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IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application

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Abstract

Modern healthcare facilities, especially operation theaters, rely on a multitude of medications to ensure the well-being of patients during surgical procedures. In traditional operation theater environments, medications are typically stored in locked cabinets or storage units, with healthcare professionals manually retrieving and dispensing them as needed. This manual approach can be time-consuming, error-prone, and may lead to delays in urgent medical procedures. Thus, the development and implementation of an "IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application" tailored for drug storage and retrieval in operation theaters becomes imperative and is proposed in this work. The system comprises three main components: a storage compartment system, a storage locking system, and a drugs retrieval system. These components are seamlessly integrated with an ESP32 Wi-Fi module and two Arduino Uno microcontrollers. In order, to enhance security, the automated cabinet system incorporates a three-level security feature. This includes AS608 fingerprint sensors and an S-60 electromagnetic lock, ensuring that only registered users can access the cabinet. The system leverages the Kodular application, which integrates with a Google Sheet Database for user authentication and administration. Experimental results demonstrate that it efficiently retrieves correct and substitute drugs, allowing healthcare professionals to monitor drug availability. In addition, it is shown that the HC-SR04 ultrasonic sensor system is efficient in tracking intended drugs within the storage compartment. The system also updates the remaining drug balance using Firebase Database, providing a reliable and efficient solution for operation theater applications. In a nutshell, by integrating various sensors and IoT technologies, this automated cabinet system significantly improves drug retrieval accuracy and efficiency, thereby enhancing patient safety and minimizing the risk of medication errors.

1. Introduction

Medicines and drugs play very crucial role in saving the life of patients. Modern healthcare facilities, especially operation theaters, rely on a multitude of medications to ensure the well-being of patients during surgical

procedures. In an urban hospital, drug bottles are put into small cells in a cabinet due to the space limitation. Usually, more than 400 drugs are put together in a small working space [1]. This overcrowding, combined with the similarity in drug shapes increases medical errors in drug dispensing in hospitals. According to the Bangladesh Bureau of Statistics (BBS) 2018 data, approximately 73% of adults, equivalent to about 42 million individuals, had a literacy rate, and within this group, more than 21% of patients did not adhere to their prescriptions, 30% couldn't recognize their medications, and in some cases, between 12% to 20% mistakenly consumed medications intended for other patients [2]. In order to address these issues, medical device manufacturers, including Philips, have developed products that dispense sorted trays at predetermined time intervals, and these products also incorporate onboard alarm and reminder features [3]. The incorporation of drug delivery automation holds paramount importance in alignment with the current existing devices. This integration not only contributes to efficient personnel cost management within hospital pharmacy operations but also complements the responsibilities of the nursing budget, which oversees the vital aspects of drug administration and charting [4][5]. By employing this innovative system, the precision and security of drug storage and retrieval can be enhanced which ultimately, streamlining healthcare procedures in operation theaters while ensuring accurate drugs control.

In traditional operation theater environments, medications are typically stored in locked cabinets or storage units, with healthcare professionals manually retrieving and dispensing them as needed. This manual approach can be time-consuming, error-prone, and may lead to delays in urgent medical procedures. In order to make sure that the intended patient received the correct drug at the right time with accurate dosage, healthcare professionals should consistently verify patient information, drug characteristics and prescription details due to the close resemblance in drugs' names, appearances, colors and packaging. Furthermore, these similarities in labeling and packaging increases the risks of drugs being wrongly retrieved, that might lead to medical errors which can cost a patient's life. In order to address those issues, the development and implementation of an "IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application" becomes imperative and is proposed in this work. The cabinet consists of multiple storage compartments which is transparent and equipped with AS608 fingerprint sensor to unlock 60-S electromagnetic lock by integrating Arduino UNO for safety purpose. It incorporates HC-SR04 ultrasonic sensors in storage compartments to track the availability of drugs by integrating the ESP32 Wi-Fi module with Firebase database. On the other hand, it also incorporates another system equipped with HC-05 Bluetooth module and Arduino UNO integrated with Kodular application to ensure the correct drug is located based on the patient's specific needs when undergoing a procedure in the operation theater. Additionally, it can provide crucial information on drugs substitution to assist healthcare professionals in making informed decision, maintain a well-managed drug supply and improve the quality of healthcare services in operation theaters.

2. Methodology

This section discusses the methodology applied in completing this work.

2.1 Block Diagram

The block diagrams of IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application can be viewed in Fig. 1. From the figures, the block diagrams are divided into three sections which are the input, control unit, and output. The input in Fig. 1 (a) which is the block diagram of the storage compartment system consists of 5V DC adapter and four HC-SR04 ultrasonic sensors. As for the control unit, the ESP32 Wi-Fi module is used as the microcontroller while the output consists of a Firebase database, Piezo buzzer, four green and four red LED. Fig. 1 (b) shows the block diagram of the storage locking system, where the input for the system consist of 12V DC adapter and AS608 optical fingerprint sensor. As for the control unit, Arduino UNO is used as the microcontroller. The output consists of relay module, 60-S electromagnetic lock, OLED 0.96" display, green and red LED. The block diagram of the drugs retrieval system is seen in Fig. 1 (c), with the Kodular application and a 12V DC adapter serving as the system's inputs. The microcontroller utilised in the control unit is another Arduino UNO. The output consists of four blue LEDs and Google Sheet database.

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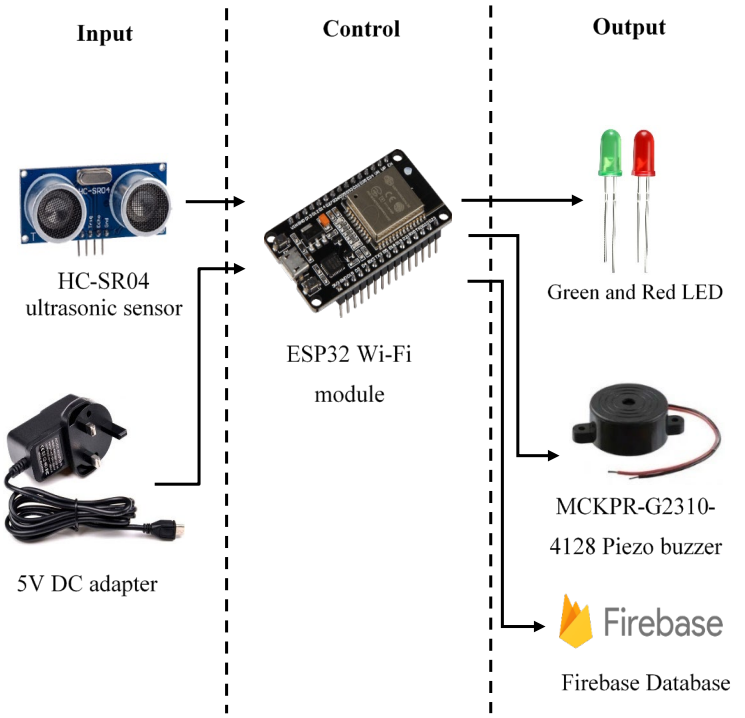
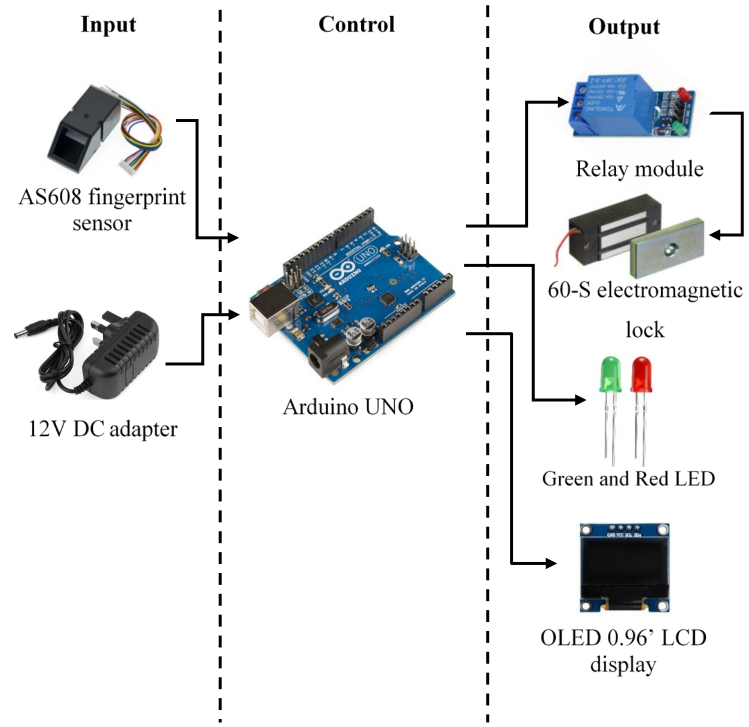
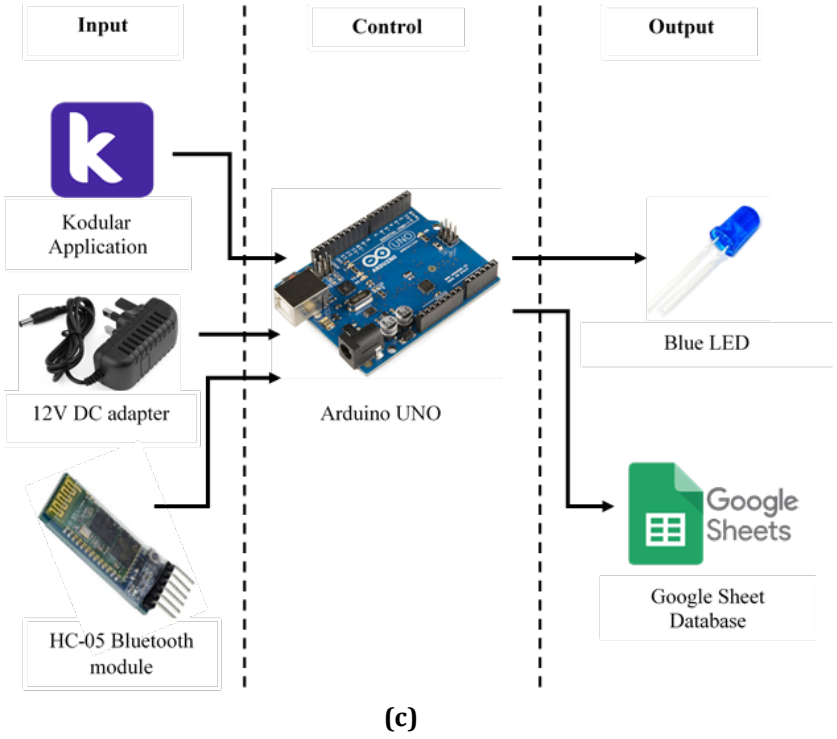


(a)



(b)



(c)

Fig. 1 *The block diagrams of IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application*
(a) Block diagram of the storage compartment system using ESP32 Wi-Fi module;
(b) Block diagram of the storage locking system using Arduino UNO picture;
(c) Block diagram of the drugs retrieval system using Arduino UNO

2.2 Kodular Application

Kodular application is a visual development platform that facilitates the creation of Android applications without traditional coding. It employs a drag-and-drop interface and a block-based programming language, making app development accessible to those without coding experience. With features like real-time testing, cloud-based project storage, and a variety of built-in components, users can design multi-screen applications and export them as Android application packages. Kodular also offers a supportive community for collaboration and assistance, contributing to its goal of simplifying the app development process and enabling a diverse range of individuals to bring their ideas to life.

2.3 Firebase Database

Firebase database is a cloud-based NoSQL database provided by Google as part of the Firebase suite. It is designed for real-time data synchronization and storage, particularly for mobile and web applications. Firebase database uses a JSON type data structure and offers several key features. Real-time data synchronization allows data changes to be instantly reflected across connected devices, ensuring a seamless user experience. It supports offline data access, allowing applications to function without an internet connection and syncing changes when connectivity is restored. Firebase database integrates with Firebase Authentication for secure access control. The database is serverless, eliminating the need for users to manage infrastructure, and it scales automatically to handle varying workloads.

2.4 Google Sheet Database

While traditional databases offer robust features, Google Sheets, a simpler and more accessible features. As a cloud-based spreadsheet application, Google Sheets database can function as a powerful tool for organizing and managing project data. It functions as a central database to store various types of project information, such as component specifications, circuit schematics through drawings or linked images. Additionally, Google Sheet stores experimental results including data tables, graphs, and project timelines with task checklists. This allows for easy data retrieval, comparison, efficient project management and documentation.

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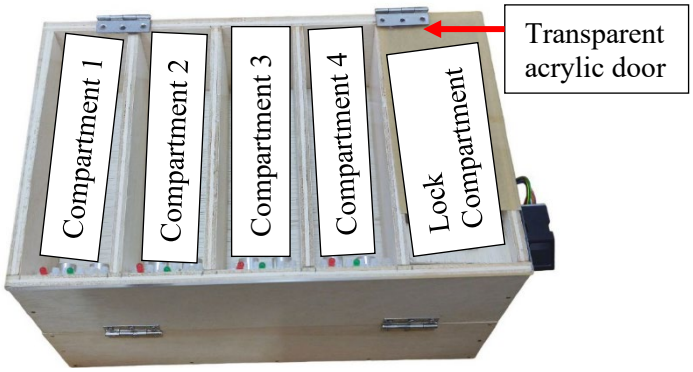
3. Results and Discussion

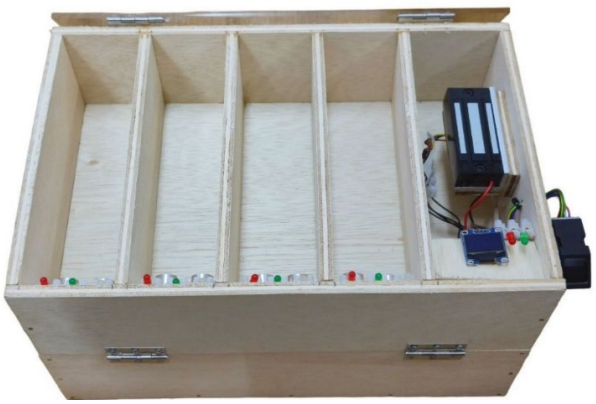
This section discusses the results obtained from testing the complete prototype of IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application. The results are divided into three main parts. Firstly, the storage compartment system which gives real-time drugs count update. Additionally, the storage locking system which provides a secure entry for drugs retrieval. Finally, the drugs retrieval system which provides accurate drugs retrieval and substitute indication.

3.1 Final Product

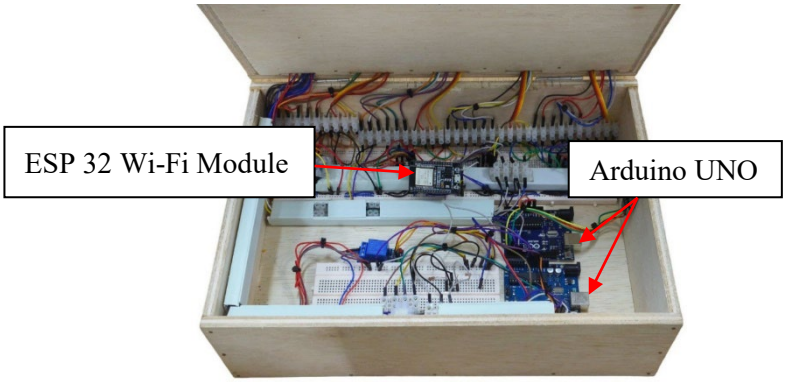
The complete prototype of IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application, as can be seen in Fig. 2, consists of storage compartment system to monitor the stock of drugs in real-time, storage locking system to secure the compartment and drugs retrieval system to indicate the intended and substituted drugs. with the in Fig. 2 (a) shows the overall view of the final product. The storage compartment, which can be viewed in Fig. 2 (b), stores the drugs in four compartments and keeps the electromagnetic lock neat and tidy in the last compartment. On the other hand, the bottom deck compartment in Fig. 2 (c) acts as a control unit of the cabinet system that stores the three microcontrollers together with their components.



(a)



(b)



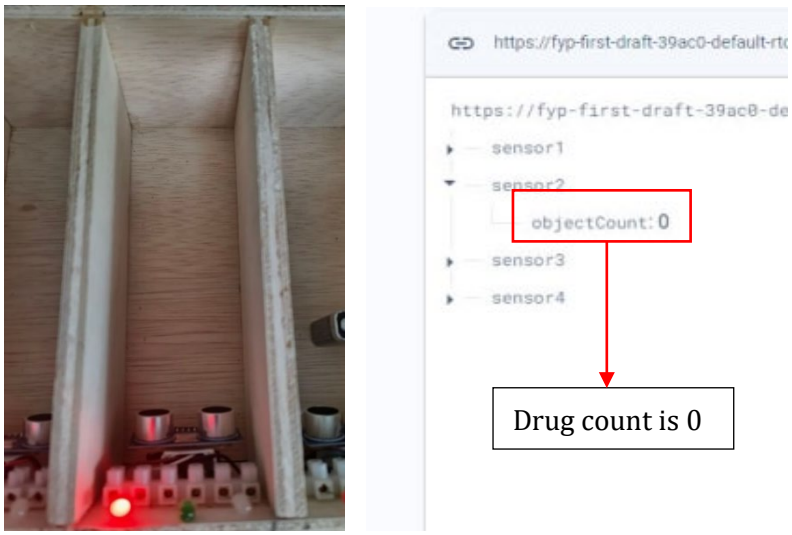
(c)

Fig 2 The complete prototype of IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application:
(a) Overall view of the final product (b) The storage compartment
(c) Control unit of the cabinet system

3.2 Storage Compartment System

The placement of ultrasonic sensors and arrangement of the objects plays a crucial role in this storage compartment system. The ultrasonic sensors will measure the drug count in reverse order based on the distance. When there are four objects placed in front of an ultrasonic sensor with a 4 cm space between each object, the sensor will count the closest object as the fourth and update the drug count as four in the Firebase database. If the closest object is removed, the distance from the ultrasonic sensor to the next object increases to 8 cm. Consequently, the ultrasonic sensor will update the remaining drug count as three in the Firebase database. For the purpose of validation, an experiment is performed where the compartment is tested with and without drugs. In this case, 9 V batteries are used to represent the drugs which are placed in front of the ultrasonic sensors within the range of 20 cm in the storage compartment system. The results are recorded and observation are summarized in Table 1. From the table, it is shown that the 'objectCount' feature of the child node in Firebase Database is able to update the remaining balance of the drugs in compartment 2 of storage compartment system.

Table 1 *The assessment of storage compartment system with different drugs count*

Drug count	Hardware and displayed result on Firebase Database
0	
	Observation: It can be seen from the display of Firebase Database that the drug count (*objectCount*) from the ultrasonic sensor 2 in compartment 2 is 0.

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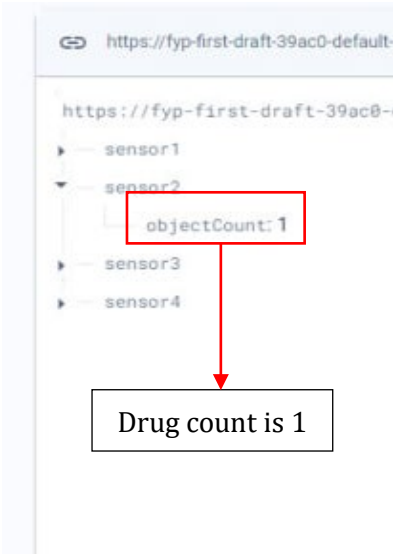
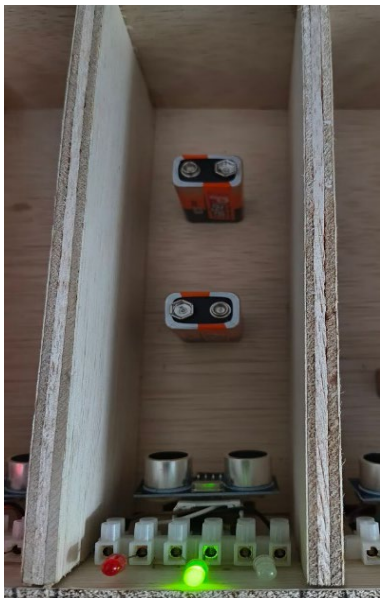
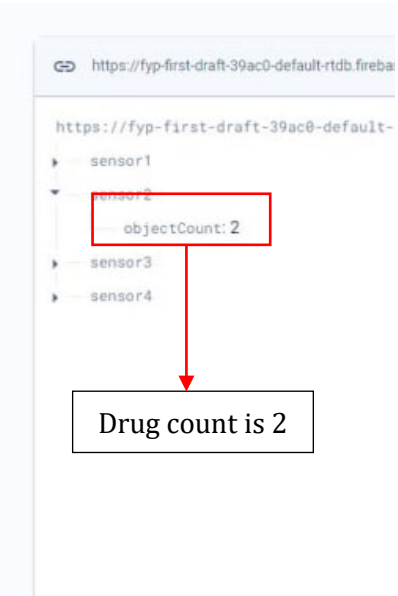
1



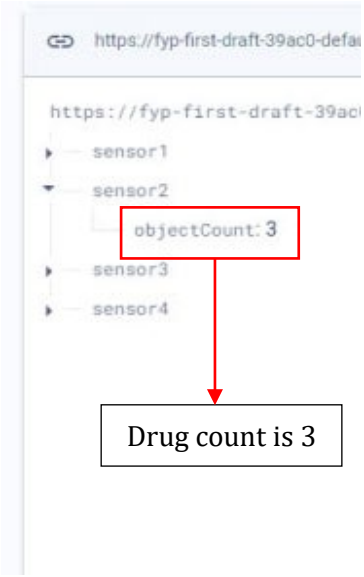
Observation: It can be seen from the display of Firebase Database that the drug count (*objectCount*) from the ultrasonic sensor 2 in compartment 2 is 1.

2

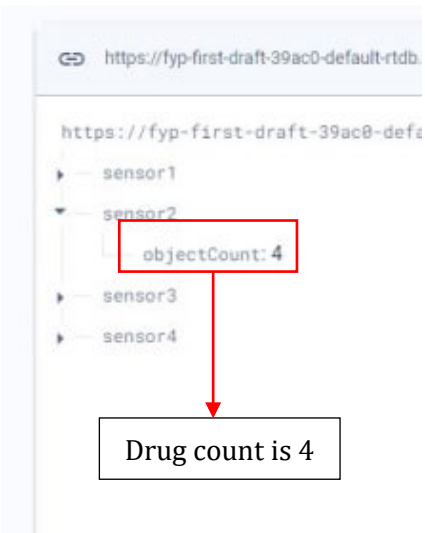




Observation: It can be seen from the display of Firebase Database that the drug count (*objectCount*) from the ultrasonic sensor 2 in compartment 2 is 2.

3		

Observation: It can be seen from the display of Firebase Database that the drug count (*objectCount*) from the ultrasonic sensor 2 in compartment 2 is 3.

4		

Observation: It can be seen from the display of Firebase Database that the drug count (*objectCount*) from the ultrasonic sensor 2 in compartment 2 is 4.

3.3 Storage Locking System

The configuration of storage locking system of the IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application consists of AS608 optical fingerprint sensor, 60-S electromagnetic lock, single channel relay module, OLED 0.96" display, two LEDs and 12 V DC power supply with the Arduino Uno. For the purpose of validation, an experiment is performed where the locking system is tested in locked and unlocked condition with valid and invalid fingerprint. The results are recorded and observation are summarized in Table 2. From the table, it is shown that the automated cabinet system provides a secure entry as it requires the user to scan his registered fingerprint on the scanner located at the right side of the cabinet as a second level security system before retrieving the drugs. The first level security system is introduced in the software level where the user has to authenticate his fingerprint on the 'Login Page' in Kodular application as can

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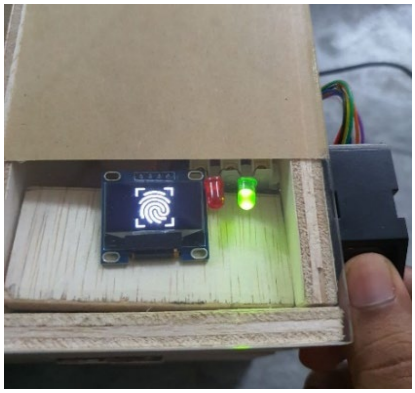
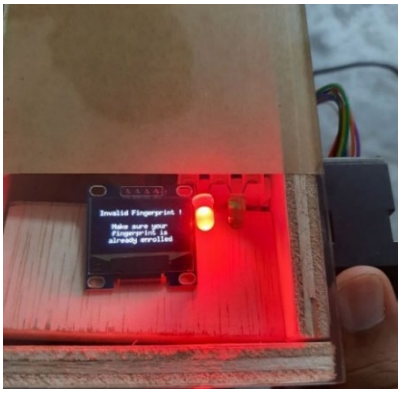
be seen in the following section. After the drugs are retrieved, the user has to scan his fingerprint again to securely lock the automated cabinet system which serves as the final level security system.

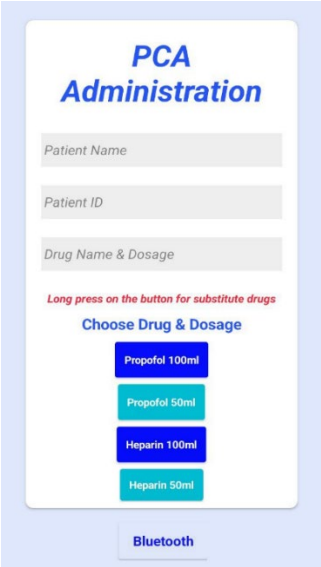
Table 2 *The assessment of storage locking system in different states of the 60-S electromagnetic lock*

	Condition of fingerprint	
State	Valid	Invalid
Locked	 **Observation:** It can be seen from the green LED and OLED display indication that the fingerprint is valid.	 **Observation:** It can be seen from the display green LED and OLED display indication that the fingerprint is invalid.
Unlocked	 **Observation:** It can be seen from the green LED and OLED display indication that the fingerprint is valid.	 **Observation:** It can be seen from the green LED and OLED display indication that the fingerprint is invalid.

3.4 Drugs Retrieval System

This section shall analyze the operation of drugs retrieval system as a part of IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application. The system consists of a HC-05 Bluetooth module and four blue LEDs with Arduino UNO connected to Kodular application and integrated to Google Sheet database. In order to evaluate the performance of the drugs retrieval system, there are several procedures to be followed. The results are recorded and observation are summarized in Table 3. From the table, it is shown that the Kodular application could accurately locate the correct drugs from the automated cabinet system based on the patient's specific needs.

Table 3 *Procedures of the drugs retrieval system in the Kodular application and Google Sheet Database*

Procedures	Activities
1	 The user shall click on the fingerprint icon on the 'Login Page' in Kodular application to perform the fingerprint authentication.
2	 Next, the user shall connect the application to the Bluetooth module by clicking on the Bluetooth button in the 'Administration Page'. Then the user should key in the input details which consists of patient name, patient identification, drug name and dosage before clicking the retrieval button.

3

Patient & Drugs Register Database

File Edit View Insert Format Data Tools Extensions Help

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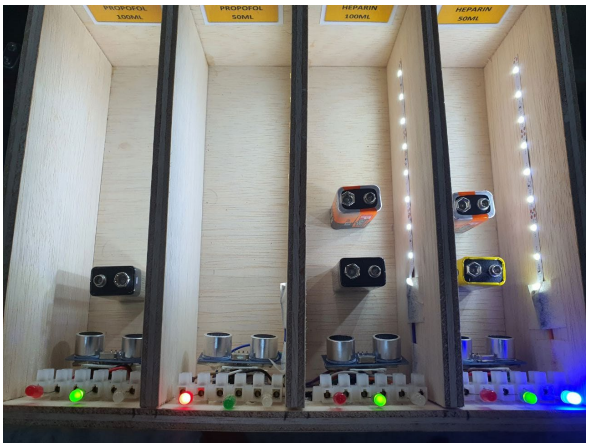
E2

	A	B	C	D
1	Timestamp	Patient Name	Patient ID	Drug Name & Dosage
2	16/06/2024 21:52:23	Testing	111111	Testing 111111
3	16/06/2024 21:52:51	Testing	111111	Testing 111111
4	16/06/2024 22:01:20	Testing	111111	Testing 111111
5	19/06/2024 02:41:21	Testing	21212	Propofol 50ml
6	19/06/2024 02:41:58	Testing	21212	Propofol 50ml
7	19/06/2024 03:28:48	hdhhd	75586	dhhfsse
8	19/06/2024 03:36:38	Sivenesh	120899	Propofol 50ml
9	19/06/2024 03:41:47	Sivenesh	120899	Propofol 100ml

Then, the user should **s**hort press the intended retrieval button for the retrieval process. This shall trigger the blue LED in the compartment and the input details as entered in the first procedure will be saved to the Google Sheet Database.



4

Patient & Drugs Register Database

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E2

	A	B	C	D
1	Timestamp	Patient Name	Patient ID	Drug Name & Dosage
2	16/06/2024 21:52:23	Testing	111111	Testing 111111
3	16/06/2024 21:52:51	Testing	111111	Testing 111111
4	16/06/2024 22:01:20	Testing	111111	Testing 111111
5	19/06/2024 02:41:21	Testing	21212	Propofol 50ml
6	19/06/2024 02:41:58	Testing	21212	Propofol 50ml
7	19/06/2024 03:28:48	hdhhd	75586	dhhfsse
8	19/06/2024 03:36:38	Sivenesh	120899	Propofol 50ml
9	19/06/2024 03:41:47	Sivenesh	120899	Propofol 100ml
10	19/06/2024 03:41:54	Sivenesh	120899	Propofol 100ml

In the case where the intended drugs are not available, i.e: the storage compartment is empty, the user shall long press the

	same retrieval button to locate the substitute drug in another compartment. This shall trigger the blue LED in that compartment containing the substitute drug and similarly the input details will be saved to the Google Sheet Database. After getting the intended drugs, the user shall scan his fingerprint again to securely lock the automated cabinet system.

4. Conclusion

The IoT-Based Automated Cabinet System for Drugs Storage and Accurate Retrieval for Operation Theater Application has been designed and developed in this work. The automated cabinet system consists of storage compartment system, storage locking system and drugs retrieval system. Multiple input and output components are integrated with the ESP32 Wi-Fi module and two Arduino Uno as the microcontrollers. In order to enhance the security feature, the automated cabinet system provides a three-level security feature consisting of AS608 fingerprint sensors and S-60 electromagnetic lock to ensure only the registered user can have access to it. The system utilizes the Kodular application which is integrated with Google Sheet Database for user authentication and administration; and also to retrieve the correct and substitute drugs efficiently, enabling healthcare professionals to monitor drug availability. The experimental results indicate that the HC-SR04 ultrasonic sensor system can effectively track the intended drugs in the storage compartment and update the remaining balance using Firebase Database, providing a reliable and efficient solution for operation theater applications. The integration of various sensors and IoT technologies has significantly improved the accuracy and efficiency of drug retrieval, thereby enhancing patient safety and reducing the risk of medication errors.

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Conflict of Interest

Authors declare that there is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Sivenesh Balachandran;* ***data collection:*** *Sivenesh Balachandran;* ***analysis and interpretation of results:*** *Sivenesh Balachandran, Shaharil Mohd Shah;* ***draft manuscript preparation****: Sivenesh Balachandran, Shaharil Mohd Shah. All authors reviewed the results and approved the final version of the manuscript.*

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