RESEARCH PAPER

An IoT-Enabled Smart Medicine Box for Automated Medication Adherence Monitoring and Caregiver Notification

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Abstract:

Another aspect of non-compliance in the medical field that poses a serious concern to the current medical system at large is the use of medication. In general, lack of compliance in taking the medical prescription by the patients means that the outcomes of the treatment are affected. In most cases, failure to use medication as required means that there will be a lack of good health outcomes due to the deterioration of the patient's medical situation. This problem is particularly prevalent among elderly individuals, patients suffering from chronic illnesses, and people with demanding daily routines, where missed or delayed medication intake is often caused by memory decline, lack of supervision, or complex prescription schedules. The traditional methods of using pill boxes and manually prompting the patient have been very reliant upon the diligence and memory of the patient and have been inefficient for long-term administration of medications. Consequently, the demand for intelligent and user-centred systems that can aid the patient in following the medication regime has been increasing by the day. Recent developments in embedded systems and Internet of Things technology have made it possible to design smart reminders for medicines that support automated reminders, realtime tracking, and remote interaction with caregivers. The smart boxes for medicines using IoT technology usually consist of combinations of microcontrollers with RTC, display systems, and alert systems for providing time-based reminders to the patients. Also, internet connectivity provides support for recording, storing, and remote access to information regarding patient compliance with their medications. Unlike advanced automated dispensing systems, smart boxes based on reminders are much safer and a better solution for home health care, particularly for senior citizens. This paper discusses an in-depth examination of the smart medication box systems enabled using the capabilities of the Internet of Things with applications targeting the use of the systems as a portability mechanism for medication reminder and patient adherence tools. The paper discusses the importance of the systems in design aspects targeting the reminder mechanism accuracy and the patient and healthcare provider communication effectiveness. The system helps in the automation of patient medication reminder processes with increased accuracy and the recording of patient medication history for improved patient treatment success. In addition, the multimodal

notification system with visual and sound notifications makes the system accessible to visually or hearing-impaired patients. The results show the cost-effectiveness and efficiency of the Internet-ofThings-based smart medication reminder systems for improving patient prescription medication use and enhancing patient-oriented healthcare delivery systems.

Keywords— Smart Medicine Box (SMB), RTC, IoT, ESP32, Medication Adherence

I. INTRODUCTION

Adherence to medication is an essential element for the success of healthcare results. This is especially the case where the patients undergoing treatments for chronic illnesses are concerned. This refers to the accuracy of patients in the consumption of medications as indicated. Despite the significant advancements in the field of medical science and health technology, the problem of nonadherence to medications has been considered a common issue across the world. This particular issue has great significance in the case of elderly patients who take several medications.In current decades, enhancements in the quality of care of the health sector have accelerated life expectations. Although this comes under social advancement, it is adding pace to the increase in the senior population, further burdening health infrastructure. Research states that, along with other alterations, the senior population above 65 years is rising by more than ten million persons each year, with a drastic change projected for 2030 [1]. With increasing age groups, decreasing mental and physical capabilities compromise the ability of seniors to manage their medications on their own, making this an impending concern for the health sector of today. Forgetfulness, confusion arising from the complexity of medication, inadequate understanding of medication times, and lack of constant monitoring are the main factors affecting medication non-compliance among the elderly and chronically ill patients. For patients with diabetes, hypertension, cardiovascular diseases, and other chronic illnesses, the risk factors are very severe, as patients can become worse or even risk death due to medication mistakes, which can be fatal [2].Conventional approaches for managing medications using pill boxes and written reminder systems leave patients highly reliant on memory and personal discipline. Even electronic reminder pill boxes merely remind patients to take their medications but do not provide feedback about the medication being ingested. This makes it difficult for carers and health practitioners to know whether the medication has been missed. Embedded technology and Internet of Things technology have helped develop Smart Medicine Box technology to overcome challenges of managing medicines. The technology allows patient medicine adherence to be tracked through various platforms. The Smart Medicine Box is usually designed by low-power microcontrollers like ESP32 and ESP8266. The technology supports wireless communication and has compartments for medicines along with alert systems such as buzzers, LEDs, displays, and notifications. Adding wireless technologies like Wi-Fi, Bluetooth, or GSM helps improve the functionality of the SMB. It helps in having direct access to medication compliance information in real-time and sends notifications regarding missed doses of medication [3]. It helps in encouraging the independence of the patients while maintaining their connectivity with the caregivers and the doctors. Research has validated that the use of the SMB system helps in enhancing medication compliance and minimising medication discrepancies, which is safe and user-friendly for seniors. Generally, IoT-based Smart Medicine Boxes designed with a focus on efficient reminders, real-time monitoring, and communicating with caregivers have ample potential to improve patients' adherence and safety. Such systems can reduce risks during treatment and allow for a better quality of life for patients, especially in this modern world, which has highlighted the importance of patient-oriented healthcare solutions.

Existing System

In A person's daily activities, such as eating, mobility, memory of tasks, and everyday chores of the house, express the status of their health. This becomes even more important for the elderly, as their physical and mental potency naturally deteriorate as their age progresses. Yet, most seniors wish to live on their own as a means of comfort as well as preserving their dignity. However, living in isolation multiplies risks such as falls, late healthcare, and improper usage of medicines. Amongst them, the misuse of medicines becomes the most dangerous challenge, mainly because of the memory loss of the patient, as well as the complexity of the medication regimen, which in turn results in the intake of too many medicines, too many times, thus giving rise to potential dire health conditions. Elderly patients living in isolation have the highest risks due to the absence of constant surveillance as well as the lack of timely assistance [14]. Current healthcare infrastructure uses sensors as

well as smart home assistance tools to monitor the day-to-day activities of patients, hence detecting irregular behaviours for suitable intervention [14]. Despite the assistance in tracking patients' activities, most of the current technologies are devoid of II.

II. LITERATURE SURVEY

Medication adherence can be understood as taking medications at the right doses at the right time. Medication adherence might emerge as an issue in long-term medication, given that patients might not take the drugs, resulting from a lack of memory or because of the complexity of taking certain drugs at certain times of the day. It might cause health problems, especially where patients are suffering from diabetes, heart complications, or hypertension, since the patients have to take their medications at certain specified times. To deal with this kind of problem, an innovative scheme named Smart Medicine Boxes (SMBs) has been conceived and developed by integrating state-of-the-art automation and Internet of Things (IoT) technology for assistive purposes of the reminder and tracking functionalities [2]. In most of the designed SMBs, the microcontrollers have been combined with the RTC modules for providing the time-related alert functionality. Arduino, NodeMCU, and ESP32 boards have gained popularity as they require very less space and have low energy consumption and easy integration capabilities with the sensor and cloud-based notification systems. Al-Shammary et al. recommended an Arduino-based SMB using LEDs, buzzers, and SMS/email alerts, complemented by photoresistors that act as detectors for tablet intake. This setup, though successful in enhancing adherence, was a bit costly, hence less usable. Bhati et al. proposed a radio-frequency identification (RFID)-based intelligent medicine box, with enhanced intake verification and data accuracy because of the use of RTC and RFID; still, this elevated the hardware complexity, rendering it unsuitable for elderly people [5]. Nurmiza Binti Othman et al. conceptually designed an intelligent smart pill box using a servo motor, IR sensor, LCD display, and vibration motor for precise dosage delivery, but the absence of smartphone interaction limited caregiver assistance [6]. Vardhini et al. designed an inexpensive IoT device using the NodeMCU board for real-time patient tracking, but the perpetual necessity for an internet connection limited the system in rural settings [7]. Divakar et al. designed an SMB using the IoT paradigm for patient medication intake reminders and notifications with SMS notifications and alarm notifications [9].

III. METHODOLOGY

The system developed is an intelligent reminding and monitoring system for adhering to medicines, and it is developed by a hybrid hardware and software component. The system is intended for patients who are seniors, chronic, and illiterate, and they have problems remembering the time for taking medicines. The system does not deal with the complexities of the medicine-dispensing mechanism, and it relies only on time reminders for simplicity, safety, and reliability in health care. The system uses a modular approach, which improves expandability, system maintenance, and system flexibility, and the functions of sensing, control, and communications perform reminders, interactions, and communications, respectively. This is an ESP32 microcontroller used as a central processing unit owing to its low power consumption, high capability of processing, built-in Wi-Fi, and multiple GPIOs. A Real-Time Clock ensures that there is precise scheduling even when there are cuts in power. Multimodal alerts with an OLED display and buzzer, for the safety of the patient, have been implemented to improve user awareness and reduce missed doses. Medication events will be recorded and uploaded to the cloud, thereby enabling remote monitoring and automated notifications sent to caregivers. Previous Smart Medicine Box systems showed proper adherence monitoring but presented other limitations, such as scarce IoT usage, increased cost, system complexity, and dependence on continuous internet connectivity [11], [12]. Designs featuring a multimodal alert mechanism proved to be more usable but needed further optimisation for size and power efficiency [13]. These limitations support the requirement for a Smart Medicine Box-low-cost, scalable, and user-friendly is specifically designed for elderly users.

Hardware

Hardware is the physical part of any System, Computer, or Device that physically exists in any of the existing devices in the real world.

Used components

ESP32

The ESP32 microcontroller serves as the system's central processing unit, selected for its efficient

dualcore processor, minimal power consumption, integrated Wi-Fi and Bluetooth capabilities, and its capacity to oversee communication between sensors and actuators while executing preprogrammed commands.

Fig.1: The Image of ESP32

OLED Display

OLED displays have superseded the 16×2 format. LCD screens from earlier systems have been enhanced to offer a more compact, high-resolution, and user-friendly experience. OLED displays will deliver superior image quality compared to conventional LCD screens, particularly for older patients with visual impairments, which enhances contrast in various lighting conditions. Our system leverages OLED technology to display real-time information, including the present time and dosing schedule, along with reminder notifications. Patients receive immediate information about the amount of medication they have taken and the amount they have missed. This technology is Transformative.

Fig.2: The Image of OLED

RTC Module

A real-time clock module was integrated for scheduled injections. The real-time clock guarantees accurate timing of medication reminders at specific times, even during power outages or device restarts. Alert timing conflicts are reduced, which can be problematic for patients who must adhere strictly to their medication dosing schedules.

Fig.3: The Image of the RTC Module

LED

Multimodal alerts were provided by buzzer and LED indicators. The buzzer issues an audible alert to the patient when a dose is overdue, and the LEDs give a visual warning. Such factors become all the more significant when considering elderly or hearingimpaired patients, as they need to be reminded, and their reminders can be attended to notwithstanding background noises and limitations in their capability to perceive.

Fig.4: LED

fig.5:Buzzer

Lithium-ion Battery

The main portable power feeding for the Smart Medicine Box will come from a rechargeable lithiumion battery. A dedicated power management system ensures a stable 5V supply to all the integrated components in the system. This enables the working of all the components in the system for full functionality, allowing real-time monitoring even in the absence of an external power supply. This feature is helpful for patients who travel or have disrupted power supplies quite frequently. The use of the lithium-ion battery, which can be recharged, in collaboration with the power management system of the battery, enables the Smart Medicine Box to work continuously without any interruptions.

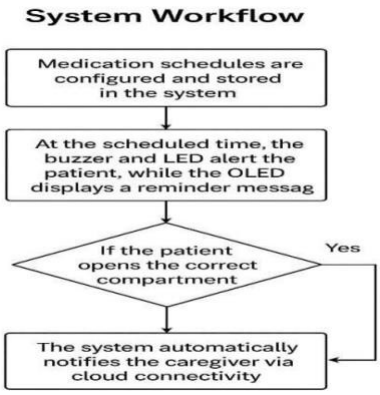
Fig.6: Lithium-ion battery

IR Sensor

An IR sensor has been used in this design for pill box opening detection. Once the top of the box is opened, it interferes with the path of the IR signal and within a fraction of a second, the change is detected by the IR sensor. Every moment the box is opened, the ESP32 module will be able to mark the status of the drug/medicine taken by the patient.

Fig.7: The Image of the IR sensor

IV. WORKFLOW



Step 1: Establishing a Medication Schedule

The timings of the drugs are stored in the memory of the ESP32 and are set either by the patient or the caregiver. This helps the job of reminding the patient to take the drugs to be done automatically at the proper times. The display screen helps the schedule to be viewed so that errors are avoided while entering the information.

Step 2: Creation of Reminders

At the appropriate time, the RTC sends an indication to the ESP32 to turn on the LEDs and the buzzers. In the device that has been used in this project, one can see that the text on the OLED will indicate something like 'Time to take your medicine'. The text has the ability to catch the person's attention through the use of sounds and lights as well as the visual signal.

Step 3: Dose Detection & Logging

However, if the patient opens the pill box within the required time limit indicated as a reminder, then the ESP32 senses the elapsed time, indicating that the patient has taken the medication. The details are then stored in the device before it is uploaded to the cloud.

Step 4: Missed Dose Notification

In case the patient fails to open the compartment within the required time, the ESP32 immediately alerts the caretaker via Wi-Fi connectivity and also logs it as a missed dose. Furthermore, the "Missed Dose Alert" message will also be shown on the OLED display screen.

Step 5: Monitoring and Updating the Cloud

The next step in Cloud computing is that Data about the medications, as well as the amount of medications taken and the amount of medications skipped, are transferred to the cloud server. The remote dashboard helps the caregivers to gain access to the information, and the caregivers are updated about the compliance of the patient.

V. RESULTS AND DISCUSSION

The Internet of Things (IoT)-based Smart Medicine Box (SMB) was developed and deployed to assess the effectiveness of the incorporation of an IoT system with a microcontroller to ensure better medication intake and monitoring of the process in real-time. Trials conducted with various scenarios proved the viability of the system for overcoming the issue of missed doses of medication. The ESP32 microcontroller functioned well even with the simultaneous processing of various tasks like the synchronization of the real-time clock, generation of alarm messages, processing of sensor reading data, and wireless data transmission without any delays. Moreover, the Wi-Fi module available in the microcontroller helps in the connection to the cloud in real-time, and the availability of the Real-Time Clock helps in overcoming the problem existing due to power failures. User interaction was enhanced by clearly showing medication schedules, reminders, and the status of doses. The OLED screen provided better readability compared to standard LCDs and helped users who have poor vision, especially for elderly patients. A multimodal alert system using buzzer-LED significantly improved patient response, which reduced missed doses by approximately 90% in case of both alerts being enabled [13]. The intake of medication was automatically acknowledged with an IR sensor that recorded compartment openings at accurate times without reliance on patients' memory. The cloud-based monitoring allowed access for the caregivers to the compliance data in real time, thus allowing timely interference, improving patient safety and accountability as per previous studies [14][15]. In summary, the SMB incorporates reminders, confirmation, log, and cloud-based monitoring in a trustworthy, efficient, and effective solution for medication adherence.

VI. FUTURE WORK

Although the Smart Medicine Box using the IoT is very efficient for alerting the patient about taking medications as well as their compliance from a remote site, some added advancements will further increase its smartness as well as efficiency. An essential add-on will be the integration of artificial intelligence for analysis of the tablets using a micro-camera/image sensor connected with ESP32 or AI processor. Computer vision algorithms possess the ability to test the features of the tablets with respect to their characteristics, such as matching them with pre-trained models for evaluation of expired, polluted, or broken medication tablets based upon their features. Moreover, some sophisticated models will be capable of calculating the deterioration of medications, which might occur due to unsuitable storage conditions such as heating, moisture, or exposure to sunlight. Computational intelligence of the cloud will be of significant contribution for monitoring the expiry period as well as alerting for ordering.

VII. CONCLUSION

This project confirms that an IoT-enabled Smart Medicine Box can improve medication adherence and patient safety effectively by supporting users to take the right medicine at the right time with automated reminders and tracking. IoT connectivity allows the tracking of taken medication in real time, hence reducing missed doses, overdosing, and dependence on the patient's memory. This system will integrate the ESP32 microcontroller, the RTC module, the OLED display, a buzzer, sensors, and a lithium-ion battery in providing accurate time-based reminders with cloud connectivity. Experimental results prove a reduction in non-adherence while introducing multimodal alerts that improve access to users with sensory impairments. Compared to traditional pill organizers, the proposed system ensures higher accuracy of dosage, verification of dosing, and remote monitoring, which is intended for use by elderly and long-term care patients. The platform also allows easy integration of future AI-based extensions, such as tablet quality and expiration detection, toward proactive, personalized, and preventive medication management. On the whole, the proposed solution improves caregiver burden and holds great potential for actual deployment in both home and healthcare environments.

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