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Sensor-Fusion–Based IoT Medicine Adherence Monitoring System

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Abstract: *Non-adherence to medication is one of the significant challenges in the field of healthcare, especially among elderly patients and patients with chronic diseases. Non-adherence may cause serious health issues for patients if they skip their medication or take the wrong medication. This paper proposes an Internet of Things (IoT) system for medication adherence, which is based on sensor fusion technology, allowing medication to be dispensed automatically while simultaneously detecting whether the patient has taken the medication. The system includes multiple sensors, such as load sensors, a Hall effect sensor, and a real-time clock module, which can be used for medication schedules, patient interaction, and pill detection, respectively. The system also includes an ESP32 microcontroller for sensor data control, which controls the medication dispensing system using servo motors. The system sends notifications to patients via a buzzer, RGB LED, and LCD display, indicating the medication time for patients. The proposed system combines the data obtained from multiple sensors, which can be used for improving the accuracy of medication adherence detection while minimizing the chances of false detection. The proposed system can be used for medication adherence, pill detection, and inventory management, as indicated by the results of the experiments conducted on the proposed system.*

Keywords: IoT healthcare, medication adherence monitoring, sensor fusion, smart medicine dispenser, ESP32, load sensor

I. INTRODUCTION

Medication adherence is an important aspect in managing healthcare effectively, especially for older people and for people suffering from various diseases, for instance, diabetes, hypertension, and cardiovascular diseases. Failure to adhere to medication regimens in terms of time and amount can lead to serious health problems. Various healthcare studies have shown that a large number of people fail to adhere to their medication regimens as a result of forgetfulness or lack of an appropriate monitoring system.

The traditional medication management systems, for instance, using manual pill organizers and alarm systems, are not reliable and cannot guarantee medication adherence for patients. In recent years, however, various developments in Internet of Things (IoT) technology have led to the creation of smart healthcare systems that can assist people in managing their medication regimens. IoT-based smart medicine systems can assist in the automation of medication regimens and can enable caregivers to remotely monitor medication regimens using IoT-based devices.

Nevertheless, most smart medicine dispensers available in the market today employ single sensor technology to detect whether or not patients have taken their medication by using infrared sensors. The technology assumes that if patients have taken their medication, then it means that patients have taken their medication properly. However, patients may take medication but fail to consume it. Therefore, it has been observed that most smart medicine dispensers available in the market today are not capable of providing accurate verification of medication adherence.

For addressing all these issues associated with smart medicine dispensers available in the market today, this paper has proposed a Sensor-Fusion-Based IoT Medicine Adherence Monitoring System that can be used to improve the accuracy and reliability of medication adherence monitoring. In this paper, it has been proposed that smart medicine dispensers be integrated with multiple sensors to monitor patients' medication adherence in real time. The sensor fusion technology can be used to determine whether or not patients have consumed their medication properly. Moreover, it has been proposed that smart medicine dispensers be integrated with IoT technology to enable patients' caregivers to monitor patients' medication adherence remotely through a cloud-based platform.

II. PROPOSED WORK

Medication adherence has been widely studied in recent years due to its critical role in effective healthcare management. Several research efforts have focused on developing automated medication dispensing systems and IoT-based healthcare monitoring solutions to assist patients, particularly elderly individuals and those suffering from chronic diseases.

Abhijith et al. proposed an IoT-based smart medicine dispenser that automates medication dispensing using ESP32, infrared sensors, and a web-based monitoring system to enable remote caregiver supervision [1]. Similarly, Krishna et al. developed an IoT-enabled smart pill dispenser integrated with health monitoring sensors such as heart rate, SpO_2, and temperature sensors, allowing caregivers to monitor patient health parameters alongside medication schedules through a mobile application [2]. While these systems improve medication management through automation and remote monitoring, they primarily rely on single-sensor detection methods to determine whether medication has been retrieved.

Several studies have focused on improving medication adherence through automated dispensing devices. Casciaro et al. introduced a smart pill dispenser designed to assist elderly patients by providing scheduled reminders and automated dispensing mechanisms [3]. Singh et al. proposed an Internet of Medical Things (IoMT) based pill dispensing system that enables remote monitoring of medication schedules using cloud connectivity [4]. Kumar et al. developed a smart medicine reminder device that uses alarms and notification mechanisms to alert patients about their medication schedules [5]. However, these systems mainly focus on reminder-based approaches rather than verifying whether the medication has actually been consumed.

IoT-based healthcare monitoring systems have also been explored to support elderly care and remote patient monitoring. Guerrero-Ulloa et al. proposed an IoT system designed to assist caregivers in monitoring dependent elderly patients using connected devices and remote data access [6]. Huang et al. developed an intelligent pillbox system aimed at improving geriatric healthcare through medication tracking and patient interaction monitoring [7]. Additionally, global healthcare initiatives have highlighted the importance of digital technologies in improving medication adherence and patient safety, as emphasized in reports by the World Health Organization [8].

The rapid development of IoT technologies has further enabled the integration of smart healthcare devices into connected systems. Atzori et al. provided one of the earliest comprehensive surveys on the Internet of Things, highlighting its potential to transform healthcare monitoring systems [9]. Similarly, Islam et al. presented a comprehensive review of IoT applications in healthcare, emphasizing the role of connected devices in improving patient monitoring and healthcare service delivery [15].

Recent studies have also explored intelligent medication management systems using advanced technologies. Lee and Park proposed AI-enabled medication dispensers that aim to improve adherence among elderly patients by incorporating intelligent monitoring capabilities [10]. Nguyen and Tran developed a smart medication box integrated with IoT features to facilitate remote monitoring and automated medication management [11]. Patel and Kumar provided a comprehensive review of automated medication dispensing systems, discussing their advantages and limitations in healthcare environments [12]. Furthermore, Rodriguez and Kim explored the integration of artificial intelligence with IoT to create smarter drug dispensing solutions capable of improving healthcare outcomes [13]. Aldeer et al. reviewed various medication adherence monitoring technologies, including sensor-based monitoring approaches designed to track medication usage more effectively [14].

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Although these studies have significantly contributed to the development of smart medication management systems, most existing solutions rely on single-sensor detection or reminder-based mechanisms that cannot reliably verify whether a patient has actually taken the medication. This limitation may lead to inaccurate adherence reporting and reduced system reliability. To address these challenges, the proposed research introduces a **Sensor-Fusion–Based IoT Medicine Adherence Monitoring System** that combines data from multiple sensors to improve the accuracy and reliability of medication adherence verification.

III. SYSTEM ARCHITECTURE

We are building an IoT device that helps in dispensing medication. The device has two compartments for medication and an empty lid where medication is placed for the patient to take their medication when the alarm sounds and the lid is opened. The following components are used in this project: ESP32 microcontroller, real-time clock module for the alarm, LED RGB indicator for notification, buzzer for notification, Hall sensor for detecting when the lid is opened or closed, load sensor for measuring the weight of the lid to check if a pill has been taken and also for checking the quantity of medication left in the compartments, LCD display for showing the time for taking medication, and servo motor for dispensing medication from the compartment to the lid.

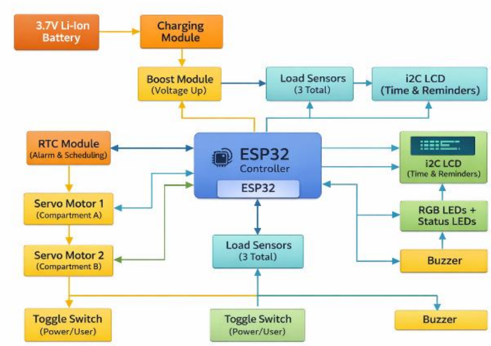

Figure 1: System architecture of proposed Sensor Fusion Based IOT Medicine Adherence Monitoring System

A. Control Unit

The main controller of this system is the ESP32 microcontroller, which is responsible for controlling various sensor inputs, controlling the actuators, and controlling system communication. The ESP32 microcontroller processes various sensor inputs and follows the dispensing logic based on the predetermined schedule of medication.

The ESP32 microcontroller also controls notification systems and coordinates all hardware components of this system.

The system also has an integrated Real-Time Clock (RTC) module that is integrated with the ESP32 microcontroller, allowing precise time tracking. The RTC module sends alarms based on scheduled medication times, allowing users to take their medication based on a predetermined schedule even during a power outage scenario.

B. Medication Dispensing Mechanism

The dispenser consists of two sections for medicine. Each section has a different type of medicine. Once the scheduled alarm sounds, the system waits for the user to open the lid. Once the user opens the lid, a servo motor spins and dispenses the pill from the selected compartment and into the lid for the user to take the medicine.

The inclusion of an LCD display allows for information to be given to the user regarding the schedule for the medicine being taken. The display allows the user to be aware of the time for the dosage and whether the medicine being taken is for an older age group.

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C. Sensor-Based Adherence Monitoring

To ensure that adherence verification is accurately performed, the system makes use of a sensor fusion method. The Hall effect sensor is used to identify whether the dispenser's lid is closed or opened. This allows the system to monitor the user's interaction with the dispenser when the alarm goes off.

The load sensor is placed at the bottom of the dispenser's lid and is responsible for detecting the weight of the pill. Once the pill is dispensed from the container, the load sensor will be able to identify the changes in the weight. The reduction in weight will help the system identify whether the user has taken the drug. The load sensor also plays a crucial role in determining whether the pill containers are running out of pills.

The use of the Hall effect sensor and the load sensor allows the system to make an accurate assessment of the user's adherence to the drug plan in comparison to other similar systems.

D. Notification and Alert System

The system utilizes different methods for notifying users about their medication routines. This is achieved by using an RGB LED indicator for visual alerts. A buzzer is used for auditory alerts at specified times for medication intake. This helps users from missing their scheduled medication routines.

These components combine to form a robust IoT-based architecture for the automated dispensing of medicine.

IV. HARDWARE COMPONENTS

The proposed system, named Sensor Fusion-Based IoT Medicine Adherence Monitoring System, consists of multiple hardware components that are designed to work together to ensure automated medicine dispensing, user interaction detection, and medicine adherence verification. Each hardware component has a specific role to play to ensure system efficiency.

ESP32 Microcontroller

The ESP32 acts as the brain of this system. It is responsible for communication with various sensors, actuators, and notification units, besides executing control logic that dictates medicine dispensing control. The ESP32 processes sensor data, controls the servo motor for pill dispensing, and handles notification systems, including LED indicators and the buzzer. The ESP32 is also Wi-Fi-enabled, making it possible to integrate it with IoT-based remote monitoring systems in the future.

Real-Time Clock (RTC) Module

The RTC module provides precise timing for medication reminders. It ensures that alarms go off at the exact set times for taking medication. It works independently from the microcontroller's clock, allowing it to maintain the correct time even if the power goes out for a while.

Servo Motor

The device has a servo motor that drives the dispensing mechanism. When the alarm rings and the user opens the lid, the servo rotates to dispense a pill from a medicine compartment into the dispensing lid. The servo motor provides precise angular motion to ensure the medicine is dispensed correctly.

Hall Effect Sensor

The Hall effect sensor detects the movement of the dispenser's lid. It sends a message if the lid is opened or closed. When the user opens the lid, the Hall effect sensor detects the change in the magnetic field and sends a message to the ESP32. This information helps determine if the user has interacted with the dispenser at the prescribed medication time.

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Load Sensor

There is a load sensor or a load cell positioned under the dispensing lid to weigh the pill as it rests on the sensor. When the pill is moved from the position on the lid, the sensor detects the change in weight. When the weight is reduced after a dispensing action, it is assumed that the user has taken the medicine. The same sensor is also useful to determine when the medicine is running low.

LCD Display

The LCD screen displays information on the medication routine in real-time. It provides information on when to take each medication and which compartment is releasing the medication. This makes the device user-friendly, especially for the elderly.

RGB LED Indicator

The RGB LED is used to provide visual alerts for different system states. Different colors are used to represent events such as medication time, successful dispensing, or missed medication.

Buzzer

In addition, a buzzer is included in the system, which will be used for audio alerts when it is time for medication intake. The buzzer will be used in conjunction with the LED indicator for better alerts concerning medication intake schedules.

V. METHODOLOGY AND SENSOR FUSION ALGORITHM

This section outlines the working methodology of the proposed Sensor Fusion-Based IoT Medicine Adherence Monitoring System. The system utilizes various sensors that enable automated medicine dispensing and precise verification of whether the patient has consumed the medicine or not. The methodology of this system is based on four major components: system workflow, sensor data collection, sensor fusion logic, and adherence decision logic.

System Workflow

The system functions according to a predetermined schedule of medication. This schedule is stored in the Real Time Clock (RTC) module. When the time to administer the medication comes, the RTC sends a signal to the ESP32 microcontroller. This signal triggers the notification system. The notification system uses the RGB LED indicator and the buzzer to notify the patient of the time to administer the medication. The LCD display shows the time to administer the medication.

The system then waits for the patient to open the dispenser's lid. This is done by the Hall sensor. When the patient opens the lid, the ESP32 sends a signal to the servo motor to administer the pill to the patient.

Sensor Data Collection

Once medication is dispensed, data is collected from the sensors to ascertain the interaction with the user and the removal of the pill. The Hall effect sensor continuously monitors the lid's position to ascertain whether it is open or closed. At the same time, the load sensor is used to ascertain the presence or absence of the pill on the lid.

The load sensor has a double role to play in the system. The load sensor is used to ascertain whether the pill has been successfully dispensed to the lid by detecting an increase in weight. The load sensor is also used to detect the removal of the pill from the lid by detecting a decrease in weight.

Sensor Fusion Logic

The proposed system would be based on a system of sensor fusion, whereby data is collected from multiple sources to confirm patient adherence to medication. Instead of depending on a single source of data from a sensor, multiple sources are used to determine whether or not the medication has been taken.

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- The fusion would be based on three key events:
- The time for taking medication based on the RTC module
- The interaction with the lid based on the Hall effect sensor module
- The presence of the pill based on the load sensor module

Medication Adherence Decision Algorithm

The decision algorithm for determining the medication adherence can be performed by using a rule-based decision logic. The decision algorithm can be explained as follows:

Alarm Trigger

The system triggers the alarm when the scheduled time for medication has been reached.

Lid Interaction Detection

The system triggers the servo motor for the dispensing of the medication when the user opens the lid.

Pill Dispensing Confirmation

The system checks whether the pill has been successfully dispensed by detecting the presence of weight on the lid. The load sensor is responsible for detecting the presence of the pill on the lid.

Pill Removal Detection

The system checks whether the pill has been removed by detecting the absence of weight from the load sensor. The load sensor is responsible for detecting the absence of the pill from the lid.

The decision algorithm can be explained as follows:

- If Alarm Time Reached → Trigger Notification
- If Lid Opened → Dispense Medicine
- If Weight Detected on Lid → Confirm Pill Dispensed
- If Weight Removed from Lid → Confirm Pill Taken

The proposed sensor fusion algorithm for determining the medication adherence can be greatly improved compared to the existing single sensor-based algorithms.

VI. IMPLEMENTATION

The proposed Sensor Fusion-based IoT medicine adherence monitoring system has been implemented with the integration of various hardware components with the ESP32 microcontroller for the automated dispensing of medicine as well as medicine adherence verification. The system has been implemented with time-based triggers, mechanical dispensers, and sensor-based monitoring.

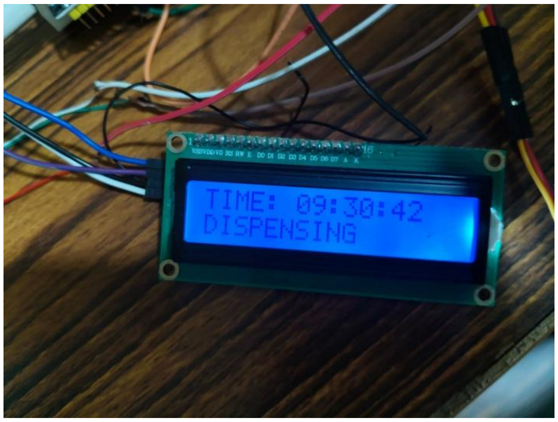

Figure 2: LCD display showing real-time system status during medicine dispensing in the proposed IoT-based adherence monitoring system.

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Hardware Implementation

The hardware part of the prototype consists of ESP32 microcontroller that is connected to different sensors and actuators. The ESP32 microcontroller controls the pill-dispensing system. The RTC module is connected to the ESP32 microcontroller using I²C protocol for precise scheduling of medication. The RTC continuously monitors the time and sends a signal to the ESP32 microcontroller when the scheduled time for medication arrives.

Two compartments for different pills have been designed. A servo motor has been attached at the bottom for controlling the pill-dispensing mechanism. When the ESP32 microcontroller receives a signal from the RTC module that the medication time has arrived, it waits for the opening of the lid. When the ESP32 microcontroller detects the opening of the lid using a Hall sensor, it sends a signal to the servo motor attached at the bottom. The servo motor rotates and releases a pill from the corresponding pill compartment into the lid.

A load sensor or load cell has also been attached at the bottom of the pill-dispensing machine. This load cell measures the weight of the pill that has been dispensed into the lid. It is connected to the ESP32 microcontroller using an amplifier module. This load sensor detects the pill both when it is attached or detached from the lid. This is a critical feature for monitoring the consumption of medication by a patient.

A 16×2 LCD has also been used for displaying messages. An RGB LED has also been used for informing the user that it is time for medication. A buzzer has also been used for giving a clear indication that it is time for medication.

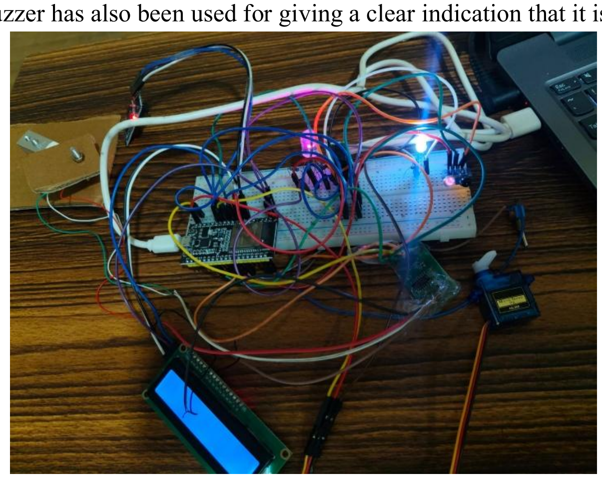

Figure 3: Prototype implementation of the sensor-fusion–based IoT medicine adherence monitoring system using ESP32, sensors, and actuator modules.

Software Implementation

The software logic for the system was created using the Arduino IDE. The ESP32 firmware is responsible for controlling the sensors, dispensing pills, and sending notifications. The system continuously checks the time using the RTC module. Once the time matches the medication time set for the day, the system turns on the LED and buzzer, indicating the time for medication. The medication message is also displayed on the LCD screen.

The firmware then checks the Hall effect sensor to see if the lid is opened. Once the lid is opened, the system dispenses the pill using the servo motor. The system then checks the load sensor to see if the pill is left inside the lid or has been taken by the patient.

The implementation also includes a sensor fusion logic module. The system combines the data from the Hall effect sensor and the load sensor to ensure patient medication adherence. The system records the medication event as successful once the pill is dispensed and the load sensor shows a reduction in weight after the pill is dispensed. The system also records the medication event as a missed dose if the pill is left inside the lid for a certain period of time.

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The above implementation ensures that all components are well-coordinated to ensure successful medication dispensing for the patient.

VII. EXPERIMENTAL RESULTS AND DISCUSSION

The Sensor Fusion-Based IoT Medicine Adherence Monitoring System was experimentally evaluated to measure the performance of the automated dispensing system and the sensor fusion approach to measure the adherence to the medicine. The system was tested under a number of scenarios to measure the response of the sensors, the dispensing system, and the notification system.

While testing the system, the RTC module sent the alarm signal to the system to administer the medicine at the set time. Once the alarm signal is sent to the system, the RGB LED indicator and the buzzer sent the notification to the patient. The LCD display shows the notification message to the patient. The system waits for the patient to interact by detecting the opening of the lid using the hall sensor. Once the patient opens the lid, the pill is released to the dispensing lid using the servo motor. The load sensor is used to measure the weight on the lid. When the pill is released to the lid, the sensor detects the increased weight on the lid. When the patient takes the pill, the sensor detects the reduced weight on the lid.

To measure the reliability of the system, a number of test cases were performed as shown in Table 1.

TABLE 1: SYSTEM TEST CASES AND RESPONSES

Test Case	*Action*	*System Response*	*Result*
Alarm Triggered	Lid opened	Pill Dispensed	Success
Lid opened but pill not removed	System detects	Remainder alert generated	Success
Lid opened and pill removed	Weight change detected	Medication confirmed taken	Success
Low medicine level	Weight below threshold	LCD warning displayed	Success

The experimental results show that the system is able to detect the user's interaction with the system. The system is also able to confirm that the medication has been taken. The results show that the servo motor is able to dispense the pill to the dispensing lid on time. The results also show that the Hall effect sensor is able to detect the opening of the lid. The results also show that the load sensor is able to detect the weight changes due to the dispensing of the pill from the container.

The use of a sensor fusion approach with the integration of various sensors has greatly improved the accuracy of the system. Unlike the use of a single sensor to detect the adherence of the patient to the medication regimen, the proposed approach has greatly improved the accuracy of the system. This is due to the fact that the proposed approach has confirmed the adherence to the medication regimen based on the detection of the opening of the lid as well as the removal of the pill from the container. This has greatly improved the accuracy of the system compared to the use of a single sensor. The experimental results show that the proposed system is reliable.

VIII. FUTURE SCOPE

The proposed system, **Sensor Fusion-Based IoT Medicine Adherence Monitoring System**, presents a reliable solution for medicine dispensing and adherence monitoring. However, there are various possibilities for improving the system in the future to enhance its efficiency.

One possible way to improve the system is to incorporate **cloud-based monitoring tools** that can be used to monitor patient medicine adherence by caregivers or healthcare providers. This can be done by linking the system to a cloud database and a mobile app.

The system can also be improved to **incorporate machine learning tools** to analyze patient medicine patterns to detect possible non-adherence behavior. Intelligent machines can be used to send reminders or alerts to patients based on their patterns.

The system can also be improved to have the ability to manage **multiple medicine compartments** to cater to patients who need to take multiple medicines at different times of the day. Additionally, the system can be improved to have the ability to support a **mobile app** to enable caregivers to program the medicine schedules on their phones.

Other possible improvements to the system can be made to have **biometric authentication tools** to ensure that only the patient has access to the medicine. The system can also be improved to have the ability to connect to **wearable devices** to enable monitoring of patient health to provide better healthcare services.

Possible improvements to the system can be made to enhance the system's efficiency to suit various medical applications.

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