PILLSAFE SMART DISPENSER AND APP

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Abstract

This report summarizes what we did for the senior design project. We design and implement a smart pill dispenser and its companion app. Compared with similar products currently in the market, our dispenser is specifically designed for drug abusers. A cascade dispensing system is designed to physically limit patients' access to pills. The app is designed with two different versions for patients and doctors to monitor patient's behaviors. A WiFi module ESP8266 is used to connect APP and dispenser. All functions for hardware and software have been successfully achieved separately with relatively good performance. Future work is covered at the end of this report and is mainly about wireless communication between the automatic dispenser and the app.

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1. Introduction

1.1 Problem and Solution Overview

Many people are struggling with drug abuse in the world. This problem has aroused great concern of the government. According to the National Center for Drug Abuse Statistics (NCDAS), 700,000 drug-overdose deaths have happened in the United States since 2000 [1]. Statistics show that $34.6bn has been used for the Federal budget for drug control in 2020 [1]. More often, the overuse occurs in daily life, because it is difficult for doctors and guardians to supervise patients to use the correct number of pills. Although there are several commercial items related to drug use on the market now, most of them are easy to get smashed and cannot prevent people from drug-abusing by just smashing the bottle [2]. Most of the existing smart pill boxes are not for drug abusers. Drug abusers can not control how many pills they take each time and when to take the pill. So overusing happens frequently for drug abusers. Fortunately, drug abusing is treatable. Thus, it is believed designing and building a device for preventing drug abuse is meaningful and useful.

Inspired by the Health Maker Lab project 5, we built a smart device to dispense pills. The Pillsafe smart dispenser has the following functions. Firstly, it has a dispenser system which can count exactly the number of specific pills needed for the patient each time to avoid overuse using a photoelectric sensor. Secondly, it has a security system to avoid any tampering with the cap or the bottle. Last but not least, it has a notification system which involves both the hardware and software. On the hardware side, it has a LCD to display instructions and an LED to notify the user when the user cannot take anymore. On the software side, it gives guardians/doctors the right to supervise the patient. The app will notify the doctor or the guardian when the patient uses the drug and if the user has any misuse performances. It also includes an algorithm to study the patients' drug taking habits and provide information for the treatment.

Details of every module will be explained later. Cost evaluation and ethical consideration will also be covered in the last two sections of this report. Our device achieves the main function to limit pill dispensing and monitor patients' behaviors, but future work needs to be done to achieve wireless communication and improve performance of the dispenser.

1.2 High Level Requirements

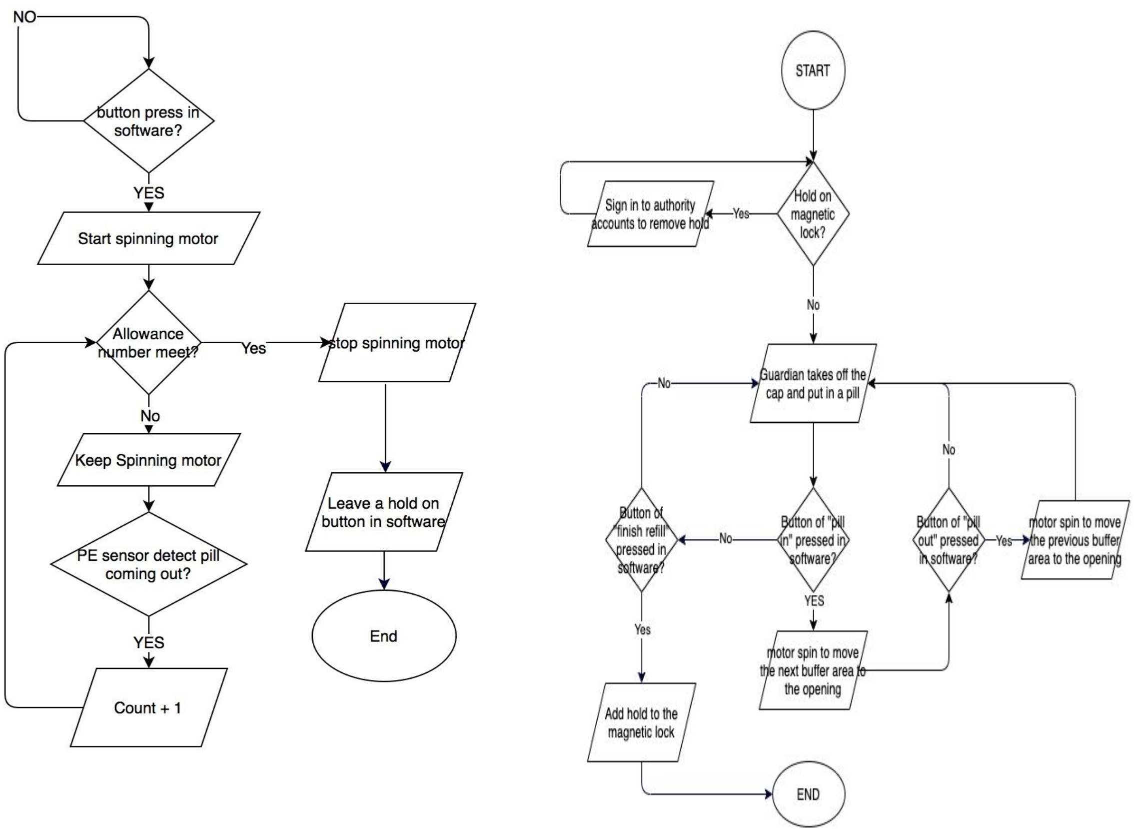
- The PillSafe bottle can add and dispense different numbers and types of pills. The dispensing success rate should be greater than 90%. In each successful dispensing, only one pill should be dispensed.
- The PillSafe Cap can protect the opening on the bottle. It should be able to detect violations, such as trying to pull up the cap or breaking the cap. The design should be

able to send out notifications when violations are detected. Notifications on users' software apps will appear in 3 s, with at most 5 s lagging.

- The Pillsafe app should allow guardians/doctors to set up the allowance number of dispensing. The app should also be able to analyze the user drug using habits, such as the interval of dispensing.

1.3 User Workflow

The user is allowed to load the pill but not dispense the pill. So the dispensing process is automatic. It is controlled by a microcontroller unit (MCU). The process of dispensing pills will be shown in Figure 1 (a) . The loading process is shown in Figure 1 (b). For authorized users, they need to open the dispenser and fill in pills. While for unauthorized users, they can choose the "start dispensing" button on the app to dispense pills automatically.



(a) (b)

Figure 1: Flowchart of User Workflow: (a) Dispensing; (b) Refilling

2. Design

The design mainly contains eight modules as shown in the block diagram in Figure 2. Design details about each individual module will be covered in this section.

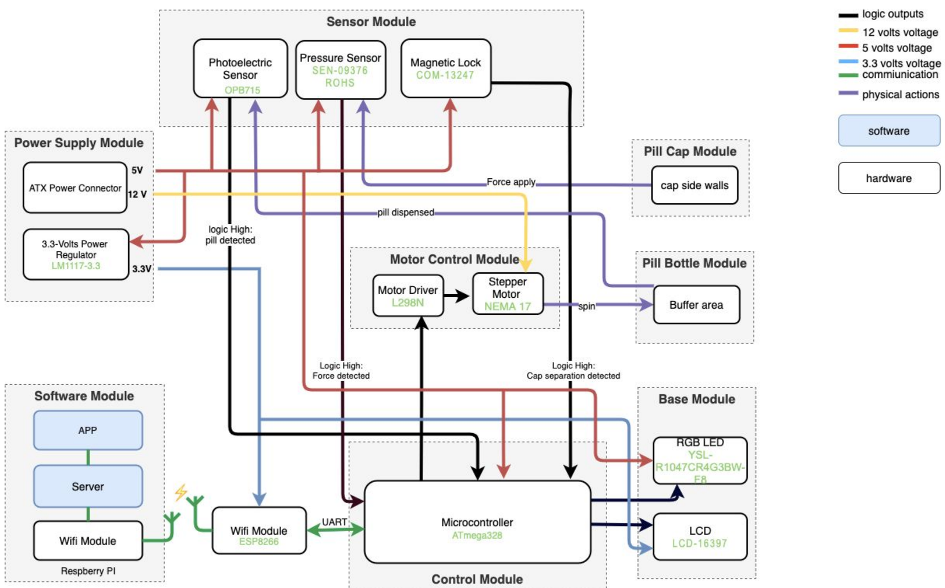
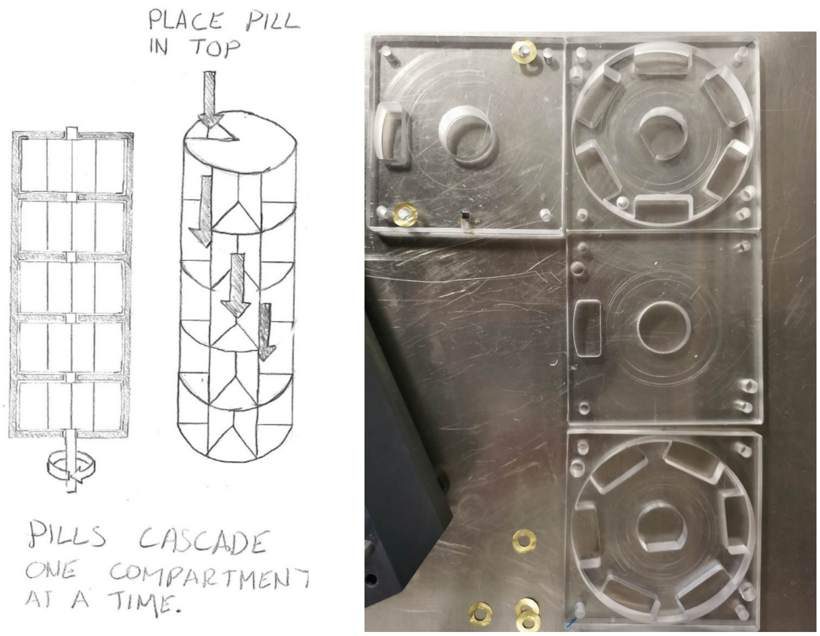


Figure 2: Block Diagram

2.1 Mechanism Design

The pill dispensing bottle is intended to provide automatic dispensing in addition to being hard to destroy. To achieve this, all electrical components and the motor are located in the lower part of the bottle to avoid being damaged from users when they are trying to take pills from the top part. In order to dispense pills automatically, we chose a mechanism that can be controlled by a motor and dispense one pill at a time. The mechanism is the cascading dispensing system as shown in Figure 3(a). One benefit of the system is that it can be easily controlled. Pills will cascade from one space to another when the motor in the middle spins. Another benefit of this design is that the user can change the pill capacity based on their preferences by simply adding or removing the pill plate section depicted in Figure 3(b).



(a) (b)

Figure 3: (a) Cascade dispenser model[4], (b) Real products

The Electrical and Computer Engineering (ECE) machine shop built a prototype for our cascading dispensing system. Each plate comprises a fixed size hole therein to be rotated by the motor. The spaces on the plate as shown in Figure 3 is 6. Its length is roughly 3 cm. Each plate is about 2 cm thick and 1 cm wide. Overall the pills dimension can be 3 cm * 1.5 cm * 2 cm. The dimension fulfills most of the pills and capsules' sizes on the market, even the largest capsule size 000 fits in well. Below the plates is the base made by PVC. PVC materials are hard to break and inexpensive. The base houses a 12 Volts stepper motor, which will be further described below in the Hardware Design Section. In front of the base is a platform. Half of the platform is caverned out to hold pills, and the other half is used as display areas for LEDs and LCD.

2.2 Hardware Design

2.2.1 Power Supply Module

The dispenser bottle itself does not require power supply. The NEMA 17 Stepper motor in the base of the dispenser requires 12 V voltage supply. In the initial design, a battery pack and a boost converter to meet the 12 V requirement was proposed. However, after consulting with the machine shop that the motor will draw as much as 400 mA when active, we realized that the lifetime will be an issue if battery packs are used. So finally the wall mount power supply is used, which has a AC to DC converter and can convert the voltage from 120 V to 12 V.

In addition, the design needs 5 Volts power supply for the sensors and the microcontroller. 3.3 V logic voltage supply is needed for LCD and the wifi module. The Sparkfun ATX Power Breakout kit is used for 12 V and 5 V and one voltage regulator to create 3.3 V from 5 V. The voltage regulator is LD1117-3.3. This regulator will provide 3.3 V output for a 5 V input. This version is an adjustive voltage regulator, it has two outputs: 5 V and 3.3 V. This makes our power connector design on the PCB more convenient.

2.2.2 Photoelectric Sensor Module

The photoelectric sensor(OPB715z) module is designed to detect the presence of pills in the dispenser. The sensor itself is a retroreflective sensor, which means that the emitter and the collector are on the sensor. The emitter will shoot out a light beam when the sensor is turned on and receives the reflected light from the objective. It has the characteristic that once the light transmission is interrupted, a logic 1, or 5 V will be produced. In the design, pills are the objective. In a normal situation, when the pill is not in the loading space, the transparency sidewalls of the plate will let the light beam go through and reflect back a high percentage of initial intensity. When the pill is loaded, the light will be interrupted and only a small percentage of the initial intensity will be reflected. In this way, the sensor indicates whether the pill is loaded or not.

Initially, the sensor was placed at the opening. But during testing, the falling speed for the pill is so high that the sensor could not react properly. A failing rate(not detected) over 95% occurs when the sensor is placed at the opening. The final location where the sensor is placed is shown in Figure 4. A new counting algorithm is created to determine whether the pill is dispensed or not.

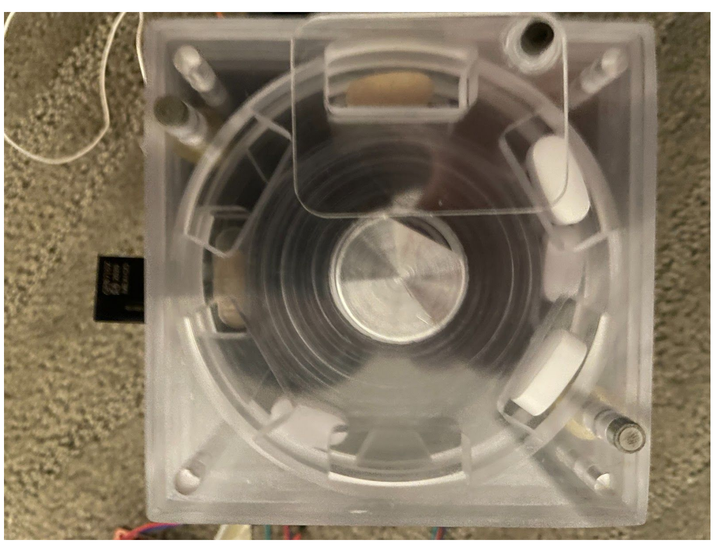


Figure 4: Final Location of PE Sensor (the black box on the left)

2.2.3 Pressure Sensor Module

The pressure sensor module is designed to detect the violations from users. It is used to trigger alarms when large forces are applied to the dispenser bottle. The methodology behind this is the force sensitive resistor and a voltage divider circuit. The Force curve is shown in the left of Figure 5 and the schematic is shown in the right of Figure 5. (we do not use the amplifier) The force will be calculated according to the analog voltage reading of the 3.3 kΩ. After analog readings are gained from the microcontroller, it is turned into digital value and calculations are done to find out the force sensitive resistor's resistance. Finally the resistance is used to calculate the forces. The equations are shown below.

$$fsrV = fsrADC * V_{cc}/1023 \quad (1)$$

$$fsrR = R_{div} * (V_{cc} / fsrV - 1) \quad (2)$$

$$fsrG = 1 / fsrR \quad (3)$$

$$force = fsrG/0.000000642857 \quad (4)$$

Where fsrV is the digital value of the voltage on the force sensitive resistor, and fsrADC is the analog reading. fsrR is the force sensitive resistor's resistance, V_cc is the supply voltage which is 5 V. fsrG is the conductance for the force sensitive resistor. "force" is the force applied on the sensor, the unit is grams. To make it sensitive, the alarm bar is set to 1 gram. In reality, this value will be set high so the fault tolerance is high.

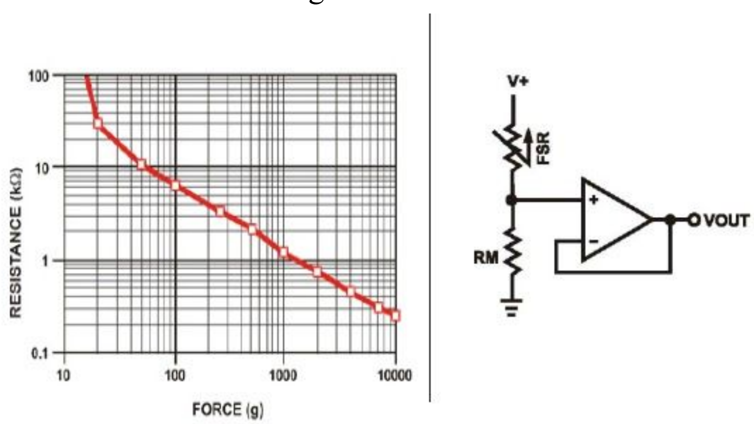


Figure 5: Force Curve(left) and Schematic(right) of Pressure Sensor

2.2.4 Magnetic Switch Module

The magnetic switch module is a normal on switch. By normally on it means that the power output will be high when the switch is closed and low when the switch is off. The switch is used to detect whether the user opens the bottle or not. The output voltage is read by the microcontroller. One part of the switch is located on the bottle and another part is located on the cap. Normally, they are together. According to the tests in the lab, it is very sensitive that even less than 1cm apart will turn off the switch.

2.2.5 Motor Module

The motor is an upscaled 12V bipolar stepper motor(NEMA17HS13-0404S-PG5) with active torque of 4Nm and 1.8 degrees per step. The motor is driven with an H-Bridge driver(L298N). This motor drive has 2 wires to control winding A and 2 wires to control winding B, which matches the bipolar characteristics of the 4 wire NEMA17 stepper motor. The motor driver requires an additional 5 V power supply. Four separate PWM signals from the microcontroller control each polar of the motor. It also has a heat sink.

More importantly, a calibration for the motor is needed. According to the datasheet, the motor rotating degree per step is 1.8. However, due to the heavy load on the base, in other words, the four plates, the motor's step per revolution is not 240. This means that the motor can not rotate 360 degrees in 240 steps. The detailed calibration process will be introduced in the verification section. After calibration, a correct relationship between the step and rotating angle for this specific physical design is created. This is good to demo for this class, but in reality, the physical design will be changed by adding or removing plates. So some other methods such as a larger power motor or an angle sensor will be used to do the calibration automatically.

2.2.6 Display Module

The display Module contains two parts. The LEDs and the LCD. Three regular LEDs for green, yellow, and red colors are used. LED lights are used to notify the user the situation of dispensing. Green will light up when the pill dispensing process starts. Yellow will light up when the pill is dispensed to notify the user to take the pill. Red will light up when detecting violations.

The LCD screen is used to display instructions. It will print words such as "dispensing start" " 1 pill dispensed, please take the pill" "dispensing finished" "Stay away from the bottle!" "Put Cap Back" " Please refill" "Wifi Connected" and etc based on situations and contents. The model is Sparkfun Electronics LCD-16397. This LCD has a size of 8.5 cm*3.5 cm, which is fittable on the base's front edge. It is also a 24*2 LCD, so it can display enough information on it. The LCD is individually programmed, and it interface with the ATmega328P with Qwiic connections, which is one of the simplest type of i-squared-c connection

2.2.7 Microcontroller Module

The microcontroller in this project is ATmega328P. The microcontroller has four primary functions to meet the high level requirements: 1) manage and transfer data through the wifi module; 2) activate the stepper motor during loading, refilling, and dispensing processes; 3) receive and process input voltages from sensors in digital input pins and analog input pins; 4) communicate with the LCD to display information to users. All of these functions are coded in the microcontroller. The platform to code the microcontroller is the Arduino IDE.

Inside the code, some libraries are used. First, the Stepper library is used to control the stepper motor. Comments such as “stepper revolution“, “clockwise”, “Mystepper.step” are used to control the speed and rotation of the motor. Specifically, 190 steps forward and 10 steps backward are used to rotate one loading space to the next. 0 step is used to stop the motor. Secondly, the Wire library is used to communicate with the LCD. Inside the library, functions such as i2cSendValue and begin/endtransmission are used. The function i2cSendValue can switch to different cases based on the variable inputted. In our design, 9 situations are coded for the function. Each switch case will contain words or numbers.

The dispensing process and the loading process are dependent on the integration of the software and hardware in this project. In the microcontroller’s code, several holds are held for the user. Only authorized users such as doctors and guardians can remove the holds. For example, if the patient opens the box, the system will send alarms. But when the doctor opens the box, the system will not send alarms.

2.2.8 PCB

In this design, the PCB should specifically make the microcontroller work individually. Also the PCB should have multiple pins for power connections. Since electronic devices are put in different locations around the dispenser, We decide to use fly wires to connect to the power pins on the PCB and place the other components at the correct location. For example, the pressure sensors are on the side walls, the LCD and LED are on the front edge of the base, the motor driver is on the back of the base and the magnetic switch is on the cap.

To integrate the power module on the PCB, the atx power connector ports and the voltage regulator are added. The schematic and board diagram is shown in Figure 6 and Figure 7 below.

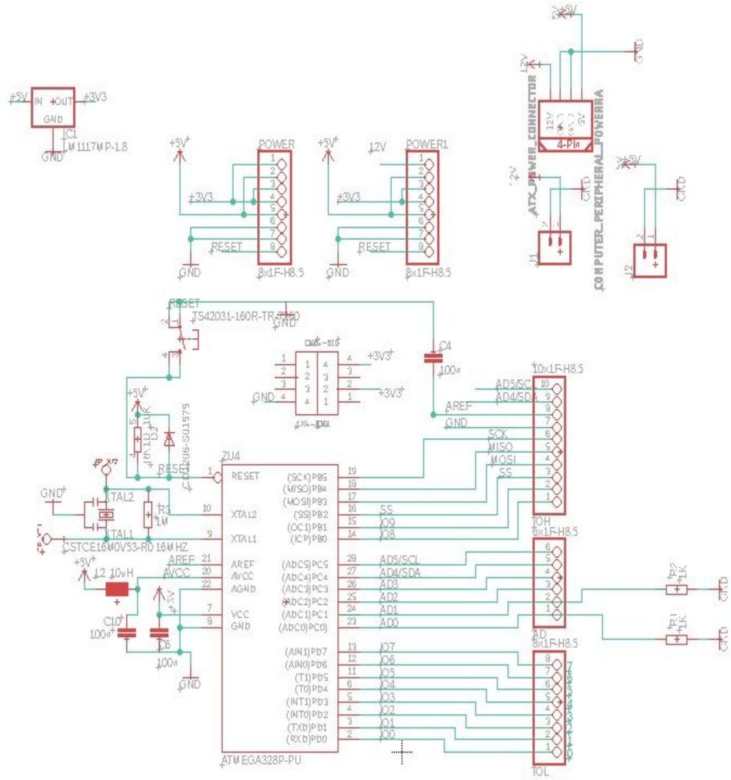


Figure 6: Schematic diagram of Microcontroller

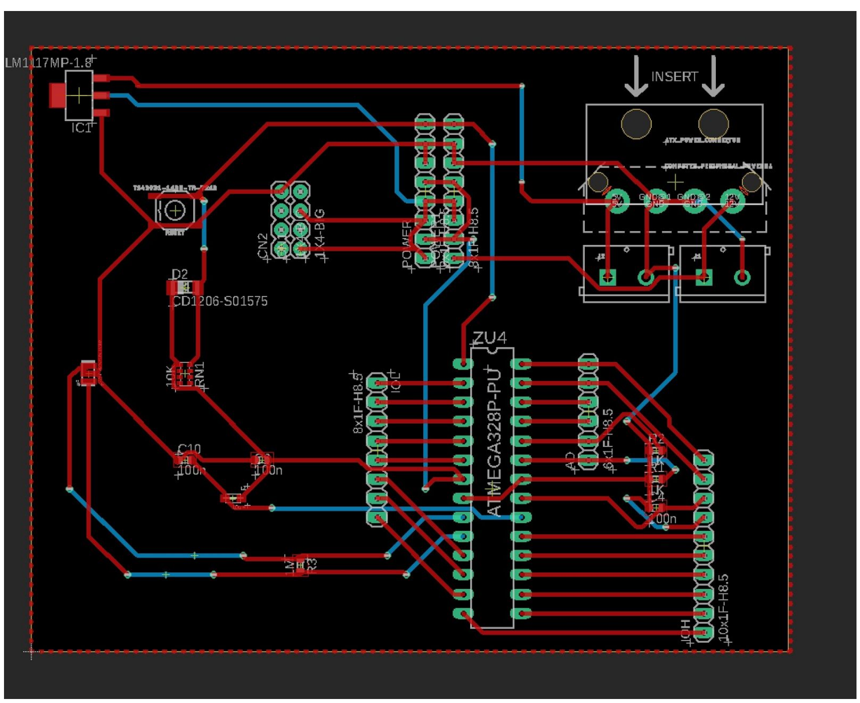


Figure 7: PCB design of Microcontroller

2.3 Software Design

2.3.1 Wifi Module

ESP8266 WiFi module is designed to achieve bi-direction communication between our microcontroller and the app. When violation behaviors such as breaking dispenser or unwanted removal of cap are detected by sensor module, MCU would send a signal to the apps through ESP8266 and then both patient and guardian would get notified on their app. In our design, the WiFi module can also allow patients and doctors to control the MCU and thus the dispenser.

2.3.2 App Module

The App module aims to receive data from the smart cap in real time. There are two different versions of the app: one for doctors and one for patients. The doctor version app has functions of setting the number of pills in the bottle(set allowance), setting the number of pills from 0 to the allowance number(refill pills), setting the app to the beginning(reset activity), and receiving the number of pills in the bottle(receive notification). The patient version app has functions of starting dispensing pills, setting the number of pills from 0 to the allowance number(refill pills), and receiving the number of pills in the bottle(receive notification). The app also has a login/sign-up module. Login page has a place to input email addresses and passwords. If the user doesn't have an account yet, he/she could sign-up one. The sign-up page would need him/her to fill out the name, home address, mobile number, email address, password, and re-enter password. Figure 8 is a picture login/sign-up page.

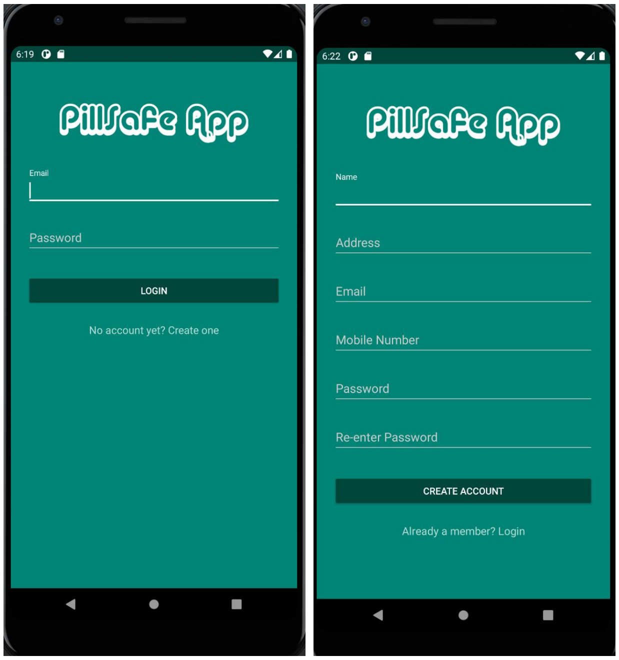


Figure 8: login/sign-up page of the App

2.3.3 Server Module

The server module aims to serve as an intermediate between and software and the hardware. I use my own computer to build a server. I used Ubuntu 18.04 as my server operating system and then I gave about 10Gb to my Ubuntu file systems. I think this is enough for our project since we are only uploading the number of pills to the server. I need to set up the IP address for the server in order for other devices to find the server[3]. Figure 9 is a flowchart of the software.

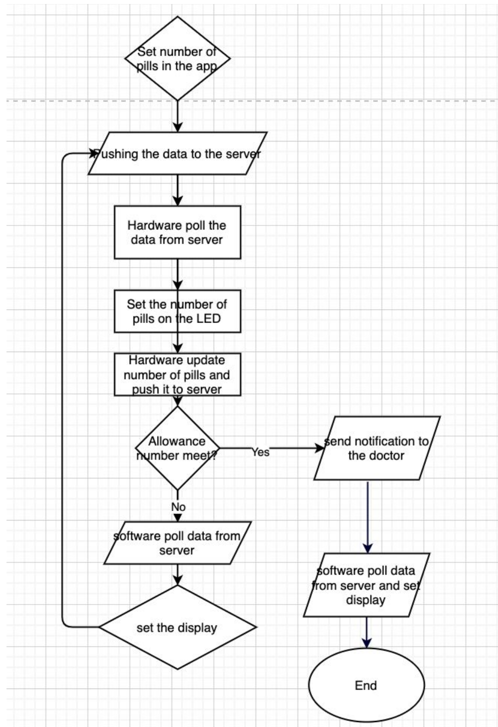


Figure 9: Software flowchart

3. Design Verification

This section details the results and data measurements found in the lab when verifying all the modules. Verification progresses and results are listed in the Appendix A. The display module and the microcontroller are verified with other modules' together.

3.1 Verification for Power Module

The verification in this section involves testing on the ATX power connector and the voltage regulator. The adapter is connected to the power supply on the wall. The ATX power connector is connected to the power adapter.Verifications are done by connecting the pins to the voltmeter. The power range for 12 Volts is 12.04 to 12.4 Volts, the power range for 5 Volts is 4.9 to 5.02 Volts. The input voltage for the voltage regulator is 4.9 to 5.02 Volts. The power range for voltage regulator output is 3.22 to 3.31 Volts.

3.2 Verification for Sensor Module

3.2.1 Verification for Photoelectric Sensor

The verification in this section involves testing on the photoelectric sensor module. The tests involve two parts. First, the sensor is tested alone so that it can detect objects in range. It is connected to the voltmeter to read the outputs. The result is shown in Table 1. Second, the sensor is tested together with the display module. A message will be displayed on the LCD once a pill is loaded in front of the PE sensor. The green LED will turn on when the pill is detected.

Table 1: Test Result for PE Sensor

Distance from Opaque Object to Sensor	Voltage
No Object	3.5 mV
20 mm	3.7 mV
18 mm	3.5 mV
16 mm	9.0 mV
14 mm	9.0 mV
12 mm	9.0 mV
10 mm	9.0 mV
8 mm	4.38 V
6 mm	4.38 V

3.2.2 Verification for Pressure Sensor

The verification in this section involves testing on the pressure sensor. The tests involve two parts. First, the force sensor resistor is tested alone. It is connected to the Arduino and results are printed in the serial window. The results are shown in Figure 10. The pressure sensor can successfully output a numerical value for force applied on the force sensitive resistor. Second, the sensor is tested together with the display module. A message warning user to stop touching the bottle is displayed when the force is above the alarm-bar. The red LED is on at the same time.

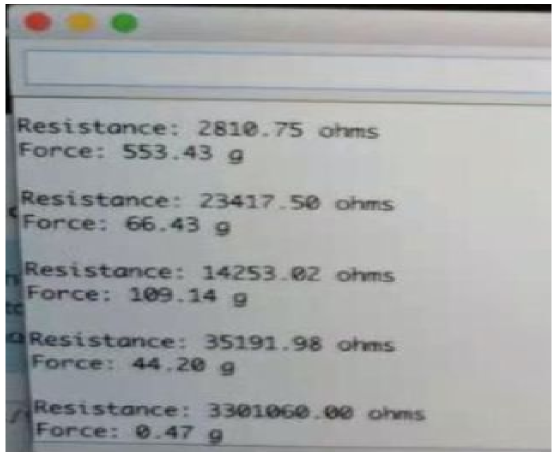


Figure 10: Test Results for Pressure Sensor

3.2.3 Verification for Magnetic Switch

The verification in this section involves testing on the magnetic switch. The tests involve two parts. First, the magnetic switch is tested alone to verify the characteristics of Normally On. The output is connected to the voltmeter. The result between the distance and the voltage is shown in Table 2. Second, the magnetic switch is tested with the display module. Once the switch is off, a message warning user “do not open the bottle” is displayed on the LCD screen. The red light is on at the same time.

Table 2: Effective Distance Measurements for Magnetic Switch

Distance between the Two Parts of the Switch	Voltage
14 mm	4.627 mV
12 mm	- 2.356 mV
10 mm	3.001 mV
8 mm	4.926 V
6 mm	4.966 V
4 mm	4.934 V
2 mm	4.933 V
0 mm	4.982 V

3.3 Verification for Motor Module

The verification in this section involves testing on the motor. The verification involved three parts. First, the motor’s calibration is performed. The test is done by using a protractor to measure the degrees of the angle rotated from the starting point by using different steps. Steps between 20 to 200 are tested. The test is repeated three times for each step number in one trial. Due to the accuracy of the protractor, there are errors from 0.5 to 2 degrees in each try for every step number. The results are shown in Table 3. Second, the motor is tested together with the PE sensor. At different motor speeds, the accuracy of loading the pill to the correct position for the PE sensor to detect is tested. The result is shown in Table 4. The higher the speed, the lower the accuracy. The maximum accuracy is achieved by 30 rpm. The third test is done between the motor and the display module. A message "pills start dispensing" will be displayed when the motor starts rotating. A message "pills stop rotating" will be displayed when the motor stops dispensing after the correct number of revolutions. At the same time, the yellow LED is on.

Table 3: Test for Motor Step

Steps	Round 1	Round 2	Round 3
20	6	6	7
40	13	13.5	14.5
60	19.5	19.5	21
80	23	25	24.5
100	26	26.5	28
120	40.5	39	42
140	47	47	47.5
160	52	50	51.5
180	58.5	58	59
200	64	65.5	66

Table 4: Test for Motor Speed

Motor Speed(revolution per minute)	PE sensor accuracy
60	60%
40	80%
30	90%
10	90%

3.4 Verification for PCB

The verification for this part involves testing about the PCB. We have ordered two rounds of PCB for this project. The verification for the first round of PCB failed because the power and the ground were wired inaccurately. The output of 5 V can not be read from the power pins. The PCB in Figure 7 is the second round of ordering. The power connectors are tested on this PCB and the results are shown in section 3.1. The reset button is tested to work properly on the PCB. The microcontroller failed the verification on the PCB due to the missing of the external clock. So in order to present at the demo, we decided to move the components to a breadboard instead of the PCB which we can add an external clock to make the microcontroller work properly.

3.5 Verification for microcontroller

The verification for this part involves testing about the microcontroller, ATmega328P. The ATmega328P is programmed and boosted to work on the board instead of the Arduino. The functions of the microcontroller is verified that it successfully receives readings and sends commands to correct modules.

3.6 Verification for Display Module

The verification for this part involves testing about the LEDs and the LCD screen. The LEDs are tested along with simple circuits and they can light up Red, Yellow, and Green color individually under 5 V voltage supply. The LCD is verified with default commands in the Arduino IDE platform and the LCD's microcontroller. The display module correctly displays the information when interfacing with other modules.

3.7 Verification for Wifi Module

The verification in this section involves connecting ESP8266 with the local WiFi network. Figure 11 shows ESP8266 has successfully connected to local WiFi called "Tower at Third". The test is conducted with testing software called "Uart Assistance".

Figure 11: Test for ESP8266 to Connect to Local WiFi

Figure 12 shows ESP8266 is able to perform bi-direction communication between dispenser and the app. This test is conducted with testing software “USP-TCP232-Test".

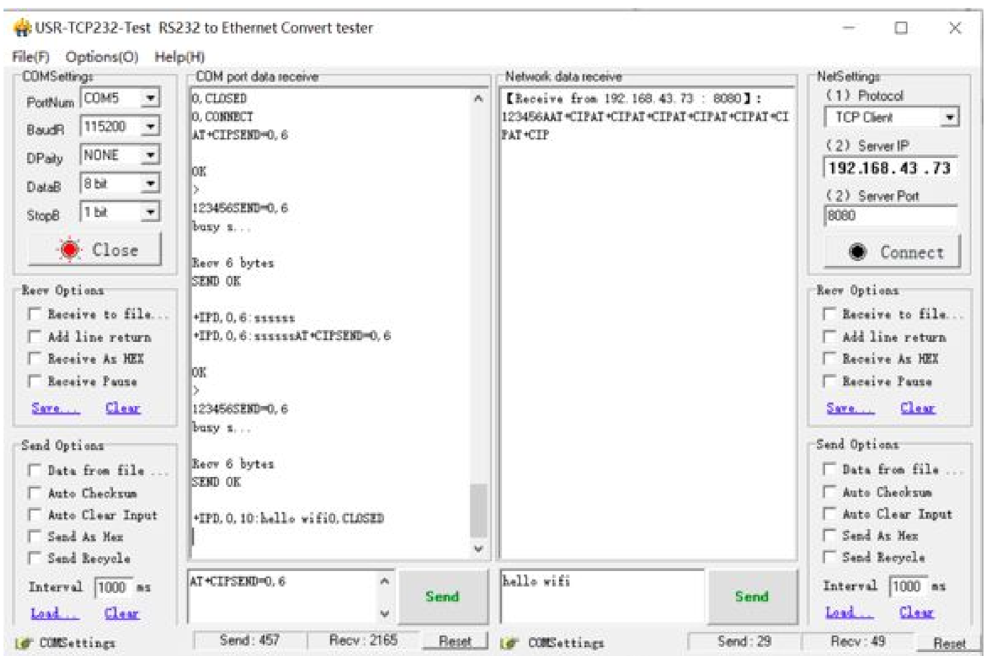


Figure 12: Test Bi-direction Communication of ESP8266

3.8 Verification for Software Module

3.8.1 Verification for App and server

The verification in this section involves testing the communication between the server and the app. The verification involved three parts. The app can receive and send messages from and to the server, it could set the allowance number, and reset the whole app(reset activity). The pictures below show that the app and server can successfully connect with each other and receive notification from each other. The allowance number could be set properly.

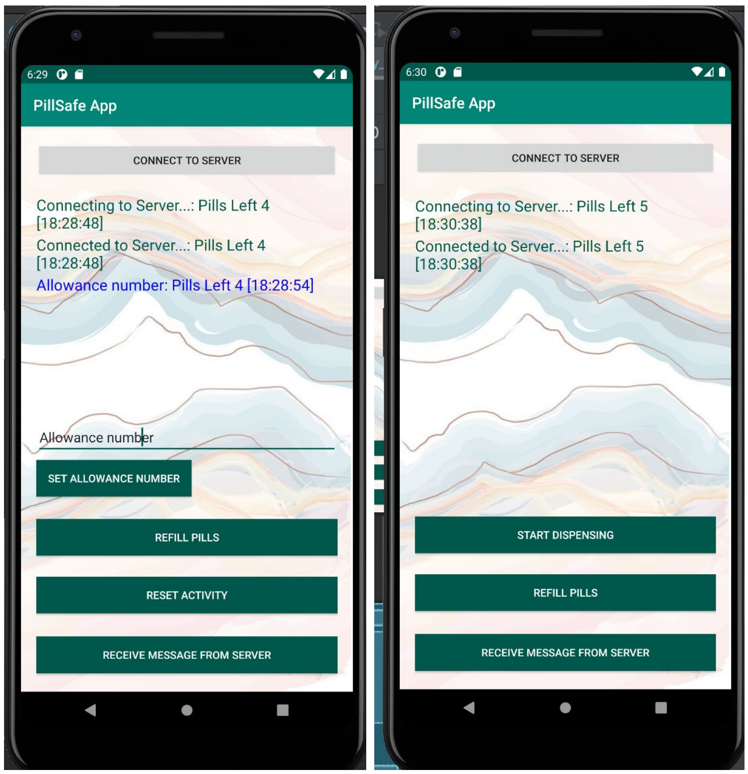


Figure 13: Test Communication of the App

4. Cost

4.1 Parts

The bulk cost is given for the individual cost of a part when purchasing more than 100 pieces of it. Table 5 summarizes the parts cost for this project.

Table 5: Parts Cost

Part	Manufacturer	Quantity	Retail Cost ($)	Bulk Cost ($)	Actual Cost ($)
VAOL-5LDE2	Visual Communications Company	3	0.10	0.08	0.30
LCD-16397	SparkFun Electronics	1	19.95	17.96	19.95
OPB715Z	TT Electronics	1	6.84	6.55	6.84
COM-13247	SparkFun Electronics	1	3.50	3.15	3.50
SEN-09376	SparkFun Electronics	1	11.25	10.13	11.25
NEMA 17	OSM Technology Co.,Ltd.	1	7.87	6.21	7.87
L298N	Qunqi	1	5.99	2.47	5.99
ESP8266	Espressif Systems	1	6.95	6.26	10.00
LM1117IMPX-3.3	Texas Instruments	1	1.76	1.10	1.76
ATmega328	Microchip	1	5.50	4.68	5.50
Total	$ 72.96				

4.2 Labor

Labor cost for each team member:
$30/hour x 20hour/week x 13 week = 7800 dollars
Total labor cost for three members = 7800 x 3 = 23,400 dollars

5. Conclusion

5.1 Accomplishment

Every function listed in the design document has been achieved except wireless communication between the dispenser and the app. The dispenser was able to be successfully loaded with pills and dispense pills automatically and the photoelectric sensor can detect the pills successfully, meeting the first high level requirement. The magnetic switch and the pressure sensor can successfully protect the dispenser from violations, meeting part of the second high level requirement that violations can be detected. The app has different versions and functions for users, meeting parts of the third high level requirement that an app is designed to help users use the dispenser. The unachieved high level requirements are caused by the failure of wireless communication between the app and the dispenser. Due to the same reason, there is not enough data to do analysis as well.

5.2 Uncertainties

The uncertainty of our project is relatively large since the photoelectric sensor will miss pill counting when a pill is stucking between layers. However, the uncertainty will be minimized to a very low point when we solve this problem by doing more tests on the motor speed and adding more friction between the holding place in the cascading dispensing layers and the pills by using less smooth material with the layers.

5.3 Ethical and Safety Considerations

It is important to consider possible ethical and safety issues involved with a technical project. Since our app is able to get first hand information about users' drug habits, we are responsible to protect our users' privacy. To protect our users' privacy, we designed a password protected login system and every user is required to sign a privacy agreement for other users when they sign up. Also, our project is designed for public health. Every feature in our project is designed to prevent drug misuse. These are implement of #1 of IEEE code of Ethics: "to hold paramount the safety, health, … , to protect the privacy of others, ... [5]"

Despite the facts talking above, we should also consider the user's individual/personal rights. Since this application will give the absolute control to the doctor/provider side, there might exists discrimination, financial or sexual orientations which violating #8 of IEEE code of Ethics [5]. Even though we are not able to control the behavior on the administrator side, we will give users/patients the right to stop the program under emergency situations.

We will guarantee our device is safe for our users. To accomplish that, we will pay close attention to points that can possibly cause safety issues to users later. Firstly, we need to be careful of the voltage we apply to the battery, since the battery could explode and cause danger if an overcharge happened. Secondly, the smart cap contains mechanical parts for the user interface module. We would make sure that these mechanical parts are safe to physical bodies. These are another implement of #1 of IEEE code of Ethics: "to hold paramount the safety, health, ... [5]"

5.4 Future Work

Future work of our project will be focused on achieving wireless communication between software and hardware, improving performance and adding more advanced functions.

As for wireless communication, we would like to allow patients to remotely control the dispenser either under the same or different wifi environment with the device itself. Doctors would be able to control multiple dispensers for different users remotely under different wifi environments with the dispensers.

To improve performance of our project, the whole circuit will be integrated into a PCB. We would also do more tests on the motor to avoid pill stuck problems that we currently believe are caused by low motor speed and smooth and easily sliding surface of pill holding layers.In addition, infrared (IR) sensor could be a good replacement for photoelectric sensor since IR sensor has a relatively shorter time cycle than PE sensor, which could potentially boost our accuracy of pill counting and also requires less time interval for the pill to stay.

In future work, we could design and implement more advanced functions to the software part to better serve our users. We could establish a model to record and analyze patients' medication habits. We could also incorporate some databases with our app to give advice to users about health medication habits and lifestyle. Moreover, another thought we could incorporate into our app is to set up a reward system which rewards patients who maintain a health frequency of taking pills. This should provide a positive driving force to our users who are suffering with drug addiction.

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Appendix A   Requirement and Verification Table

Table 6: System Requirements and Verifications

Requirement	Verification	Verification status (Y or N)
1. Steady Power Supply a. Supply 11.5 to 12.5 Volts for the motor and magnetic lock, 4.75-5.25 Volts for sensor modules, and 3.2-3,4 Volts for all other modules	1. Steady Power Supply a. With input voltage of 120V AC from the wall mount, we use a voltmeter to measure and ensure 12V, 5V, and 3.3V output voltages are gained at Vout pins of circuit with power connector and voltage regulator.	Y
2. Violation Behavior Detection a. When the pressure sensor is untouched, the MCU receives voltage approaching 0V. When the pressure sensor is touched, the MCU receives voltage close to 5V (Vcc). b. The state of open/close of the magnetic switch is sent to the MCU. Opening the magnetic switch is able to trigger an alarm when the dispenser is not in a refilling state.	2. Violation Behavior Detection a. Measure the resistance of the pressure sensor with an ohmmeter and measure the output voltage of the pressure sensor when it is untouched and when it is applied with a force. b. After connecting the magnetic switch with the MCU, a high/low voltage is measured at the analog input pin of the MCU for an open/close state of the magnetic switch. Use the MCU to set the dispenser to refilling state, a different output should be detected when force is applied.	Y
3. Dispensing Mechanism a. The dispensing mechanism should only allow one pill being dispensed at	3. Dispensing Mechanism a. The cascade dispensing layers hold six pills for each layer and one pill for each	Y

each time. b. The dispensing mechanism should have size tolerance for typical capsule sizes.	holding place. When the stepper motor makes a move, exactly one pill is being dispensed to the next layer and will be eventually given to the user. b. The dispenser is able to dispense capsules with size 0, 00 and 000.	
4. Pill Counting Accuracy a. The photoelectric sensor should be able to detect the pill and output a logic HIGH to the MCU.	4. Pill Counting Accuracy a. The photoelectric sensor indeed can detect the capsule with different sizes and with serial print, the MCU did increment pill count according to the reading from the PE sensor.	Y
5. Motor Control a. The stepper motor should be able to rotate at a proper speed and be able to rotate the dispensing layer at a proper angle so that a pill can safely land into the next layer each time when the motor rotates.	5. Motor Control a. The motor is able to correctly load a pill to the next layer for each rotation it makes.	Y
6. Display a. The LEDs should notify users for different stages of dispensing. b. The LCD should notify users for different stages of dispensing as well as alarm users when violention behavior is detected.	6. Display a. Green LED lights up when the pill dispensing process starts. Yellow LED lights up when the pill is dispensed to notify the user to take the pill. Red LED lights up when detecting violations. b. The LCD successfully	Y

	gives instructions to the user during dispensing and alarm user when detecting violation.	
7. Control a. The MCU should be able to control the motor module and display module.	7. Control a. The MCU can control the stepper motor, LEDs and LCD.	Y
8. Wireless Communication a. The WiFi module should be able to connect to the local WiFi network. b. The WiFi module should be able to do bi-direction transmission of data between the dispenser and the App. c. The WiFi module should be able to perform wireless communication.	8. Wireless Communication a. The WiFi module is able to connect to the local WiFi network. b. The WiFi module is able to do bi-direction transmission of data. c. The WiFi module fails to do wireless communication due to time limits.	Partial
9. APP a. The app should be able to send notifications to patients and doctors when violations are detected. b. The app should allow patients to start the dispensing process and allow doctors to change the allowance number of pills.	9. APP a. The app is able to send notifications. b. The app allows patients to choose when to start dispensing and allows doctors to update the allowance number of pills.	Y