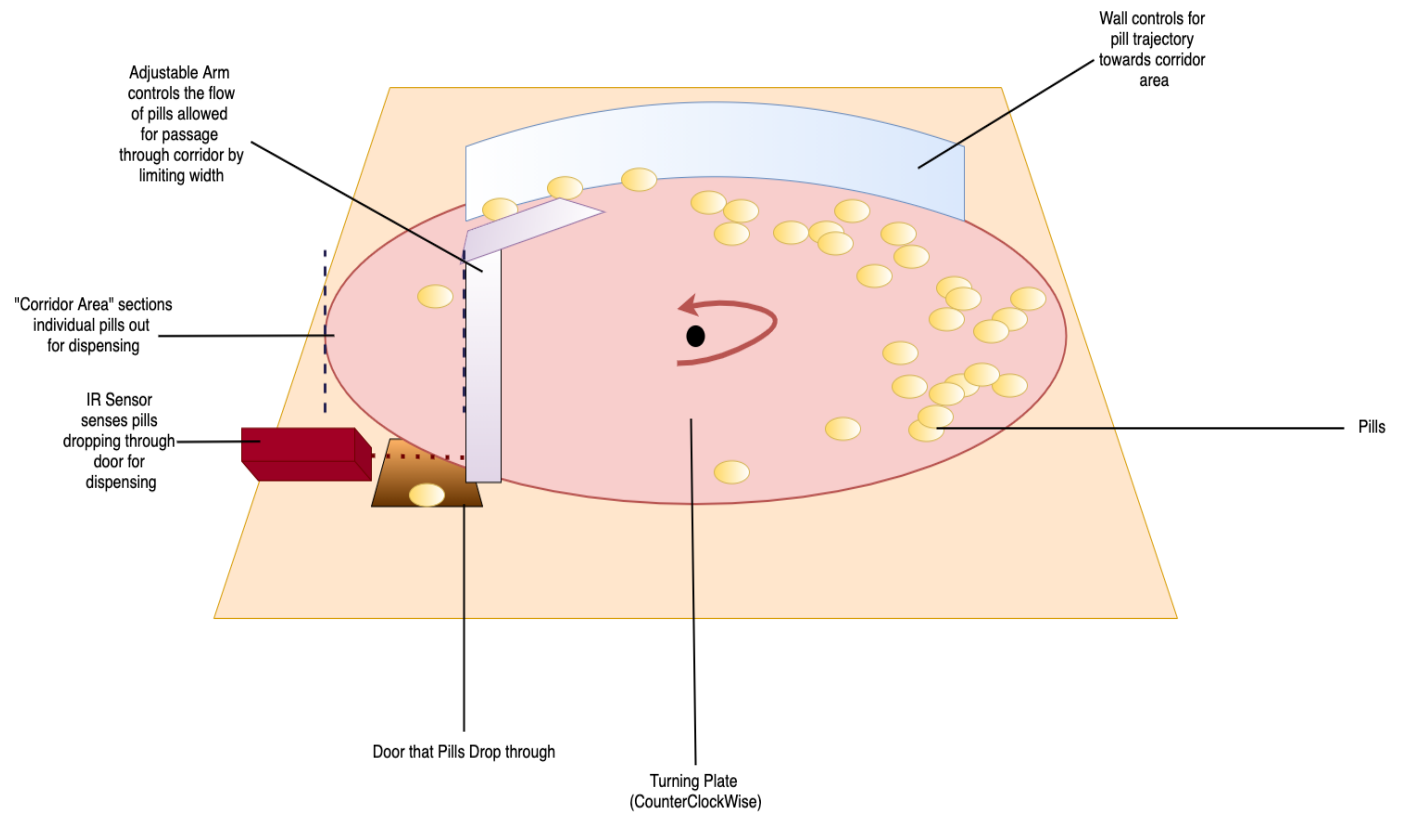


Figure 2.3. Magnified View of Plate

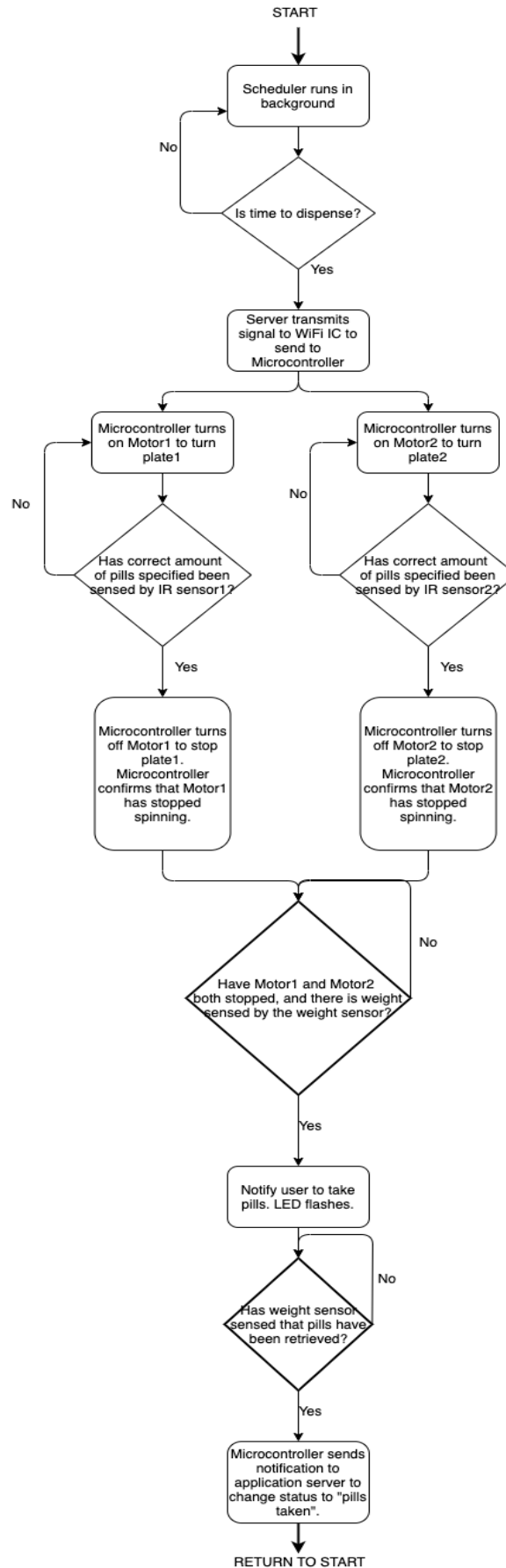


Figure 2.4. Pill Dispensing Flowchart

2.2.4 Sensor Module

The sensor module is made up of IR sensor(s) and a FX292X-100A-0100-L load sensor which keep track of how many pills leave the plate at the top and whether the pills are actually removed from the bottom.

2.2.4.1 IR Sensors

The IR sensors are located where the pill exits the rotating plate to keep track of the number of pills that exit to the cup. This is to ensure only the prescribed number of pills are dispensed.

Requirement	Verification
<ol style="list-style-type: none"> 1. Must operate at $4.1 \text{ VDC} \pm 1.4 \text{ VDC}$ 2. Must be able to detect a pill from a minimum of 50mm away to a maximum of 200mm away 3. Must be able to detect different sizes of pills 	<ol style="list-style-type: none"> 1. <ol style="list-style-type: none"> a. Use a multimeter to check voltage drop over sensor when in circuit is $4.1 \pm 1.4 \text{ VDC}$ 2. <ol style="list-style-type: none"> a. Use a small object and place it at 50mm. Connect an LED to turn on when IR sensor senses object. b. Use the same small object and place at 200mm. Connect an LED and to turn on when IR sensor sense object. c. Move the small object back and forth between 50mm and 200mm and check to see if connected LED stays on. 3. <ol style="list-style-type: none"> a. Use a small 6mm pill within the range of detection and connect an LED to IR sensor. Check to see if LED turns on. b. Use a medium 9mm pill within the range of detection and connect an LED to IR sensor. Check to see if LED turns on. c. Use a large 12mm pill within the range of detection and connect an LED to IR sensor. Check to see if LED turns on.

2.2.4.2 Weight Sensors

The FX292X-100A-0100-L load sensor is located below the cup where the pills will be dispensed to. This sensor detects the weight and therefore can tell the difference between weight when the pill is dispensed and once it has been removed by the user.

Requirement	Verification
<ol style="list-style-type: none"> 1. Must operate at 5 ± 0.25 VDC 2. Must be able to differentiate between when the cup has no pills and when it does have pills (through difference of weight measurements) 3. Must be accurate in deciding when pills are in cup and when they are not 	<ol style="list-style-type: none"> 1. <ol style="list-style-type: none"> a. Use a multimeter to check voltage drop over sensor when in circuit is 5.0 ± 0.25 VDC 2. <ol style="list-style-type: none"> a. Place a 4 oz or 8 oz paper cup on top of the weight sensor and use a multimeter to check the voltage drop. Add 6mm, 9mm, or 12mm, or all three pills and check the voltage drop over the weight to see if it has changed from the previous measurement. 3. <ol style="list-style-type: none"> a. Place a 4 oz or 8 oz paper cup on top of the weight sensor and use a multimeter to check the voltage drop. Add 6mm, 9mm, or 12mm, or all three pills and check the voltage drop over the weight to see if it has changed from the previous measurement. b. Try the above test with different numbers of 6mm pills, 9mm pills, and 12mm pills.

2.2.5 Safety Module

The safety module is meant to deter overdose of pills or tampering with the system.

2.2.5.1 EM Lock

The 1528-1191-ND EM Lock will be used to ensure that the front of the mechanism is locked at all times unless specified to be unlocked through the app. The microcontroller will maintain control over the lock.

Requirement	Verification
<ol style="list-style-type: none"> 1. Must remain locked in its natural state when under 9 VDC is applied. 2. Must unlock when $10.5 \text{ VDC} \pm 1.5 \text{ VDC}$ is applied to lock. 	<ol style="list-style-type: none"> 1. a.. Use a multimeter to probe the voltage entering the EM lock at increments of 0.5 volts, starting from 0 VDC. The lock should remain locked. 2. a. Use a multimeter to probe the voltage entering the EM lock at increments of 0.2 volts, starting from 8.8 VDC to 12 VDC. The solenoid should retract when 9 VDC is reached and remain unlocked until a value larger than 12 VDC is reached.

2.2.6 WiFi Module

Data from the control module (microcontroller) is sent via UART to be accessed on a WiFi network. A WiFi SoC (System-on-a-Chip) operates off SPI flash program memory and uses an antenna for both receiving and transmitting.

2.2.6.1 WiFi IC

We have chosen our WiFi IC, the ESP8266, with cost in mind. This chip includes a 32-bit microcontroller and WiFi transceiver. This was chosen since it allows for easy information relay to and from a local server created from the WiFi module. It operates at 160MHz (overclock) and has data input communication with the PIC32 microcontroller via UART.

Requirement	Verification
<ol style="list-style-type: none"> 1. The WiFi IC must be able to communicate over IEEE 802.11b/g/n at >100kbps with a 50 nominal RF connection 	<ol style="list-style-type: none"> 1. <ol style="list-style-type: none"> a. Connect voltage to the microcontroller and wifi modules

<p>2. The WiFi module must be able to communicate over UART</p>	<p>b. Upload a sketch using the Arduino for UART connection between the devices</p> <p>c. Connect the TX/RX pins and check that the devices communicated</p> <p>2.</p> <p>a. Connect the wifi module to the microcontroller using TX/RX pins</p> <p>b. Using the Arduino test the communication using driver code to ensure that data is being send back and forth</p> <p>c. Test using both HTTP and a WiFi hotspot</p>
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2.2.7 Software Module

Data from the WiFi IC is sent to the software module through the server. The PIC32 with the microcontroller is able to communicate to the server that will receive and send the data to the application.

2.2.7.1 Server

The server design will consist of a microcontroller, a cellular receiver, and a WiFi dongle. The main function of the server is to send and receive data to/from the mobile application.

Requirement	Verification
<p>1. Must be able to establish port connection for host-client transmission of data from microcontroller to application</p> <p>2. Use POST and GET requests for transferring data, interface between microcontroller to application</p> <p>3. Must establish WiFi connection</p>	<p>1.</p> <p>a. Create a web server using the Arduino IDE using given code</p> <p>b. Add in credentials and test the web server by entering the ESP IP address into a web browser</p> <p>2.</p> <p>a. Using the created web server, connect LEDs with simple web server code and test that LEDs</p>

	<p>can turn off and on by command on web browser through IP address.</p> <p>3.</p> <p>a. Using LED and web browser testing, if successful, then WiFi connection is established.</p>
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2.2.7.2 Mobile Application

The main function of the application is to allow the caregiver to put in details of the pill intake and keep track of when the pill has been taken and when to refill. This will serve as the main interface for any adjustments to the pill dispensing.

Requirement	Verification
<ol style="list-style-type: none"> 1. Must be able to connect to the server by WiFi and access updates from the server. 2. Must allow the caregiver to successfully unlock the machine for medication refill and be updated on the status of pill dosage and dispensing. 3. Should allow the caregiver to input prescription details to change the mechanical environment such as dispensing the appropriate medication and locking and unlocking the dispenser to add in more medication. 	<ol style="list-style-type: none"> 1. a. Echo statements between WiFi point and server ports. Send a statement between the host and client to confirm that the connection has been made. 2. a. Verify that the application is connected to the server and WiFi IC first with Requirement 1. Then, use print statements to verify that the correct data is sent when selected by caregiver on User Interface. Use print statements when debugging on microcontroller to show that output voltage to control EM lock turns HIGH. 3. a. Use print statements to verify user input is received correctly as raw strings then converted to correct types after processing and storing.

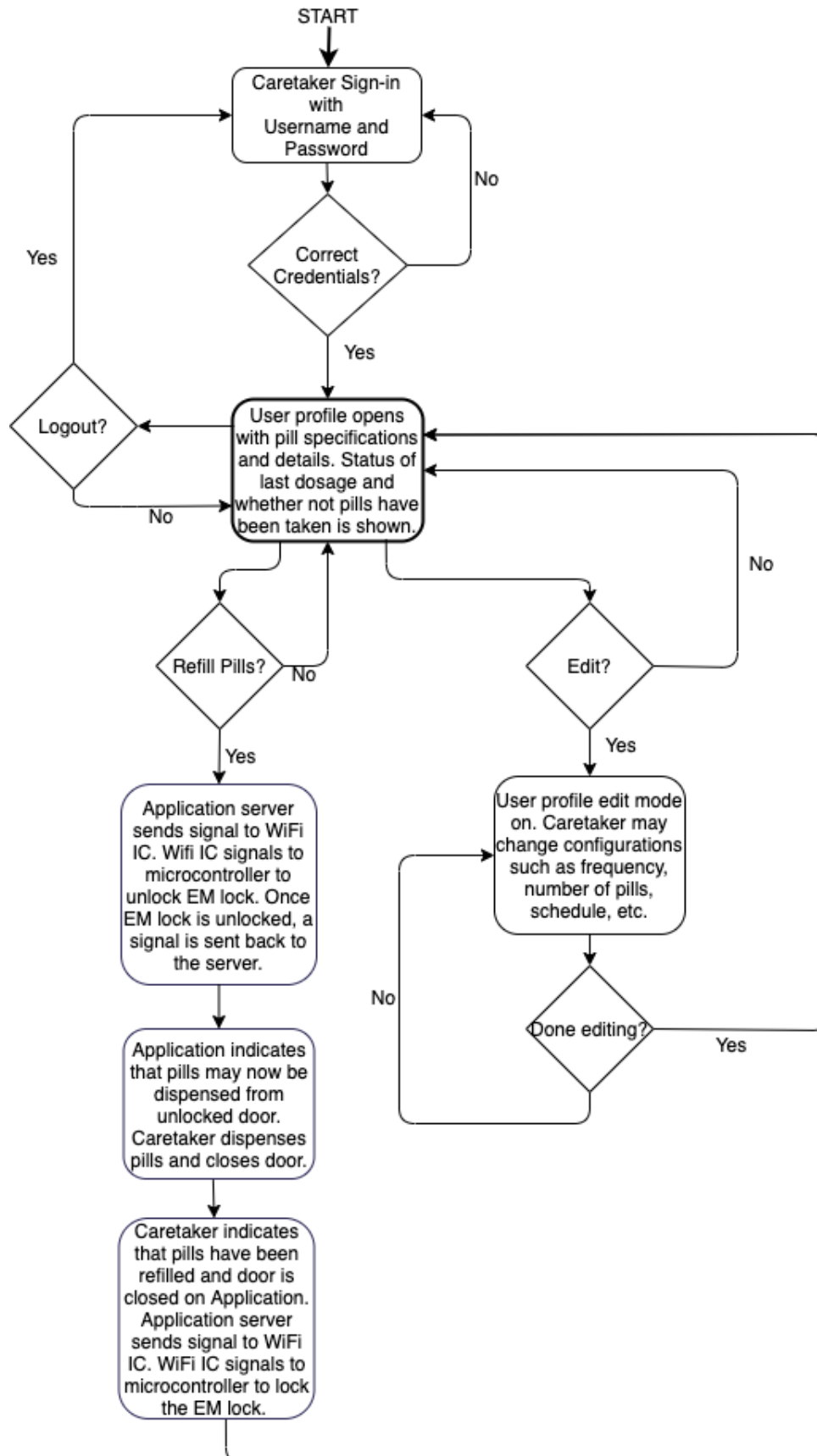
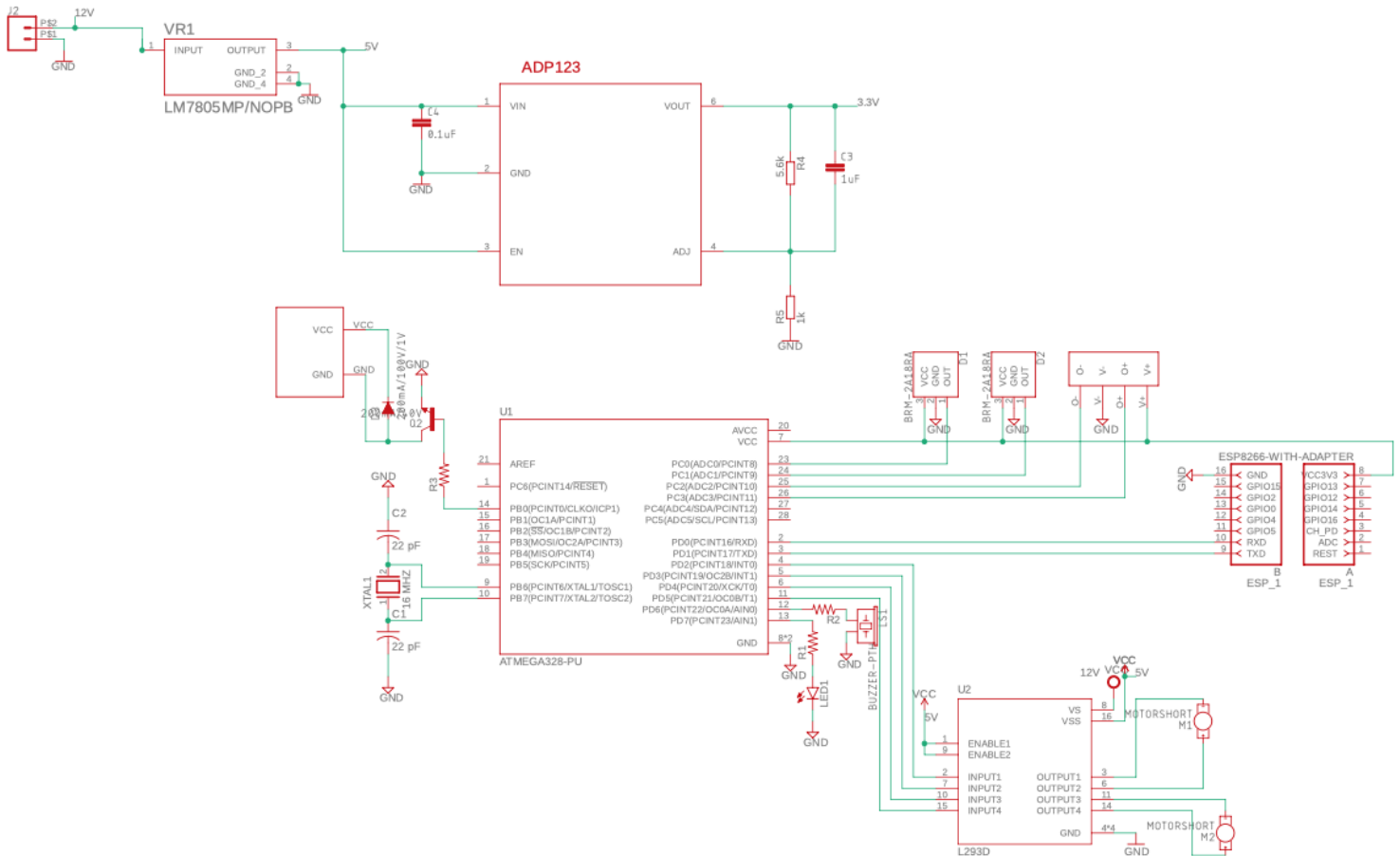


Figure 2.5. Caretaker Application UI Flowchart

2.3 Schematic



2.4 Tolerance Analysis

As modern medicine continues to improve, lifespans are potentially extended through medications and pill dosages to address health issues. However, most people who have to take medication to maintain their quality of life tend to be of the older generation and will forget what pill to take, when to take it, and how many they have to take. There are many caregivers who will be responsible for keeping track of this information, but it can become quite difficult when caring for many different people.

An important factor for the success and proper functioning of our pill dispenser is ensuring that that correct number of pills are dispensed. In order for us to ensure the correct dosage is dispensed each time, we use an IR sensor to detect when a pill is ready to be dropped and we keep a count in the microcontroller using the output of the IR sensor. Once the correct count of pills has been reached, the motor for the disc, which the pills sit on, must stop immediately to prevent further pills from being dispensed.

The IR sensor must be able to detect a pill in the range of 50mm to 200mm. Based on the graph below, different photodiodes yield a different range of Analog-to-Digital voltage output. The output is sent to the microcontroller in order to make the decision to stop the motor. Thus, the photodiodes in the IR sensor must be sensitive enough to detect the pill at the aforementioned distances.

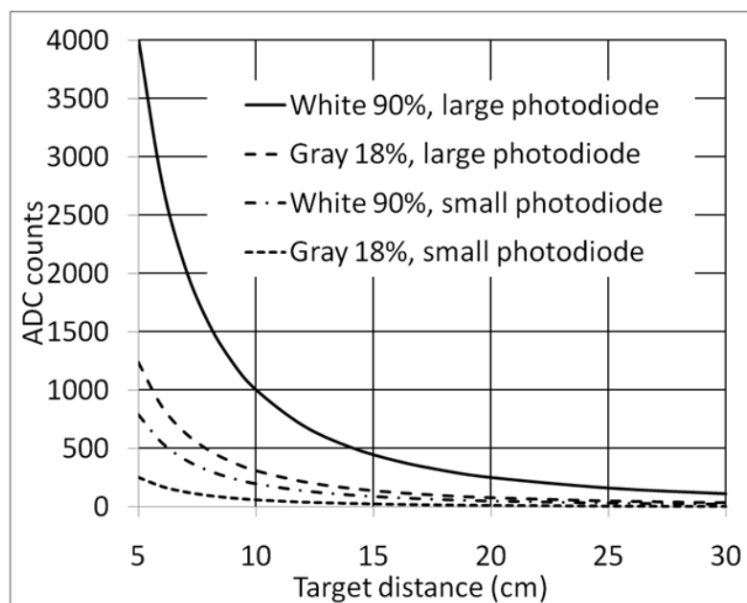


Figure 2.6. Proximity Response Using Kodak Gray Cards, PS_RANGE = 0, PS_ADC_GAIN = 0 (Single 25.6 μ s LED Pulse), 22.5 mW/sr, No Overlay (Preliminary)

Given a diameter of 140 mm, the plate should rotate such that pills passing through the corridor have sufficient space in between. An estimated 100 mm will be the length of the arm. Thus, the pills will have a runway of 100 mm before dropping down. This length of runway should have an IR sensor placed enough in advance to sense a pill, forward the signal to the microcontroller, send a signal back to stop the motor, and physically stop the rotations before it is sensed by the IR sensor. With an average weight of 500mg, the average pill's velocity must reach termination before the IR sensor; in turn, the motor must spin the plate such that the pill's velocity will reach termination before the IR sensor. This factor assumes that the IR sensor operates optimally according to the reception of IR light and propagation of signals to the microcontroller.

In addition to the delay caused by the propagation of signals from the IR sensor to the motor, it is important to account for the pill sliding after the disk has stopped spinning. The extra distance traveled by the pills will be the sum of the distance traveled because of the propagation delay and the distance the pills slide. Accounting for both of these, we can determine how much of a time error can be tolerated to allow for the pill we want to dispense to be dropped but having the disk stop before the pill after it drops as well.

$$\text{distance traveled} = \frac{v^2}{2\mu g} + v\Delta t, \text{ where } v = (R - r)\omega$$

R = radius of disk

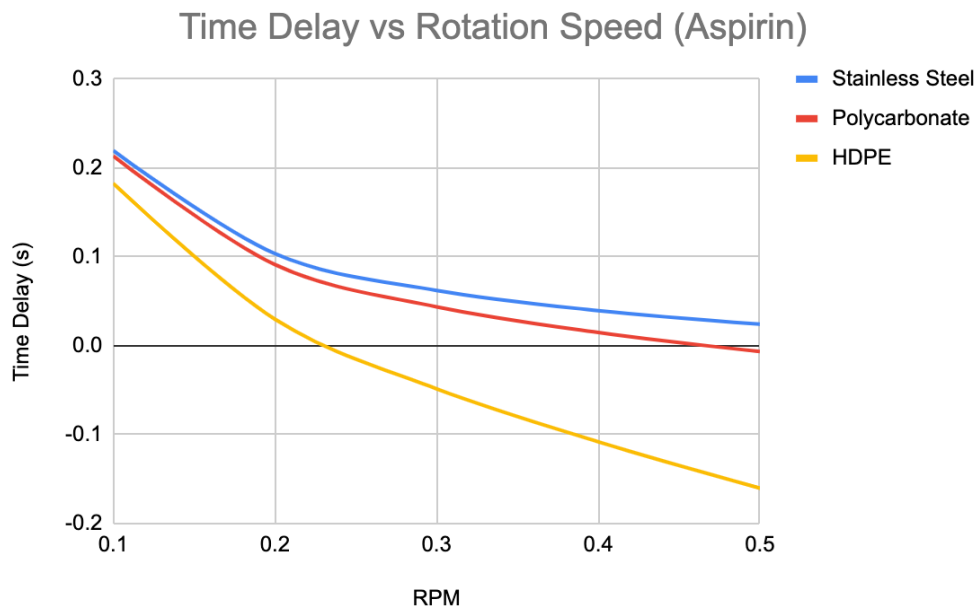
r = radius of pill

μ = coefficient of friction

This can be manipulated to find the maximum tolerated time delay for a single pill to be dropped.

$$\Delta t < \frac{3r}{2(R-r)\omega} - \frac{(R-r)\omega}{2\mu g}$$

Assuming our disk has a radius of 0.07m and the radius of the pill is 0.006m, we can solve for the maximum tolerated time delay of a pill on different surfaces with different coefficients of friction. We found the coefficient of friction of pills on different surfaces in a paper investigating the sliding coefficient between pills and different surfaces [5]. Taking the coefficient of friction of Aspirin 325mg film coated tablets on different surfaces, we found what the maximum tolerated time delay would be on our mechanism at different speeds.



Using this information, we can see the difference in using different materials as the disk. Another important factor is that we will need to run the motor quite slowly if we don't want to dispense more pills by mistake.

3 Cost and Schedule

The cost of development can be calculated assuming 10 hours per week of work for 16 weeks for 3 team members. We will assume an average salary of an electrical/computer engineer of \$35 an hour.

$$3 \text{ people} * \$35/\text{hour} * 10 \text{ hours/week} * 16 \text{ weeks} * 2.5 = \$42,000$$

3.1 Cost Analysis

Description	Manufacturer	Part Code	Quantity	Cost
EM Locking Mechanism	Adafruit Industries LLC	1528-1191-ND	1	\$14.95
Motor Driver	Texas Instruments	L293D	1	\$2.67
Load Cell (0-100g)	Phidgets Inc.	CZL639HD	1	\$7.00
DC Motor	Jinlong Machinery & Electronics, Inc.	Q4TL2BQ360003	2	\$7.16
WiFi IC	MakerFocus	ESP8266-01	4	\$12.99
RGB LED	SparkFun Electronics	COM-00105 ROHS	1	\$2.05
Microcontroller	Microchip Technology	ATmega328-PU	1	\$2.30
Power Supply AC to DC converter	ShenZhen HuaKe Light Electronics Co., Ltd.	12V100W	1	\$36.99
Linear Voltage Regulator	Texas Instruments	LM7805	1	\$1.40
Linear Voltage Regulator	Analog Devices Inc.	ADP123	1	\$1.22
Speaker	Adafruit Industries LLC	AL-30P	1	\$1.85
IR Sensor	Vishay Semiconductor Opto Division	SI1143-M01-GMR	2	\$3.70
Transistor	Adafruit Industries	TIP120	1	\$2.50

	LLC			
TOTAL COST:				\$96.78

Section	Cost
Labor	\$42,000
Parts	\$96.78
Total	\$42,096.78

3.2 Schedule

Week	Jerry	Deonna	Pallavi
3/8	Talk to Machine Shop, Order Parts	Talk to Machine Shop, Order Parts	Talk to Machine Shop, Order Parts
3/15	Testing EM Lock	Testing IR Sensor	Testing Load Cell
3/22	Setup Application Interface, Test Motor	Verify PCB design, Test Motor	Setup port-to-port server control
3/29	Solder on standard parts, continue Application Interface	Solder on Microcontroller, fix mechanical pill dispenser into frame	Solder on standard parts, fix mechanical pill dispenser into frame
4/5	Test Pill Dispenser with application interface and load cell	Test Pill Dispenser with motor and IR sensor detection	Test Load cell with application interface
4/12	Debugging Application Interface	Make last hardware adjustments and Microcontroller tweaks	Debugging Motor Controller
4/19	Mock Demo	Mock Demo	Mock Demo
4/26	Demo/Final Paper	Demo/Final Paper	Demo/Final Paper
5/3	Demo/Final Paper	Demo/Final Paper	Demo/Final Paper

4 Safety and Ethics

There are a few potential safety hazards with our project. This is mainly regarding the use of a microcontroller, sensors, motors, EM Lock, and a WiFi module. This is because there could be the issue that the microcontroller stops working or sends wrong information about the amount of pills to dispense. If it is too many pills, overdose can cause fatal or potentially lethal side effects such as internal bleeding, bruising, poisoning, etc. If the sensors and modules overheat, this could negatively affect the medication as pills become ineffective over 86°F [4].

Another large safety concern is if the outlet adapter does not work properly, it could allow too much amperage and cause a fire or short circuit the system. To safeguard against this, we will thoroughly test the adapter to ensure it works as expected and double check the connections of the subsystems and modules to ensure they are not receiving more current than they should be. This will lessen the likelihood of a fire. To mitigate the possibility of a short circuit, we will have to double check how we connect power and ground to all of our sensors and modules.

We develop this project in firm belief of IEEE Code of Ethics 1.1 “to hold paramount the safety, health, and welfare of the public”[1] at the heart of our project. This solution proposes to accept the growing elderly population and help assuage the inevitable need for more precise caregiver control. Thus, we also consider safety lock features in case of potential abuse of our product by addicts.

We also seek “to improve the understanding by individuals and society of the capabilities and societal implications of conventional and emerging technologies”[1] by giving control of the drug distribution to medical caregivers instead of engineers. This technology is being developed for health fields in hopes of improving coverage with accessible innovation.

Furthermore, we earnestly acknowledge the use of prior developed technologies in our modeling of the dispensing system as 1.5 states that we must “be honest and realistic in stating claims or estimates based on available data, and to credit properly the contributions of others.”[1] The aforementioned mechanical complexity we model and alter our dispensing system after seeks to make for a safer and more accurate system for patients.

5 Citations

- [1] Ieee.org, "IEEE IEEE Code of Ethics", 2016. [Online]. Available: <http://www.ieee.org/about/corporate/governance/p7-8.html>. [Accessed: 29- Feb- 2016].
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