

## Inpatient WiFi-enabled medication dispenser for improving ward-based clinical pharmacy services

Khaleel Nawfeal Khaleel<sup>1</sup>, Mazin N. Farhan<sup>1</sup>, Mohammed G. Ayoub<sup>2</sup>, Mohammed Sabah Jarjees<sup>1</sup>

<sup>1</sup>Department of Medical Instrumentation Technology Engineering, Technical Engineering College Mosul, Northern Technical University, Mosul, Iraq

<sup>2</sup>Department of Computer Technology Engineering, Technical Engineering College Mosul, Northern Technical University, Mosul, Iraq

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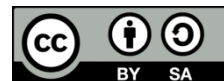
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### ABSTRACT

Medications are vital for patients and especially for those who are receiving treatment in hospitals. Providing medications for these people is essential to maintain their health. On the other hand, medication dispensing error is one of the most common challenges that face clinical pharmacists and medical staff. These errors frequently occurred due to poor medication systems and/or human factors (i.e. environmental conditions, fatigue or staff shortage). These factors may affect prescribing, transcribing, administration, dispensing and monitoring practices which can result in disability, severe harm and even death. Avoiding medication dispensing errors is the key motivation of this paper. Consequently, a biometric-based dispensing system has been designed and implemented. The system can be installed at hospital wards and used for delivering and monitoring inpatients doses. It consists of three parts; hardware, software and mechanical part. Three 4-phase stepper motors are used for controlling the mechanical part of this system. An optical fingerprint sensor is used which is compatible with the ESP32 low-power SoC for scanning patients' fingerprints to recognize and store their data. The system directly updates its database whenever is used by the inpatients, so that nobody can get additional doses. This system is cost-effective, reliable and easy to use.

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### Corresponding Author:

Mazin N. Farhan

Department of Medical Instrumentation Technology Engineering, Technical Engineering College Mosul

Northern Technical University

AlMinsaa St, Mosul City, Nineveh Governorate, Iraq

Email: mazin.nadheer@ntu.edu.iq

## 1. INTRODUCTION

The profession of pharmacy has changed dramatically in recent decades. Because of the rise of chronic diseases and disorders linked to a sedentary lifestyle [1]. One of the most common safety incidents for patients in hospitals (inpatient) is medication error [2]–[4]. About 80,000 medication error were reported in 2014 in Wales and England [5]. The process of dispensing medications is not only taking medicines from shelves and giving them to the patient but also sticking label on the pack with the direction of use and the dose details [6]. In 2014, more than a billion prescriptions were dispensed from England pharmacies. Whereas, about 4 billion prescriptions are annually dispensed in USA in 2014 [7]. These huge numbers of prescriptions usually lead to medication dispensing errors. As a result, community pharmacists are now required to conduct advanced clinical services such as medication reviews, illness management consultations, guaranteeing the quality and completeness of patients' health records, and administering medication optimization and therapy monitoring programs [8], [9]. Noncommunicable diseases NCDs such as cancer,

cardiovascular disease (CVD), chronic obstructive pulmonary disease (COPD) and type-2 diabetes, refer to medical conditions that are not primarily initiated by acute infection, causing long term health consequences and usually long term treatment is needed [10], [11]. On the other hand, infectious diseases (IDs) are syndromes caused by viruses, bacteria, parasites or fungi under certain conditions. In 2019 three IDs- tuberculosis, diarrheal diseases and lower respiratory infections- were considered in the top causes of death worldwide [12]. Therefore, patients with such medical conditions should take their prescribed medications in time, if they do not, it may cause death in some circumstances. Consequently, both of IDs and NCDs need essential short-to-long term high quality treatments.

The most important part of inpatient care with noncommunicable diseases (NCDs) or Infectious diseases (IDs) are the quality of using medicines. Thus, wisely selection of management options, choosing suitable medicines and use them safely and effectively are the main caregiver/medical staff roles for such medical conditions. Failure to following these roles may lead to a drug-related problem. Drug-related problems are defined as “an event or circumstance involving drug therapy that actually or potentially interferes with desired health outcomes” [13]. Large number of hospital admissions may result from drug-related problems and most of them are avoidable [14]. These problems including drug-related ones, hospital readmissions and health care expenditure are reduced to some extent in high-income countries due to the improvement of their clinical pharmacy services [15], [16]. Whilst, the clinical pharmacy services are still limited in developing countries [17], [18]. Limitations may due to lack of clinically qualified pharmacists, poor pharmaceutical literacy, limitations in medicines regulatory capacity, lack of utilization of research evidence, poor essential medicines availability and restrictions in accessing high quality medicines [19], [20]. Therefore, results of implementation clinical pharmacy services in high-income countries cannot be generalizable to developing countries.

Pharmacy automation refers to automating routine tasks achieved at pharmacies. Routine tasks include: counting objects (such as tablets or capsules), measuring powders and liquids, making mixtures for compounding and finally updating databases. Pharmacies usually dispense capsules or tablets prescriptions with classic ordinary way (using simple tray and spatula) which is considered a time consuming task. Therefore, automation is the best solution to accelerate the process [21], [22]. One of the earliest tries of pharmacy automation was patented in 1970s, it was done in the United States by Kirby and Lester, it was just a simple tablets counter. After that, a numerous projects have been done using a variety of techniques and technologies to improve designs from the computer integrated tablet counter (Kirby Lester, KL20) to robotic medication dispenser (Scriptpro’s SP200, Kirby Lester’s KN60) which is a hand-free medication dispenser [21]. There are numerous types of digital medication dispensing systems are currently available in the market. The implementation of such systems are accomplished using various methods and technologies. The majority of these kind of systems, which are presented in the literature, take into consideration the elderly people with different neurodegenerative illnesses such as Alzheimer and post-stroke dementia [23], [24]. However, people with infectious and noninfectious diseases including diabetes and high blood pressure hardly been used as a target group for the aforementioned systems, especially those are staying in a hospital while receiving medical care or treatment.

Ibitoye *et al.* [23] proposed an inexpensive system to present a medication dispenser for people with neurodegenerative illnesses. The system is used Arduino UNO as a microcontroller with three micro servomotors for controlling the pill storages. Moreover, it included a keypad as well as a liquid crystal display for displaying instructions for the user. This study claims that the system is used to monitor the patients’ medication adherence level. On the other hand, another study by Joy *et al.* [25] proposed an intelligent pill dispenser called SIMoP box for monitoring and dispensing purposes. The system used to provide medications as well as food in the case of isolated patients. They used stepper and DC motors for pills arrangement as well as a buzzer for alarming the patient to take the dose at the specified time. Their proposed system capable of outfitting different functionalities for home care patients such as liquid dispenser, pill dispenser and room temperature regulation. However, it seems that the system did not equipped with any smart component that could be monitored remotely in order to ensure that the elders adherence to their medication.

Different robotic techniques have also been used in developing and implementation prototypes as autonomous medication dispenser. These systems were used for medication purposes for senior citizens such as tracking the patient location and dispenses the medication as well as the ability of tracking the time of the dose [24]. Ahadani *et al.* [21] used simple components for prototyping and fabricating a low cost robotic medicine dispenser. The prototyped system can be used by pharmacists to count pills and dispense it into vials. Therefore, the usage of the system is limited to pharmacists and cannot be used widely neither for hospitalized patients nor at home. Moreover, dispensers unable to hold all kinds of medicines available in the pharmacies. Therefore, this type of system is expected for usage only for common diseases which are required frequently.

Artificial intelligence (AI) especially computer vision and internet of things (IoT) technologies also got attention for researchers for developing such management systems. Researchers from Quebec and Carleton University developed a medication dispenser based on computer vision. The system verifies the amount of drug at each time in order to guarantee the right medication intake by the patients, which can be used, in long-term healthcare. The developed system uses a color camera as imaging sensor and the output of this camera is compared with the pills database on the server, therefore this system uses Wi-Fi connection for sending the captured data in order to perform the comparison using machine-learning approaches [26]. On the other hand, Medina *et al.* [27] proposed a low-cost oral medication intakes system that can be used for patients with a fever. The system is analyzed the streamed biosignals from patients through a wearable sensor and make a decision for the doses time.

This paper aims to present a time-saving and secure smart medication dispensing system that could be used to serve inpatients with IDs and NCDs in hospital regular or isolation wards. Moreover, the system used wireless integrated chip that can be stored the authentication outcome of patients in the cloud for remotely monitoring purposes. The paper is organized as follows: next part illustrates the hardware and software of the developed medication dispenser in details. Part 3 addresses the performance and evaluation of the system as well as the discussion of the obtained results. Finally, part 4 concludes this study.

## 2. METHOD AND MATERIALS

### 2.1. System design and description

The proposed system is comprised of three main parts hardware, software and the mechanical part. The hardware section is composed of different electronic components which are listed in Table 1. ESP32 development board is the main part in the proposed design, which is used as microcontroller for controlling the other components in the system. It is a low-power and cost-effective system-on-chip (SoC) integrating Wi-Fi and Bluetooth communication capability. Another significant part is the optical fingerprint sensor. It offers a high-quality and robust touch sensor for scanning fingerprints in order to store the patients data in the fingerprint-database. This sensor is allowed to save up to 128 templates, which represents the inpatients' fingerprints. Regarding the software part, Arduino IDE with necessary libraries are used for programming the aforementioned components. The final part in the system is the mechanical part; in which three 4-phase stepper motors are set for controlling the plastic tube pill storages. Table 1 shows the list of selected components that required for the final design including items description and quantities.

Table 1. Components used for the proposed medication dispenser system

S/N	Components	Description	Quantity	Advantage
1	ESP32 development board	Processing unit	1	Low cost microcontroller with wireless communication
2	Optical fingerprint sensor	Input unit	1	Simple biometrics sensor offers high accuracy for fingerprint recognition
3	4-phase stepper motor	Control unit	4	NN
4	ULN2003 driver board	Control unit	2	NN
5	Shift register	Control unit	2	NN
6	Pill storages tubes	Storage unit	4	Easy to fill and manage

NN: Not necessary

### 2.2. System structure

The fingerprint sensor has a transistor-transistor logic (TTL) universally asynchronous receiver/transmitter (UART) interface, which can be easily connected to the microcontroller UART. The patient fingerprint templates are stored in the flash memory of the sensor for comparison while the whole sketch of the system store in the microcontroller internal flash memory. In order to achieve that, Adafruit fingerprint library has been used for interfacing the fingerprint sensor with the ESP32 development board and acquiring the data. Moreover, stepper motors with driver boards also connected to the microcontroller in order to control the pills tubes. Due to the limited number of digital inputs and outputs in the ESP32 development board, a shift register is needed to add in order to drive multiple stepper motors. IFTTT platform is used to connect the system to the cloud. It is used widely for many IoT applications such as smart home and medical care. The platform allows to stores the authentication data in Google Spreadsheet online. The system must be connected first to the internet through a wireless access point, then, the data that obtained from patients will be stored online in a spreadsheet. Taking patients fingerprint after admitted to the hospital is the first step in order to store their data in the fingerprint-database. This is done by placing their fingers on the optical fingerprint sensor for fingerprint scanning and saving process. Consequently, programming the

SoC according to the stepper motors that is associated with the required tube depending on patients' records. While the system is used by patients, a copy of their records including ID and time will be sent through a Wi-Fi and stored in the Google Spreadsheet directly for remotely monitoring purposes by healthcare team to ensure that the patient takes the medicines correctly. Figure 1 shows the block diagram of the system including the processing and communication unit in addition to the optical fingerprint sensor that is the system input. It is obvious that despite the system uses simple and accessible components, it is considered as robust and secure due to the optical fingerprint sensor.

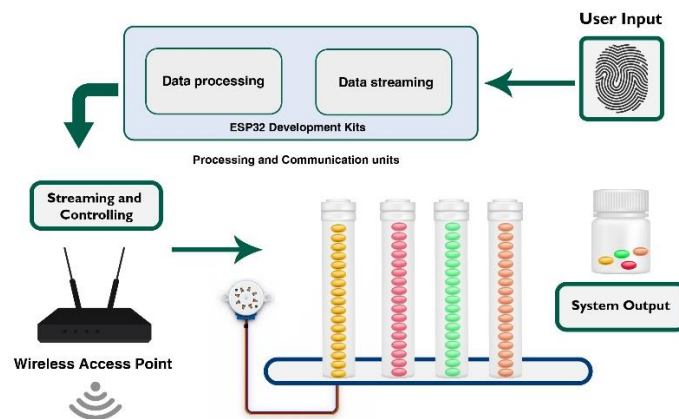


Figure 1. Structure of the entire proposed medication dispenser system

### 3. RESULTS AND DISCUSSION

The performance of the implemented system, which is shown in Figure 2, has been evaluated by several trials. Each of the participants has been asked to perform several trials to measure the accuracy of the system. Moreover, the system is evaluated according to the finger orientations; this will assure that the system can be worked with different conditions.

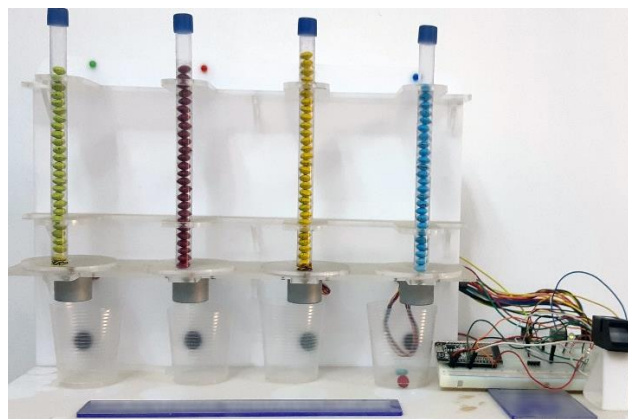


Figure 2. The implemented medication dispenser system

#### 3.1. Prototype performance and evaluation

Each of the participants was asked to perform several trials to measure the accuracy of the system. The trials were being achieved randomly and wrong trials were performed intentionally. Table 2 shows the trails that were achieved by the participants. Where (✓) and (✗) mean true and false response of the system, respectively. In the 2<sup>nd</sup> trail of participant 1 and the 1<sup>st</sup> trail of participant 2, both participants were asked to use a wrong finger. While a wet finger was used by participant 3 in trail 3. Participant 4 was also asked to put his correct finger but removed it quickly, trail 5. The rest of the tails were achieved normally. It can be

noticed that all the responses of the system were correct in all trails as shown below. Consequently, the system has 100% accuracy.

Table 2. Trails achieved by each of the participants

Trial no.	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
1	✓	✓	✓	✓	✗
2	✗	✓	✓	✓	✓
3	✓	✓	✗	✓	✓
4	✓	✗	✓	✓	✓
5	✓	✓	✓	✗	✓

**3.2. Finger orientations**

The orientation of the finger was also tested to evaluate the system. Figure 3 shows the different orientation of participant’ finger during authentication process to evaluate the system by its confidence level. Initially, the reference fingerprint template of participants were oriented vertically (0°) as shown Figure 3(a), then, three different directions were, taken and compared with the reference fingerprint, are 90° in Figure 3(b), 180° in Figure 3(c), and 270° in Figure 3(d), which is shown in Table 3.

It can be noticed that the confidence level is changed with the changing of the orientation angle. However, the change in the confidence level was not consistent and it has a different value from one participant to another. The confidence level of the fingerprint sensor may not only sensitive to the orientation angle but also to the data-base and image processing of the sensor.

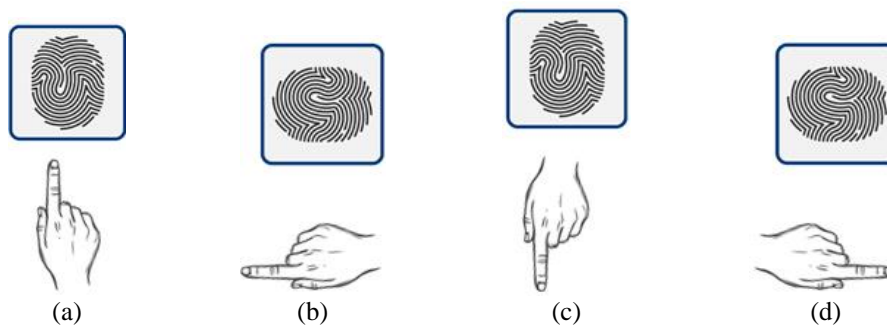


Figure 3. Different orientation of participants’ finger at (a) 0°, (b) 90°, (c) 180°, and (d) 270°

Table 3. Orientation angles of participants’ finger with the confidence level of the fingerprint sensor

Participant	Confidence Level	Orientation angles of participants’ finger			
		0°	90°	180°	270°
1		108	60	107	71
2		92	65	62	93
3		70	67	84	106
4		80	90	59	74
5		74	62	92	71

**4. CONCLUSION**

Medication dispenser systems offer simple and flexible solution to avoid/reduce routines and medication errors in hospitals and medical centers. In this paper, we have proposed a smart medication dispenser system that could be installed and used at hospital wards. The system can be used for delivering and monitoring purposes in order to ensure that patients adherence to their medication. Thus, every patient in the ward will receive his/her prescribed medication according to the database that set by the clinical pharmacist in coordination with physician or specialist. The whole process is organized and monitored by the clinical pharmacy administration in the hospital and inpatients database is always being up-to-date by the system. Nevertheless, patient with adermatoglyphia (absence of fingerprints) cannot be served by this system and should ask the chemist in person for his/her medication.

The proposed medication dispenser system can be furtherly enhanced in order to increase the reliability of the system. For example, patients fingerprint templates can be stored in advanced database

system. Moreover, two factor authentication also suggest to ensure that every patient take their own doses on time leaving no room for mistake. Adding these implicit enhancements will makes it possible to use the system as robotic medication dispenser without the need of medical workers to intervene.




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## BIOGRAPHIES OF AUTHORS






**Khaleel Nawfeal Khaleel**    is an academic lecturer who works at the Northern Technical University (NTU). He received a B.Eng. degree in Medical Instrumentation Technology Engineering in 2000 from the Northern Technical University, Mosul, Iraq. Khaleel obtained his postgraduate Diploma in Electronic Engineering from University of Aleppo, Faculty of Electrical & Electronic Engineering Syria, 2006 and Master Degree in Electronic Engineering (Medical Instrumentation Engineering), University of Aleppo, Faculty of Electrical & Electronic Engineering, Syria, 2011. His email is Khalil.nawfeal@ntu.edu.iq.






**Mazin N. Farhan**    is academic lecturer at the Northern Technical University (NTU). He received his Bachelor degree in Medical Instrumentation Technology Engineering from the Northern Technical University in 2007. He also received a Master degree in Medical Devices from the University of Strathclyde, Glasgow, UK in 2014. He has studied and worked with medical Instrumentation and have had the chance to get an in depth understanding of medical devices and their environment. He is looking to use his engineering skills in improving the current state of medical devices. His top research interest topics are medical image processing, biosignal processing and medical sensors. His email is: mazin.nadheer@ntu.edu.iq.



**Mohammed G. Ayoub**    is a lecturer of Computer Engineering at Northern Technical University, Mosul, Iraq. He obtained his undergraduate degree in Computer Technology Engineering in 2006 from Technical Engineering College of Mosul. From 2014 to 2015, Mohammed was doing his MSc on Electronic Communications and Computer Engineering in the department of Electronic and Electrical Engineering, the University of Nottingham, UK. After obtaining his MSc degree in 2015, he was appointed as an assistant lecturer at the Department of Computer Technology Engineering, the Northern Technical University, Iraq. His primary research interests revolve around the application of signal processing and sensor data techniques to solve and understand biomedical engineering problems. His email is: mohammed.ghanim@ntu.edu.iq.



**Mohammed Sabah Jarjees**    received the B.Eng. degree in Medical Instrumentation Technology Engineering, 2002, and the Technical Master Degree in Medical Instrumentation Technology Engineering, 2006 from Technical College of Mosul, Northern Technical University, and Mosul, IRAQ. He received the PhD in Biomedical Engineering, University of Glasgow, Glasgow, United Kingdom, 2017. He is currently assistant professor and works as head of Medical Instrumentation Technology Engineering Department. His email is: mohammed.s.jarjees@ntu.edu.iq.