A Smart Medicine Pill Box for Improving Medication Adherence

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Abstract: Non-adherence of patients toward their medicinal prescription is a known problem in the medical field. This problem is commonly seen among the elderly because with old age comes poor memory and a higher risk of getting diseases. With that problem in mind, the research developed a smart pill box that tries to improve medication adherence. The pill box automatically dispenses medicine on a set time based on the input schedule in the mobile application and has an LED and buzzer to indicate that medication is due. An IR sensor detects whether the medication has been taken out of the pill box and logs the time it was taken. An additional wearable device that has an LED and buzzer was also developed as an additional notification system. In the functionality tests, the proponents were able to determine if the basic functionalities of the system were met. These tests showed that the system is capable of dispensing medicine at a configured schedule along with triggering its alarms however, as time progresses the real time clock of the microcontroller started to incur delays therefore becoming out of sync with actual time. A user acceptance test was also conducted in order to determine the usability of the system. Testers noted that the pill box system was usable and straightforward to use however they also noted that time discrepancy is a major concern.

Key Words: Internet of Things; Embedded Systems; Smart Pill Dispenser; Medication Adherence

1 INTRODUCTION

Medication adherence is important for treating long-term or chronic diseases (Ruscin, 2021). While maintenance medicine helps the patient fight or recover from an ailment, it may not be as effective if it is not administered regularly within the scheduled or prescribed time period. This raises the problem of people forgetting to take their medicine, increasing the risk of their ailment get-ting worse (U.S. Food & Drug Adminisration, 2021). There are strategies that pharmacists use to improve medication adherence, one example would be pharmacists following up with their patients whether they have taken their pill (Lamb, 2021). Aside from strategies there are also tools widely available in the market to improve medication adherence, one of the most common tools used is a pill organizer that can be as simple as a box with compartments labeled with the days of the week to help patients remember what pill they need to drink during that day.

The main objective of this research is to develop a modular smart medicine pill box that is able to automatically dispense medication when due, notify the patient that medication is due, and keep track of the patient's medicine consumption progress for a single person. Interface for the schedule input of the smart medicine pill box uses an Android-based application on a smartphone. It is assumed that smart pill box is not connected to the Internet. The system also has an additional wearable device for added notification.

2 SYSTEM DESIGN

2.1 Overview

The smart pill box is an automated modular pill box system that dispenses medicine at the configured scheduled time of the user through a smart phone application. The system is composed of a main pill box, a modular (supplementary) pill box, a wearable device for notification and a smart phone application for configuration.

Initial setup of the dispensing schedule is through a mobile application on a smart phone connecting to the wireless access point of the main pill box. All modular pill boxes and wearable should also be near the main pill box to connect to the wireless access point. After programming the schedule, the smart phone can disconnect its connection to the main pill box. All pill boxes can operate independently as it can keep track its own time. The setup of the system is shown in Fig. 1.

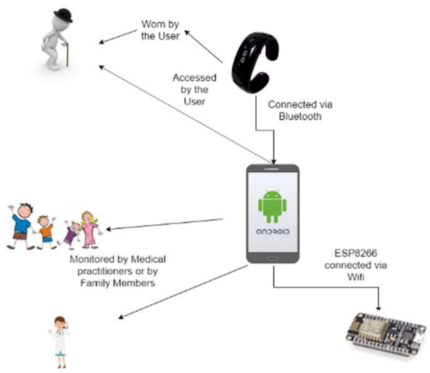


Fig. 1. Overview of the system

2.2 Pill Box Design

The design of the smart medicine pill box follows a circular shape. At the top there are six compartments for storage of the medicine and one dispensing chute. The stepper motor is located directly below said compartments and is responsible for moving the compartment dividers in order to push the medicine for dispensing. An IR sensor is located directly below the stepper motor. It is responsible for detecting if there are any pills inside the dispensing compartment and for triggering the LED and buzzer. A picture of the pill box is shown in Fig. 2.

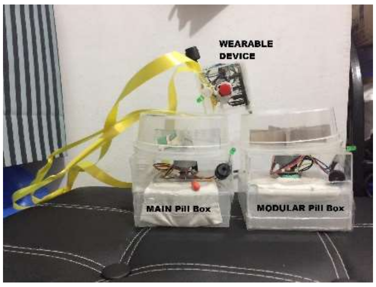


Fig. 2. Actual prototype of the system

Both main and modular pill boxes use the NodeMCU ESP8266 (NodeMCU ESP8266, 2021), which is a microcontroller with 802.11 b/g/n WiFi module, stepper motors, buzzer, LEDs and IR sensors. The pill box uses the stepper motor to push the medicine into the dispensing chamber and then triggers the buzzer to signal that the user should take his/her medicine. An IR sensor in the dispensing chamber is used by the microcontroller to check if the medicine was removed from the chamber. The hardware design of the pill box prototype is shown in Fig. 3.

The 802.11 b/g/ WiFi module is used by the main pill box to setup a wireless access point during initial setup. The mobile phone app, modular pill box and wearable connects to the wireless access point on the main pill box.

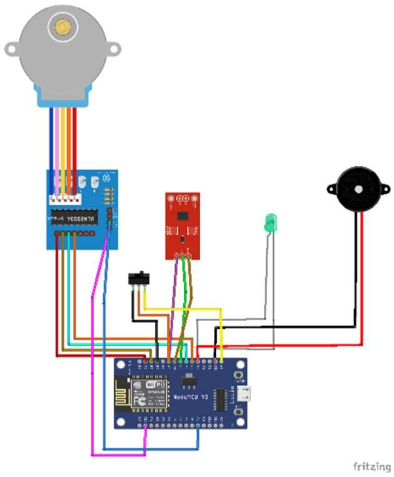


Fig. 3. Hardware design of the pill box

As the pill boxes receive the medicine dispensing schedule from the mobile application, it will be configured with its system time and sync it with its own RTC. The schedule is then stored in a dictionary containing the name and dispensing time of the medicine.

Once the schedule has been set, the pill boxes activate dispensing mode where the system will constantly check if a schedule matches the real time clock (RTC) time. If a schedule does match, the hardware functions of the pill box are triggered. After the hardware functions, the system will now wait for the medicine to be removed from the dispensing chamber. Once the IR sensor no longer detects anything inside the dispensing compartment it stops it alarm and return to its time monitoring function. MicroPython (George Robotics Limited, 2021) was used to program the microntrollers.

2.3 Wearable Design

The wearable unit of the system uses the same hardware as the pill box except for the stepper motor. It is also programmed with the medicine dispensing schedule into its dictionary. Then it monitors the time using its own RTC time and triggers the alarm on schedule. Alarm only stops when a button is pushed on the wearable. The wearable circuit is shown in .

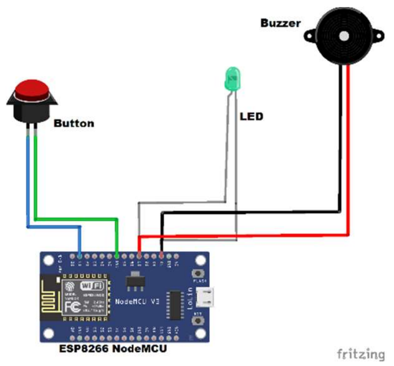
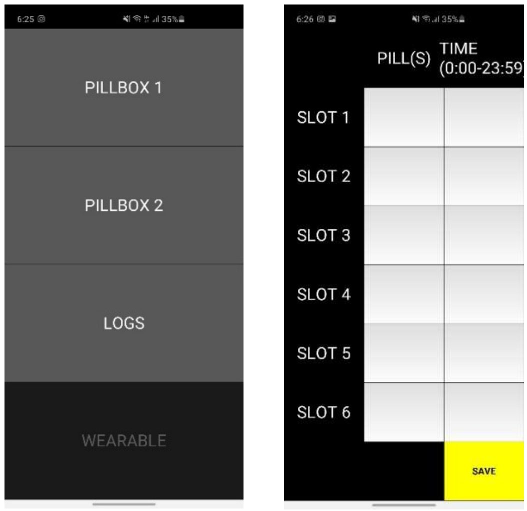


Fig. 4. Wearable circuit

2.4 Android Application

The mobile application was built on Kivy (Kivy, 2021), an open-source Python library which enables quick deployment on multiple platforms. With Kivy, the development of the mobile application was simpler especially during debugging since the application is executable on both PC and Android.

The initial screen of the mobile application shown in Fig. 5(a), tries to detect the main pill box, modular pillbox and wearable. From the initial screen, the user can also access the logs on the pill boxes. The logs contain when was the medicine dispense and when was it taken from the dispensing chamber.



(a) (b)

Fig. 5. Initial screen on the mobile application

After selecting a pill box, schedule for the pill box can be setting the dispense time on each slot, as shown in Fig. 5(b). There is no need to set the time on wearable as it will be automatically programmed based on the time in the pill box.

3 SYSTEM TESTS

Test such as the Medicine Dispensing Schedule Test was conducted in order to determine if the Smart Medicine Pill Box is able to dispense pills at specific time while a User Acceptance Test (UAT) was conducted in order to check the usability of the system.

3.1 Medicine Dispensing Test

This test as conducted in order to determine if the pill boxes can dispense medicine at a configured schedule and trigger its alarms. This test was done twice with first one dispensing medicine three times at 15-minute intervals (Table 1) while the second one was scheduled to dispense medicine twice between 8-hour intervals (Table 2). The on board RTC of the ESP8266 was able to dispense the medicine on time but started to delay after a long time while running. It is also important to note that even if the results in Table 1 were on time by the minute, there was a significant delay of around 40 seconds. The RTC module of the ESP8266 is highly affected by the running temperature of its CPU. An increase in the temperature will likely cause the RTC to run out of sync therefore highlighting the importance of having an external RTC to keep track of time. Notice that there is already an accumulated error in dispensing time in Table 2.

Table 1. Results of the first medicine dispensing test

Expected	Actual
3:30	3:30
3:45	3:45
4:00	4:00

Table 2. Results of second medicine dispensing test

Expected	Actual
12:00	12:00
20:00	20:01
12:00	12:05
20:00	20:10

3.2 User Acceptance Test

The user acceptance test was conducted by two people. They were given specific test cases to follow and was allowed to use the pill boxes as they see fit. The first tester had the schedule and results as seen in Table 3 and Table 4. He used this over the span of two days. The second tester on the other hand the schedule and results in Table 5. She used the device for one day. Overall, both users had the same feedback regarding the usability of the system. They both stated that it was able to perform its basic functionalities and was successful in reminding them of their medication. The first tester highlighted the usefulness of the wearable device as he was doing chores and forgot to take his medicine. They also noted that the time delays were a major point of concern and that a smartwatch would make more sense as a wearable device rather than something that is worn around the neck.

Table 3. Main pill box schedule and results for first tester

Expected	Actual
8:00	8:00
13:00	13:05
8:00	8:05
13:00	13:06

Table 4. Modular pill box schedule and results of the first tester

Expected	Actual
13:00	13:00
20:00	20:06
13:00	13:10
20:00	20:11

Table 5. Main pill box schedule and results of second tester

Expected	Actual
19:00	19:00
8:00	8:01
12:30	12:36

4 CONCLUSION AND FUTURE WORK

The goal of this study was to develop a modular smart medicine pill box that is capable of dispensing medicine and notifying the user. An accompanying mobile application is used in order to configure medicine details such as name and schedule. An additional wearable device was also developed in order to help notify the user when medication is due. Functional tests were conducted to determine if the prototype can perform its basic functions. Through these tests, it was noted that the RTC of the ESP8266 was not that reliable and was causing delays of up to ten minutes. Last, a UAT was conducted in order to determine the usability of the system. Users said that the system was usable and the mobile application was straightforward and easy to use. One user highlighted the usefulness of the wearable device in notifying him. They also noted that time discrepancy was a major concern along with the volume of the buzzer.

To remedy the time discrepancy issue, an external RTC is needed to keep track of time. Depending on the RTC's specification, it can keep time drift within 1 minute of actual time. An external RTC also frees up the microcontroller for other tasks like real-time log retrieval and schedule updating. Also, time can be tracked correctly even when the system is shutdown.

The current wearable is bulky because of the circuitry. During the development, there was a plan to use Android-based smart watches but was non-programmable. Although a customized circuitry was developed, it was bulky because of the circuitry and power came from a power bank. It is planned that the circuit sized be reduced, integrate a motor/vibrator and use coin-type lithium battery so that the notifier can be worn on the wrist or neck.

Another limitation of the system is it cannot detect if a pill chamber is empty as there is no notification for the user to refill. Currently, an infrared or weight sensor can be used to detect if a chamber is empty. The design of the box should also be revised in order to fit a sensor per chamber. Another solution is to use software-based tracking by asking the user the number of pills in a chamber and deducts the number of pills every time is dispenses.

Although the target of the developed system is for home use, it can also be useful in hospitals. To be useful in hospitals, the system should have multi-patient tracking ability. This helps nurses to keep track medicine intake of multiple patients. Aside from multi-patient tracking, security should also be improved for hospital use. Security areas of concern for the pillbox are: authentication, authorization, and communication. Authentication and authorization ensure that only authorize users can access the box and only certain boxes can added in the IoT system. Malicious boxes can poison the medicine intake log or medicine inventory. Communication should be secured to avoid eavesdropping which ensures data privacy of patients.

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