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Medication box management system with automatic dosing integrated with IoT-based Android app and Firebase

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ABSTRACT

Utilizing Firebase technology and an Android internet of things (IoT) application, the research endeavors to create a smart medicine box in order to enhance the efficacy of automated drug management. Hardware implementation, software implementation, and 3D design planning for automatic dosage adjustment are the methods utilized. The results prove that the application effectively controls the dosage, evacuation schedule, and quantity of the medication based on the user's input. Boundary value analysis (BVA) black box testing demonstrated that every feature of the application functions as intended. Furthermore, the efficacy of drug production testing indicates that the smart medicine box exhibits a notable level of precision, albeit with a limited number of inaccuracies that could be rectifiable through additional parameter and mechanism optimizations within the drug box. Consequently, the investigation has effectively produced an automated drug management system that has the potential to enhance drug use supervision and safety, particularly for elderly services individuals residing alone.

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1. INTRODUCTION

Hypertension and tuberculosis (TB) are a significant global health problem [1], [2]. Therefore, medication should be administered accurately, including timely, accurate dosage and accurate method of use. Hypertension is often referred to as a "silent-killer" where the sufferer may not be aware of their hypertensive condition unless they have a blood pressure test [3], [4]. In addition, non-compliance with antihypertensive medication is a major factor in patients' under-controlled blood pressure. Therefore, following the recommended rules in regular use of hypertensive drugs is an effective way to control blood pressure, and this requires adherence in taking the medication [5]. Then TB is a contagious disease that is the second cause of death worldwide and the actual deaths can be prevented [6]. Compliance with the treatment of TB is crucial to preventing the spread of the disease, avoiding the emergence of drug resistance, and death. Lack of compliance with the treatment of TB is a major obstacle and stands out as one of the major challenges in controlling TB globally, as well as playing a major role in the failure of treatment [7].

With the rapid development of technology, many devices are designed to support medical activity. Some research has been done on an automated drug management system. Like "iHome Health-IoT", the drug box serves as a hub for the integration of connectivity devices and services. However, the system does not have the residual drug description feature, so users should check the drug manually [8]. Another study deals with an automated drug management system entitled "Design of on intelligent medicine box", designed to give a sense of safety to elderly people living alone. However, the system is not yet integrated with the internet of things (IoT) platform and requires periodic calibration [9]. Another study, titled "Smart pill box", aims to automate the sequence of pills and determine the time and quantity of taking pills through the application. However, in the process of communication between the application and the drug box or device, physical proximity is required because the system used is still using the type of Bluetooth communication [10]. Furthermore, the research entitled "Smart medicine box system" researches drug boxes that are integrated with the application. The study provides an application that can configure the device, then set a timetable for the drug's exit and notify the drug. However, the amount of drugs released could not be adjusted or did not support the dose adjustment feature [11]. New research entitled "IoT based healthcare system for regular patient monitoring" develops IoT-based health systems. Despite being equipped with sensors and IoT systems for regular health care, the drug box still has shortcomings. Dosage adjustment features are not available, and the drug box only has 3 drawers that must be filled first by the user or patient accompanying [12].

All of the devices in previous studies on automated drug management systems, including the iHome Health-IoT, Design of an intelligent medicine box, and Smart pill box, necessitate periodic or manual inspections. This is due to the fact that the device's communication system has not been integrated with the IoT. There are devices that utilize applications, such as the "Smart pill box," but Bluetooth remains the primary method of communication, which limits the scope of monitoring to a specific distance. Additionally, in a separate investigation, the "Smart medicine box system" and "IoT based healthcare system for regular patient monitoring" are devices equipped with IoT-integrated applications that enable remote monitoring. Nevertheless, neither instrument is equipped with an automatic dose setting feature. Consequently, patients are required to reevaluate the medications that must be consumed by the prescribed guidelines, or the patient's caregiver is required to prepare the medications in three compartments, as was the case in the "Smart medicine box system" research design. The objective of this article is to address these deficiencies by examining the design of a smart medicine box that can dispense medication by the daily dosage and the schedule for taking it, as determined by the input from the application integrated with IoT. This design will enable remote monitoring. The dosage adjustment mechanism is a critical component of the tool's design. Consequently, the integration of mechanical and electrical systems is particularly critical in the design of the drug output. The automatic drug administration system that has been developed incorporates cloud storage (Firebase), IoT technology, and an Android application [13]. This integration enables the synchronization of data between the application and the device in real-time, without being constrained by distance [14]. Users can establish the dispensing schedule, determine the required number of doses, and receive notifications regarding the time of medication consumption through the application. In addition, the application's monitoring feature offers direct access to the internal conditions of the medicine box, including the temperature of the drug storage area, time data from the real time clock (RTC) embedded in the device, the condition of the medicine box (open or closed), the alarm status (on or off), and the box status (filled or empty). The application's intuitive monitoring interface and user-friendly data input process are intended to deliver convenience in patient monitoring. The application is not constrained by the physical distance between the application and the device, as it enables data input from any location and at any moment through the use of cloud storage (Firebase) [15]. This is extremely beneficial for the monitoring and management of patient healthcare, as it enhances the precision of drug dosage adjustments and the accessibility of care managers.

2. METHOD

The method is to use experiments consisting of three main parts, namely hard drive design with 3D design, automated dose program development, and software design. Some of the main components in the hardware will be combined into a single printed circuit board (PCB), namely battery resources, microcontrollers, and servo drive for drug output regulators. The design of the drug box also involves three main aspects, namely the physical structure of the box, the drug reduction mechanism, and the outgoing drug storage drawer. The software design section describes three key elements, namely the microcontroller firmware that processes data from the sensor and performs actions such as triggering the buzzer or moving the servo. Next, the process of storing data handled by the microcontroller into the cloud storage (Firebase). The data can be accessed and exploited through Android application development platforms, especially MIT App Inventor, to facilitate user interaction with devices.

2.1. Smart medicine box system design

Smart medicine box system design illustrated in Figure 1. The designed system incorporates the DS3231 RTC. This particular RTC variant maintains functionality and delivers precise timing even in the absence of the primary resource [16]. The DHT11 sensor is located within the drug storage compartment to quantify the relative humidity and temperature of the air surrounding the medications [17]. The MC38 sensor-equipped drawer will subsequently determine whether the drawer is closed or open according to its magnetic position. The SG90 servo, which has a maximum rotational range of 180°, is utilized in drug distribution mechanisms to guarantee precise and uniform drug distribution. A PCB-integrated buzzer that functions as a sound indicator [18]. For the purpose of to alert the user that the substance has entered the pickup tray, this buzzer will become operational. The ESP32 microcontroller provides the complete voltage supply for the sensor, which has an output of 3.3 V [19]. The data obtained from each sensor is processed by the ESP32 microcontroller, after which it is transmitted to the cloud storage (Firebase) by subsequent devices. The settings menu of an Android application that has been integrated with a real-time database enables users to input time and minute information, in addition to the required number of doses, and to view the current data on the monitoring display. The ESP32 examines the time and minute data periodically. The microcontroller will instruct the servo to move in accordance with the dose number and trigger the buzzer as a notification signal once the user has entered the data.

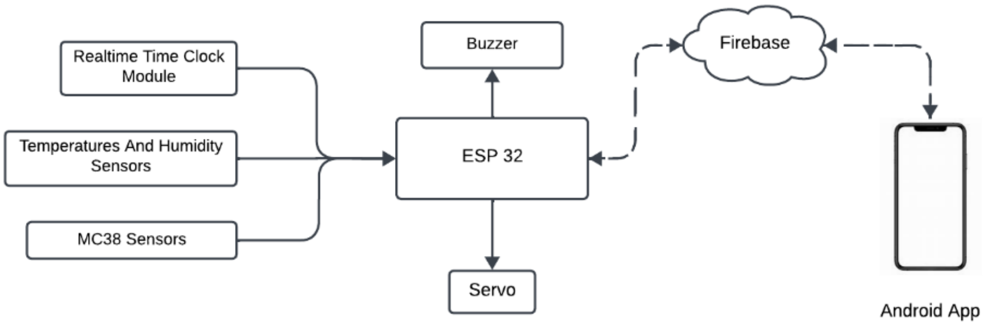
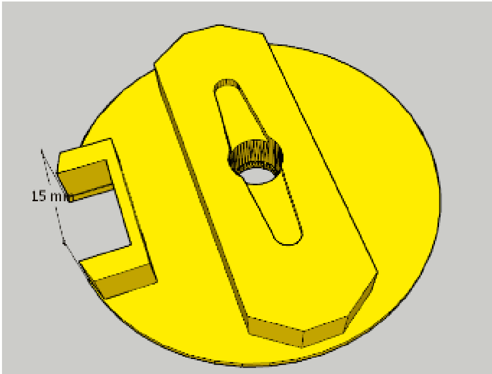


Figure 1. Smart medicine box block diagram

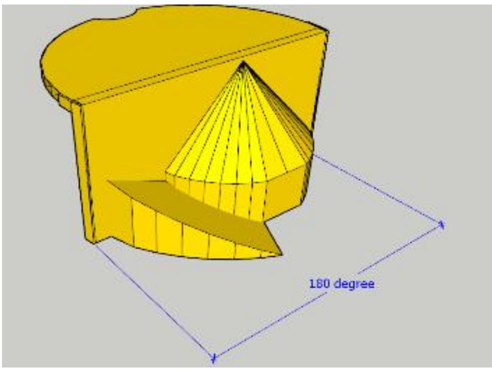
2.2. Smart medicine box hardware design

The medicine box design is generated using 3D design software, which incorporates specific geometry that enables the dispensation of one medication with each operation of the system. Figure 2(a), the drugs drive disk demonstrates the configuration of a plate that is affixed using a servo grip that rotates 180°. The disc's design, which is connected to the servo through the servo drive opening, rotates 180° in accordance with the servo's movement during the lowering process. This rotation is essential for the medication to be captured on the drug track, as illustrated in Figure 2(b) of the drug track design. The servo drive opening has been adjusted to the standard size of the medication to guarantee that only one medication is dispensed during the dispensing process. Subsequently, the servo will revert to its initial position or angle of 0°. The medication will descend and discharge into the storage compartment when the servo reaches an angle of zero degrees, as a result of the drug reduction mechanism. The application that has been developed allows users to modify the dosage of medication that is dispensed. The device will function in accordance with the three dosage quantities that are entered into the application settings.

Schematics of the electronic component network are depicted in Figure 3. Based on commercially available components, an electronic simulator generates the network schematic. Every input component, such as the charger port, battery management system (BMS), battery pads, switches, and buck converters, is integrated with the ESP32. Several sensors and a buzzer are positioned at the output to function as operation indicators for the device and medication output, respectively. Figure 4(a) illustrates the rear view of the PCB design, which is stored on the back of the medicine box. The BMS is a critical component of devices that rely on battery power as their primary source, and this design demonstrates the interconnection between various system components [20]. The Series 18650 batteries are charged by the BMS, which serves as a controller for the device's recharge. The jack charger is situated on the right side of the prescription box, as illustrated in Figure 4(b), right side view. This battery has a total voltage of 11.1 V and a maximum current of 3.6 A. The battery indicator and the on/off switch are situated on the left side of the medicine case, as illustrated in Figure 4(c), left side view. A voltage of 5 V is generated by connecting the battery's voltage to the bidirectional DC-DC converter. The ESP32 receives this voltage via the VIN interface [21]. Furthermore, the ESP32 supplies a voltage of 3.3 V, which is then distributed to additional sensor modules [18]. This intelligent medication box has a maximum current of 3.2 A and a battery capacity of 11.1 V, allowing it to function for 24 hours without requiring recharging.



(a)



(b)

Figure 2. Automatic drug dose regulator design: (a) drugs drive disk and (b) drug track

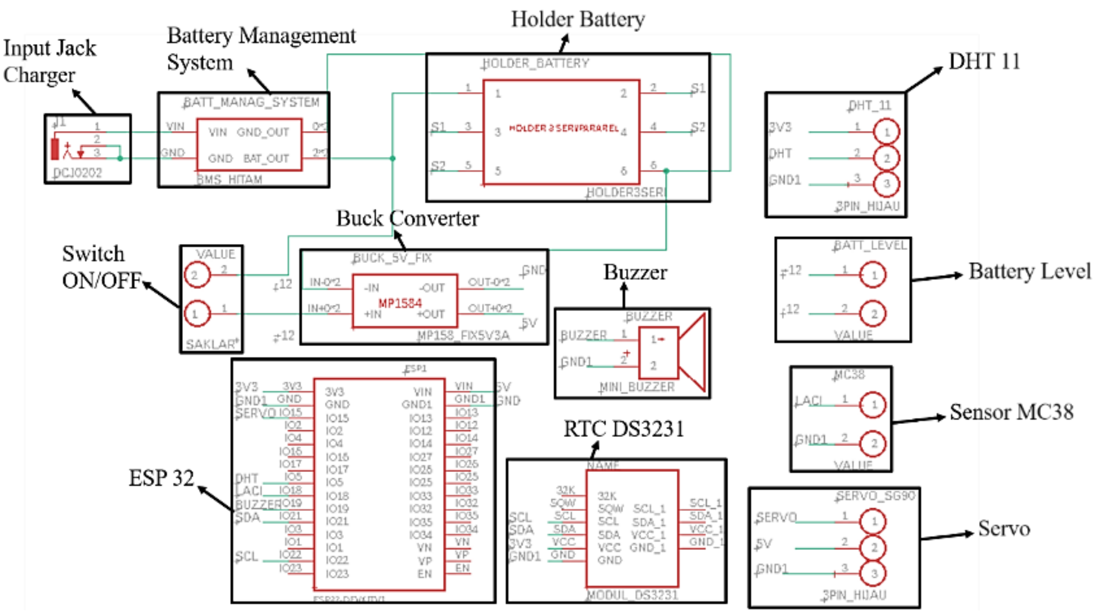


Figure 3. Electronics component network schematics

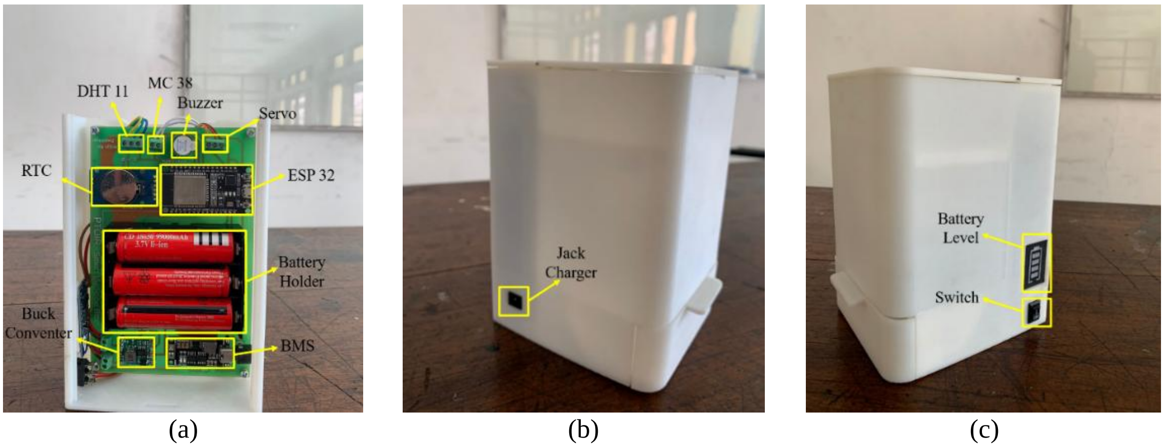


Figure 4. Smart medicine box hardware: (a) the rear view of the smart medicine box, (b) the right-side view, and (c) the left side view

2.3. Smart medicine box software design

The Arduino integrated development environment (IDE) was utilized to implement firmware programming for the ESP 32 as part of the software in the developed system [22]. Firebase serves as the cloud storage medium through which data sets acquired from ESP32 are gathered and stored. The development of Android applications was executed using MIT App Inventor, an integrated development platform that eliminates the necessity for intricate code composition [23], [24].

The communication channels among the three primary software components are illustrated in Figure 5. New data from the ESP32 firmware, including temperature, humidity, and drawer status information, will be received and stored by Firebase. The application will be presented with the stored data in real-time [25]. Furthermore, Firebase receives application-supplied configuration data, including the user-specified drug output schedule and dosage. The ESP32 firmware, which will read and implement commands in accordance with the scheduled and prescribed drug dosage, will receive this data from Firebase [26]. This process is iterated in order to guarantee appropriate drug administration.

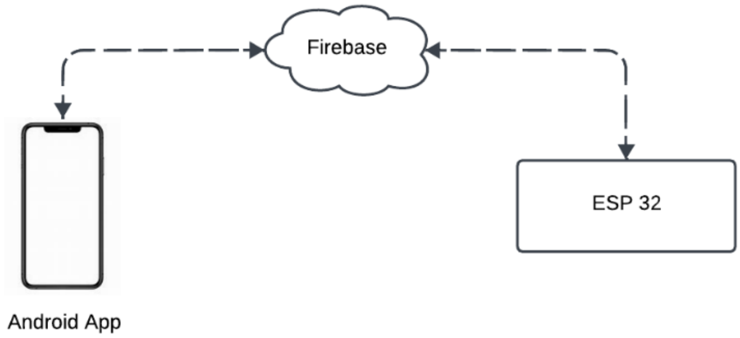


Figure 5. Smart medicine software box communication stream

The workflow of the system is illustrated in Figure 6. The system commences by initiating the application and powering on the device. The dosage and quantity of the drug, as well as the timing of its exit, can be configured by the user via the smart medication box application's on-screen parameters. Upon activation and Internet connectivity, the ESP32 program will commence by retrieving the sensor values and transmitting them to the database for visual representation on the application monitoring screen. While verifying the output schedule, the system performs an infinite number of loops and continues to read in real time. When the RTC time corresponds to the drug expiration schedule, the servo mechanism will initiate the release of the drug in accordance with the prescribed total dose. As soon as the medication reaches the lower portion of the drawer, the buzzer will activate and communicate to the application that the drawers are full.

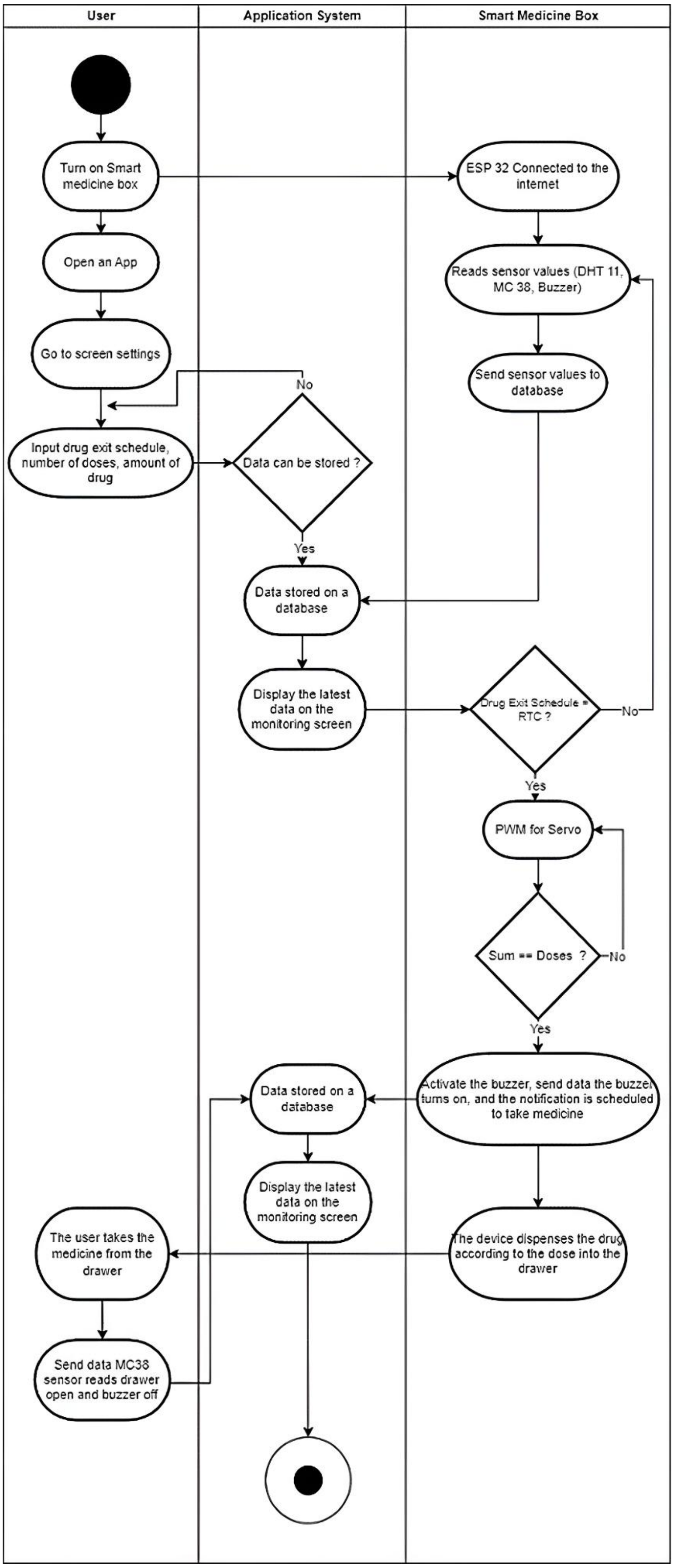
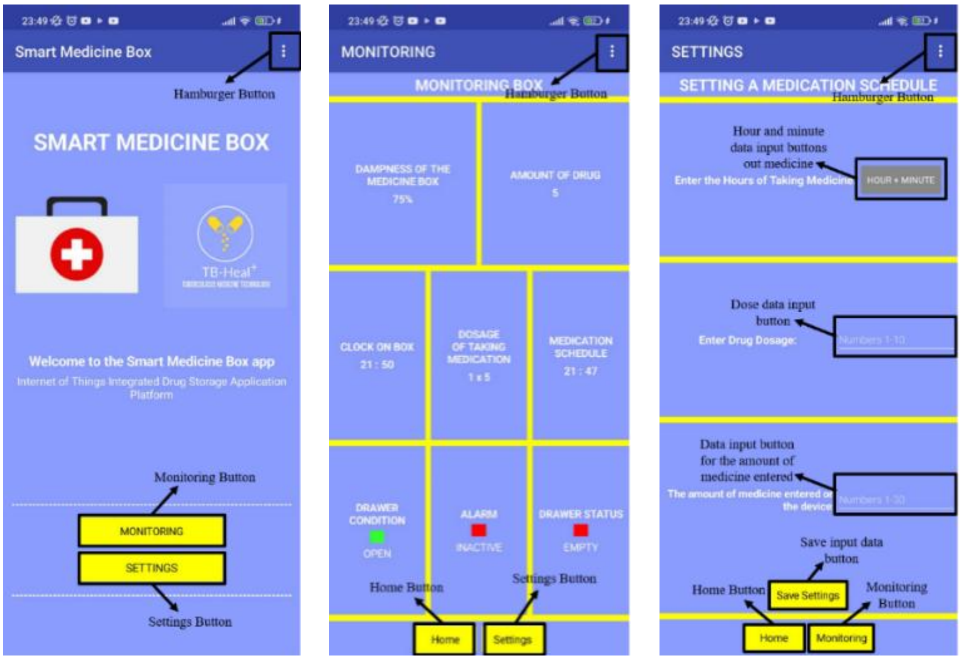


Figure 6. Smart medicine box system workflow

3. RESULTS AND DISCUSSION

3.1. Testing applications with boundary value analysis black box method

Application testing is done using the black box method. The objective of this approach is to ascertain whether the software performs in accordance with the specifications or the necessary functions. The application that has been developed comprises three primary display: Figure 7(a) the home screen, Figure 7(b) the monitoring screen, and Figure 7(c) the setting screen, as illustrated in Figure 7 of the smart medicine box software display. This method aims to determine whether the software works according to the specification or function required. In the developed application, there are 3 portable screens as shown in Figure 7. In the developed applications, there's an inputs system for drug dosage data, exit times and the amount of medication inserted into the box. Therefore, the study adds one of the black box testing techniques, namely boundary value analysis (BVA) to test the maximum and minimum limits of the values entered in the application [27], [28]. The BVA method is also used to ensure that the designed software is capable of processing the given input and generating the desired output.



(a) (b) (c)

Figure 7. Smart medicine box software display: (a) home display on smartphone, (b) monitoring display on smartphone, and (c) setting display on smartphone

The results of the BVA method tests are shown in Table 1. In order to conduct this test, a variety of features and functionalities were examined across multiple scenarios. The process of application testing encompasses a multitude of functions and attributes within each constituent element. In order to conduct testing, test scenarios are executed on the column. Testing may involve, for instance, pressing buttons intended to navigate between displays. In addition, the hamburger icon provides access to information regarding the application as well as exit options. Several maximum and minimum limits are imposed on the data input features of the tester pertaining to drug dosage and quantity throughout the testing process. According to test results, every feature operates as anticipated. When the dose data is entered below 10, the data is effectively stored in cloud storage, and the monitoring screen exhibits the data, this constitutes an example of a test result. However, if the dose inputted is greater than 10, a pop-up message indicating "TOO MANY DOSES" will appear to warn that the dose is excessive. The system will then either automatically reset the dose setting to 0 or abstain from dispensing the drug. An equivalent principle can be applied to the system for entering substance quantities. Thirty is the utmost quantity of drugs that may be entered. The application will exhibit the error message "TOO MANY MEDICATIONS" if the user attempts to enter extra. Under such circumstances, the medication quantity will be reset to 0 by the system, necessitating the user to re-enter it into the application while also indicating that the medication has been depleted. Every test result acquired is consistent with initial expectations and demonstrates that the application operates effectively in accordance with the designated criteria.

Table 1. Application test results with BVA method

Components tested	Testing scenarios	Expected results	Test results	Conclusion
Home button on screen 2 and 3	Pressing the home button.	The screen display goes to the home screen.	The screen display goes to the home screen.	Success
Monitoring button on screens 1 and 3	Pressing the monitoring button.	Screen display goes to Screen 2 (monitoring).	Screen display goes to Screen 2 (monitoring).	Success
Settings button on screens 1 and 2	Pressing the settings button.	Screen display goes to Screen 3 (settings).	Screen display goes to Screen 3 (settings).	Success
Hamburger button on screens 1, 2 and 3	Pressing the hamburger button then selecting stop this application.	Exit the application.	Exit the application.	Success
	Pressing the hamburger button then selecting about this application.	Displays application information.	Displays application information.	Success
Hour+Minute buttons on screen 3	Pressing the button then selecting the time 07.00 AM.	Changed the medication discharge time in screen monitoring to 07:30 and updated the storage in Firebase.	Changed the medication discharge time in screen monitoring to 07:30 and updated the storage in Firebase.	Success
	Pressing the button then selecting time 04.30 PM.	Changed the medication discharge time in screen monitoring to 4:30 PM and updated the storage in Firebase.	Changed the medication discharge time in screen monitoring to 4:30 PM and updated the storage in Firebase.	Success
Drug dosage field on screen 3	Press field then enter the number 5 and press the Save Settings button.	Changed the drug dose in Screen monitoring to 1×5 and updated the data in Firebase storage.	Changed the drug dose in screen monitoring to 1×5 and updated the data in Firebase storage.	Success
	Pressing field then entering the number 11 and pressing the Save Settings button.	Displays “TOO MUCH DOSAGE” and changes the drug dosage description in screen monitoring to 1×0, then updates the storage in Firebase.	Displays “TOO MUCH DOSAGE” and changes the drug dosage description in screen monitoring to 1×0, then updates the storage in Firebase.	Success
	Pressing field then entering the character “Nine” and pressing the save settings button.	Characters are not accepted.	Characters are not accepted.	Success
Field number of drugs on screen 3	Press field then enter the number 20 and press the save settings button.	Changed the number of drugs in screen monitoring to 25 and updated the data in Firebase storage.	Changed the number of drugs in screen monitoring to 25 and updated the data in Firebase storage.	Success
	Press field then enter the number 31 and press the save settings button.	Displays “TOO MUCH MEDICATION” and changes the medication dose in screen monitoring to 0, then updates the storage in Firebase.	Displays “TOO MUCH MEDICATION” and changes the medication dose in screen monitoring to 0, then updates the storage in Firebase.	Success
	Pressing field then entering the characters “Seventeen” and pressing the save settings button.	Characters are not accepted; no changes were made.	Characters are not accepted; no changes were made.	Success

The expected functionality of the component has satisfactorily attained all objectives, as indicated by the results of the BVA method test. The drug dispensing schedule is initiated by inputting the hour and minute values, as illustrated in Figure 8(a) medication schedules. Next, on the same screen, as illustrated in Figure 8(b) process of input data doses and quantities of medicines, input the necessary data into the enter drug doses and amount medicine enter sections. The ‘save settings’ icon must be selected after the input data is of an integer or numeric data type. Figure 8(c) illustrates the updated results of dosing and medication data inputs. The objective is to refresh the data in the cloud storage and present it on the monitoring interface. The monitoring interface is updated by the input data, and the cloud storage is updated to reflect the data from the input, as seen in Figure 9. Data modifications in cloud storage are contingent upon the quality and pace of the internet connection.

The cloud storage data is illustrated in Figure 9. The dataset comprises details such as the quantity of dosage administered and the drug’s expiration time. The main purpose of the component is to be read by the

ESP32 device so that it can execute a predetermined schedule for drug removal. The modifications made to the data stored in this cloud repository are subject to the velocity and reliability of the internet connection in use.

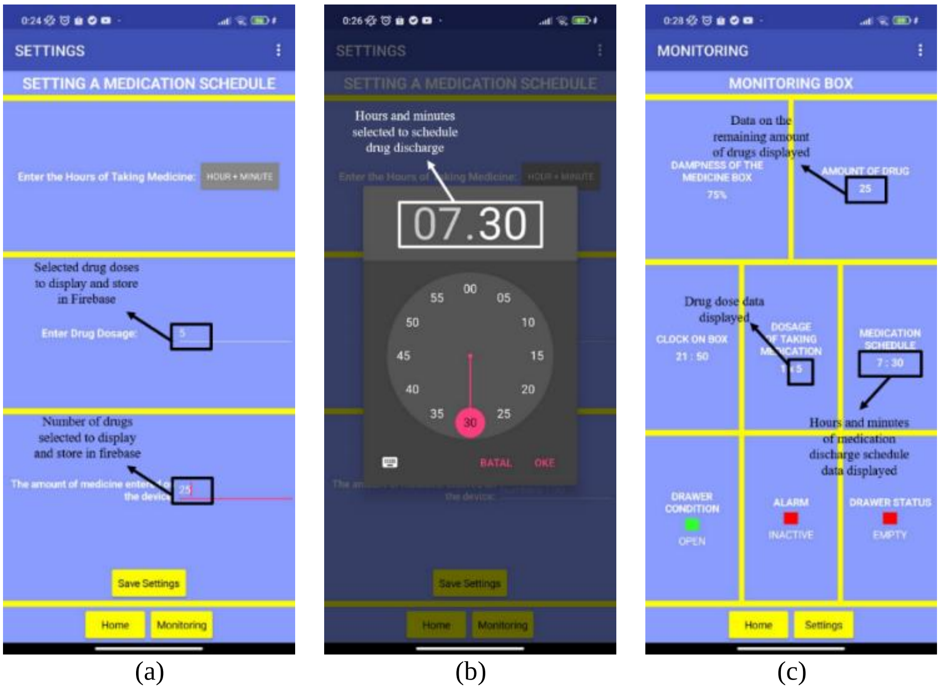


Figure 8. Data input procedure in the application: (a) medication schedule, (b) process of input data doses and quantities of medicines, and (c) updated results of dose and medication data inputs

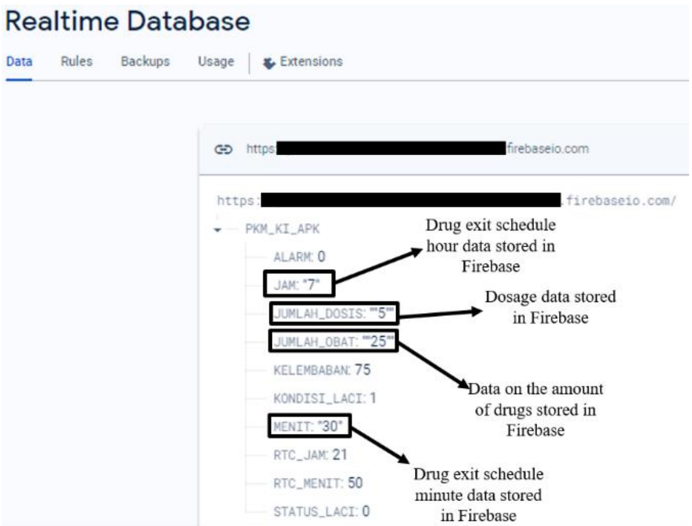


Figure 9. Cloud storage to update data from the input

3.2. Test the effectiveness of drug output from the device

This test utilizes an automatic drug dispensing system. The amount of medicine dispensed is dosage data that has been input into the application and stored in the database. The results of the drug output test are shown in Table 2. In testing the effectiveness of the tool, the drug box is set to dispense the drug continuously with the dosage rule being repeated 10 times and a time interval of 3 minutes for the next drug release. The order of medication that comes out starts from the dosage regimen 1×1, 1×2, 1×3, 1×4, and finally 1×5.

Table 2. Testing the effectiveness of drug exit

Time	Dose 1×1	Dose 1×2	Dose 1×3	Dose 1×4	Dose 1×5
1	Success	Success	Success	Success	Success
2	Success	Success	Success	Fail	Success
3	Success	Success	Success	Success	Success
4	Success	Success	Success	Success	Success
5	Success	Success	Success	Success	Success
6	Success	Success	Success	Success	Success
7	Success	Success	Success	Success	Success
8	Success	Success	Success	Success	Success
9	Success	Success	Success	Success	Success
10	Success	Success	Fail	Success	Success

The test results indicated that the device encountered an error during the dispensation of the medication as prescribed, specifically at the final 1×3 dose. An evaluation reveals that a depleted battery is one of the causes. Testing was conducted with the device connected to the charger following this incident. The findings indicated that the tool exhibited enhanced functionality, resembling its initial state of excellent condition. This provides additional support for the hypothesis that a deficient battery is a contributing factor to the device's incapability to dispense medication as initially indicated. After analyzing data from tool testing results associated with the effectiveness test, the magnitude of the medicine box's error value in the medication dispensing test was determined. The error percentage was determined by utilizing (1):

$$\%Error = \frac{failed\ trials}{total\ trials} \times 100 \quad (1)$$

In 50 trials, a total of two discrepancies were identified. The obtained error percentage value was 4%, precisely the error percentage decreases, the efficacy of the pillbox improves. The obtained results indicate that the medication box dispensing mechanism operates as anticipated, suggesting a relatively high degree of accuracy. While not insignificant, the error remains within acceptable thresholds and may be rectified through the modification of the pillbox's parameters and mechanisms.

4. CONCLUSION

Patients who suffer from chronic conditions such as TB and hypertension can enhance their medication management by utilizing an automated medication management system that includes a dose management function. Aspects including drug dispensing timing, dosage, and quantity provide the necessary adaptability to meet the specific requirements of each patient. Particularly for elderly patients, this system's user-friendliness represents a substantial benefit. Integration with IoT technology enables the application and the medicine box to communicate seamlessly, even when separated by great distances, so long as the medicine box is connected to the internet. Therefore, healthcare providers and patients are able to oversee and control treatment in real-time, transcending geography-based constraints. This automated medication management system satisfies critical patient care requirements and offers a novel and user-friendly resolution for all demographics, including the elderly. Therefore, this system exhibits significant promise in enhancing patient adherence and the overall efficacy of treatment.

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