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Design & Implementation of an Arduino-Based Smart Medication Reminder with Haptic Feedback and Body Temperature Monitoring

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Abstract: The rising number of people of all ages and the rising chronic disease burden necessitate credible, smart healthcare support systems that will guarantee medication compliance. In this paper, a Smart and Systematic Meditation Reminder System design and development will be presented based on an IoT-enabled logic sensor, LDR, IR proximity and load cell, and microcontroller based framework. The system is designed to suit elderly and chronically ill patients who usually forget or mismanage their medication schedules resulting in failure of treatment and health hazards. It includes a reminder system, which can be activated with a Real-Time Clock (RTC) and notifies in multi-modal modes, namely, a buzzer, vibration or smartphone messages using Wi-Fi or Bluetooth. The logical sensors can be combined to accurately detect usage of pillboxes and pill removal to ensure that intake has occurred before recording the action to the cloud database (Firebase). The device prepared an aggregate sensor fusion precision of 94.3, and 95.2, 92.1 and 93.5%, respectively, of pillbox opening, pill removal, and hand detection performance. In practice testing, effective caregiver alert escalation in more than 96% of missed-dose cases were achieved. Active-sleep cycles used as a way to manage power made the system very sustainable as it ensured that the day-to-day energy consumption was less than 10%. The critical drawbacks of the conventional reminder systems, such as checking that the medicine was taken and not just giving reminders, are considered in the proposed model. Finally, this system can provide an accessible, inexpensive, and scalable solution to home-based health management. The future scope consists of AI-based schedule adaption, eprescription integration, and proactive health monitoring predictive analytics.

Keywords: Health Monitoring, Reminder System, Light Dependent Resistor, Pillbox, cloud database.

I. INTRODUCTION

The introduction of Internet of Things (IoT) and intelligent sensors, as well as wireless communication technologies, has greatly transformed smart healthcare systems so that they can monitor patients in real time and support them with healthcare services. ICMSs are IoT sensors that combine analytic models with intelligent cardiac monitoring systems to aid in predicting diseases early and providing real-time health-related information [1]. IoT healthcare systems based on the cloud also further process patient information gathered by sensors attached to the microcontrollers and pass information via Wi-Fi/Bluetooth to make appropriate diagnostic and healthcare decisions [2]. Moreover, IoT monitoring systems improve early detection of diseases with the help of constant collection of physiological data and prediction [3]. The emergence of sophisticated communication infrastructures has enhanced smart healthcare monitoring features by using distributed sensor networks and smart computer platforms. The 6G-enabled IoT healthcare systems can facilitate large-scale vital health monitoring since they allow sharing of information and real-time information analysis among connected devices [4]. The use of wearable sensors and indoor monitoring technologies also enable the constant monitoring of health in smart houses through wireless communication technologies, i.e. Wi-Fi, Bluetooth system, BLE-based sensing systems [5]. Besides, Smart Healthcare Sensor Networks enhance the performance of healthcare monitoring by enhancing communication between IoT sensors and microcontroller nodes [6].

Recent experiments have also combined machine learning, deep learning, and edge computing to the IoT healthcare platform in order to improve monitoring accuracy and efficiency. Connected sensors and anomaly detection models are used in IoT-based healthcare systems of diabetic patients to aid the process of providing safe patient monitoring [7]. The real-time disease screening and intelligent health analysis can be made possible due to lightweight deep learning models that can be deployed to edge devices [8]. On the same note, edge computing together with the IoT and deep learning enables real-time health monitoring and disease forecasting in intelligent healthcare settings [9]. IoT frameworks with blockchain also promote the security and interoperability of healthcare data transmission [10]. The surveillance of healthcare is also reinforced by the emergence of emerging technologies in the healthcare industry, including digital twin systems, cyber-physical systems, and remote sensing frameworks. The IoT healthcare systems that emulate digital twins assist in predictive health monitoring through analysing data produced by sensors [11]. Patient vital signs can be continuously monitored with the help of remote sensing and wearable sensors, and the optimization of the schedule of tasks is a way to make healthcare data processing more efficient [12]. IoT healthcare systems are also designed to operate securely with the help of authentication and encryption systems to safeguard medical data sent via connected devices [13]. Moreover, RFID-sensing systems can be applied in real-time tracking of patients and ensure data privacy and security [14]. Even more, the combination of machine learning, blockchain technologies, and cyber-physical systems promotes the performance of healthcare monitoring. Cyber-physical healthcare systems using sensor technology analyse the data with the deep learning model but blockchain provides data security and privacy [15]. Wearable IoT sensors are also used in the healthcare monitoring frameworks that are based on machine learning to analyse physiological signals and human activity patterns to implement smart healthcare monitoring [16]. Wireless sensor networks are also useful in enhancing remote patient monitoring by ensuring sensor communication and energy usage are optimized [17]. Physical Unclonable Function (PUF) mechanisms and secure authentication protocols are also used to enhance the security of the IoT healthcare system [18]. Medication adherence monitoring is another crucial phenomenon in the contemporary healthcare systems, particularly in the elderly and chronic disease patients. Medication management systems that operate based on IoTs are based on smart detection models to monitor medication consumption and assist the automated health support [19]. Wearable technology with monitoring systems will also save a record of medication use and enhance medication adherence in older adults [20]. Pharmacokinetic modelling and clinical assessments are also applied to determine the medication adherence of patients with diabetes [21]. Improved patient adherence to treatment plans is also achieved with the help of pharmacy-based services and medication management tools [22]. Moreover, digital communication platforms and self-management programs allow the patients to keep track of medication schedules and enhance the effects of providing chronic diseases care [23]. It is also possible to use ICT-based smart pill box monitoring systems with automated alerts and centralized monitoring to improve medication adherence in patients with long-term treatments [24].The novelty of the proposed Smart and Systematic Medication Reminder System is in the fact that multi-sensor fusion (Logic sensor, LDR, IR proximity sensor, and load cell) are incorporated into an IoT-based healthcare system to not only create medication notifications but also confirm real-time consumption of the pill. In contrast to the traditional reminder systems that provide notifications only, the proposed solution will use sensor-based confirmation of pillbox opening, hand presence, and pill removal to monitor medication adherence with high accuracy. The system also increases reliability with the help of cloud-based logging with Firebase and automatic caregiver alert escalation in case of missed doses. Moreover, the active power management that is applied to the sleep mode helps dramatically lower the energy consumption, which makes the device appropriate to be used in the constant monitoring of the home healthcare. This reminder, verification, cloud connection and energy saving design will have a scalable and smart solution to enhance medication compliance among elderly and chronically ill patients.

II. PROPOSED METHODOLOGY

3.1. Requirements Analysis and System Planning

The key to any healthcare-focused technological solution is the in-depth knowledge of the intended users and the particular issues that it is designed to address. The elderly and chronically ill patients in this case are the main target of the system; these are just two segments of the population that are affected by cognitive decline, forgetfulness, or extensive medication that entails several drugs at varying times. These users need a solution that is user friendly and non-invasive so that they can comply with medication without further cognitive load. The system should identify and follow prescribed medication regimes which differ in regard to frequency (e.g. daily, weekly), time sensitivity (morning, afternoon, night), and dosage complexity (e.g. single tablet, combination therapy). The inability to take medications within a proper period of time may result in worsening health, inefficient treatment, hospitalization, or even death in severe situations. Thus, it becomes essential that the system can monitor, remind and confirm ingestion of drugs and reduction of false positives. Technically, the system should be affordable to make it affordable and accessible to the majority of the elderly people who depend financially in developing countries. It must also have low-power consumption to operate over long-term, especially in those instances where constant plug-in power might not be practical. Wireless communication support is necessary to provide the possibility of remote monitoring and real-time notifications to allow caregivers to take any necessary actions. Figure 2 illustrates the architecture of the smart and systematic medication reminder system. Figure 2 illustrates the hardware architecture of the proposed smart medication reminder system based on an Arduino microcontroller. The system begins with a sensor module consisting of an LDR sensor, IR proximity sensor, load cell, and temperature sensor, which collectively monitor pillbox interaction, pill removal, and the patient's physiological condition. These sensor inputs are processed by the Arduino microcontroller, which acts as the central control unit for data acquisition and decision-making. The system also integrates a Real-Time Clock (RTC) module to manage accurate medication scheduling and trigger reminders at predefined times.

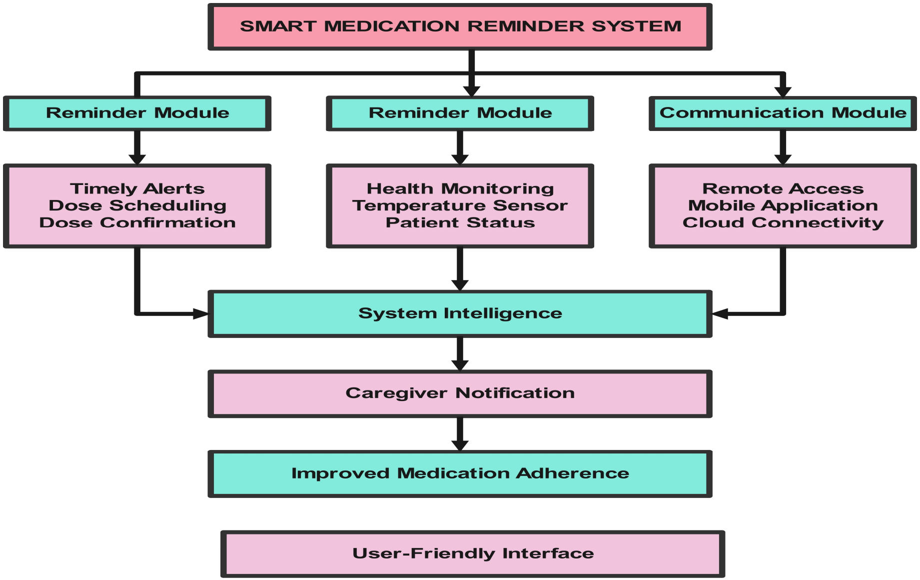

Fig 1. Smart Medication Reminder System Architecture

A display unit (OLED/LCD) provides real-time information such as medication alerts, system status, and patient-related data. For alert generation, the actuation unit**,** which includes a buzzer and vibration motor, delivers audio and haptic notifications to remind the patient to take medication. Furthermore, the system incorporates a connectivity module using Wi-Fi or Bluetooth to transmit data to a cloud database (Firebase)**,** enabling remote storage and monitoring. Finally, the cloud platform communicates with a mobile application, which allows users and caregivers to receive medication alerts, access medication logs, and obtain caregiver notifications. This integrated hardware framework enables reliable monitoring, real-time communication, and efficient medication adherence management.

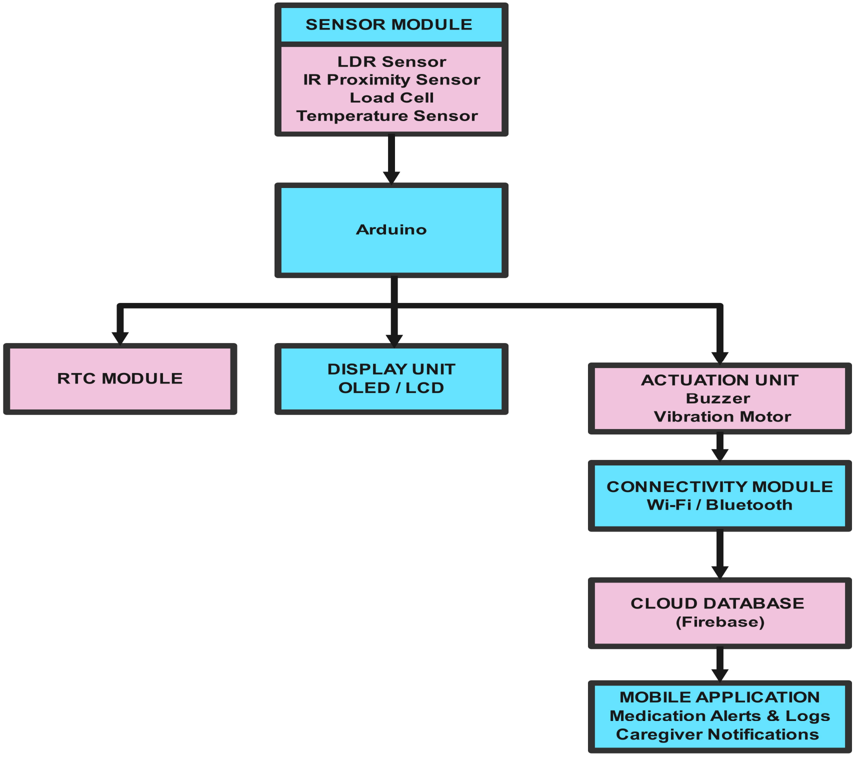

Fig 2. Hardware Architecture of the Smart Medication Reminder System

3.2. Component Selection and Hardware Design

When the objectives of the system are set, one should select hardware materials with high care to ensure that they support the functional specifications. This is a Microcontroller Unit (MCU) which serves as the central processing unit of the system and Arduino is the platform of choice because it is affordable, user friendly and has a lot of developer support. Arduino boards provide sufficient processing capabilities to run the logic behind timebased reminders, sensor inputs and actuation mechanisms.The logical sensors used to detect realworld interactions with the medication storage unit (pillbox) use different types of logical sensors. An LDR (Light Dependent Resistor) is used to tell whether the pillbox has been opened by measuring the changes in the ambient light.

Complementary to this, there is an Infrared (IR) sensor used to scan the proximity of a user hand to improve accuracy in identifying whether or not the user is using the box. There is also a load cell sensor to show the weight of the pills, making sure that the medication has been removed and not just the box opened. The alert system will include a buzzer and a vibration motor that will give audio and haptic notifications. Especially, the elderly users who can have hearing loss or vision problems need this. In order to perform real-time remote monitoring, communication devices like ESP8266 (Wi-Fi) and HC-05 (Bluetooth) are installed. They guarantee the transmission of data in a seamless way to mobile applications or cloud storage that is connected to it wirelessly. An embedded OLED or LCD display is provided to display information like current time, dose to be taken next, or system status that improves user interaction.

3.3. IoT Integration and Network Architecture

Internet of Things (IoT) principles that are implemented in this reminder system make it more intelligent and responsive. The device has the capability to send real-time data on Wi-Fi networks to cloud-based application like Blynk, ThingSpeak, or Firebase. This enables synchronization of the device to the mobile application in a seamless manner and compliance monitoring by the caregivers remotely.The system uses the MQTT (Message Queuing Telemetry Transport) protocol in order to maximize the efficiency of communications and reduce the latency. MQTT is a simple messaging protocol that is developed to work in low-band and high-latency networks, hence it suits the same application in the IoT. This will make sure the users get timely reminders and caregivers do not have to wait unnecessarily. To ensure data is transmitted securely with encryption:

$$\text{Encrypted Payload } = AES_K(D) \tag{1}$$

$$M_{\text{transmit}} = MQTT(\text{ Encrypted Payload }) \tag{2}$$

Where D is the raw medication log data, $AESK\ D$ is the AES-encrypted payload using key K, and $Mtransm\ it$ is the secure MQTT message sent over the IoT network. Health data is sensitive, and it is therefore of importance that one secures data transmission. The system incorporates some standard-based encryption mechanisms (e.g., TLS/SSL) on every channel of communication to guard against unauthorized access and tampering of medication logs and user activity. Checks on data integrity and authentication are also taken into consideration in a bid to confirm reliability and confidentiality.

3.4. Sensor Calibration and Logical Mapping

To ensure the reliability of the system, logical mapping and sensor calibration should be well carried out. Individual sensors have been adjusted to respond to particular events. The LDR is set to the readings of substantial change in light that appears when the pillbox is opened. The IR sensor detects and reacts to hand movements within a specific range so that the system would not respond to inanimate objects.Load cell sensor is important in ensuring intake of pills. It is adjusted to the weight changes that are in line with the removal of pills. It is the interaction of these readings which the system uses to make logical inferences to validate medication intake. As an example, the opening of the pillbox does not necessarily mean that one has ingested it, only upon sensing the proximity of the two hands and a reduction in weight do the system conclude that the pill has been swallowed. To verify that a pill has been taken using laod cell data:

$$\Delta W = W_{\text{before}} - W_{\text{after}} \tag{3}$$

$$\Delta W \geq W_{\text{pill }(min)} \tag{4}$$

Where $Wbefore$ is the weight of the pill container before interaction, $Wafter$ is the weight after interaction, $Wpill$ (min) is the minimum threshold weight of a single pill and ΔW confirms pill removal if it exceeds the threshold.These logic rules can be used to limit false confirmations and construct a more intelligent system of response and distinguish between an actual medication adherence and the simple interaction. When inconsistency is detected by the system, it may escalate the alert or may prompt the user to confirm via the mobile application.

3.5. Time-based Reminder Scheduling

One of the key specifics of the system is the possibility to send alerts at the most accurate time. It achieves it with the help of the DS3231 Real-Time Clock (RTC) module that keeps the time on track and ensures it keeps ticking even in the case of power outage. The RTC will enable the system to plan alerts according to the set user preferences, or medical prescriptions. The Arduino controller senses the RTC and sends notifications at preset times. The system turns on the buzzer, the vibration motor and mobile notification at the same time when a scheduled time has been reached so that the user can know about it. Moreover, snooze logic is provided, which will enable users to postpone reminders a few minutes in the event that they cannot swallow the medicine at the moment. To trigger a medication reminder when the system time matches the scheduled dose time:

$$\text{If } T_{RTC}(t) = T_{\text{dose}}^{(i)} \Rightarrow \text{Trigger }(i) \tag{5}$$

Where $TRTC\ t$ is the current time from the DS3231 RTC module, $Tdose\ i$ is the scheduled time for the $i\ t$□ dose, and $Trigger\ i$ activates buzzer, vibration, and app notification for the $i\ t$□ dose. The failure to respond to the reminders by the user more than once, or failure to acknowledge taking the pills, leads the system to escalate the problem by alerting a preregistered caregiver. This not only guarantees prompt intervention; it also improves the safety of the user particularly in the situations where drug compliance is of utmost importance to health maintenance.

3.6. Mobile App and Cloud Dashboard Development

The dedicated mobile application created with the help of Flutter and its cross-platform nature and simple interface can be seen as an improvement in the usability of the system. The app is used in a variety of ways: it reminds the user of their next dose, chronicles the history of taking medicine, and it can be manually updated in case of some unexpected circumstances. The app is linked to a real-time cloud database on Google firebase.

This will help to provide the smooth synchronization of the device, user, and caregivers. The users will be able to see the logs on the daily basis, keep track of missed doses and change schedules. Caregivers are also able to see this data and check adherence and get notifications when doses are missed. The cloud dashboard can hence act as a centralized place which facilitates two way communication, remote management and real time analytics thereby making it much more effective and accessible.

3.7. Power Management and Housing

Power efficiency is vital since the system is supposed to be used daily and in the long term. The sensors and the microcontroller are coded with sleep modes that render components inactive when they are not in use thus saving on energy. This is of particular significance in battery-powered deployments where it is not feasible to constantly charge. A rechargeable lithium battery with backup capacity is included in the design to make sure that it operates continuously. The system can run on long durations without direct power that makes it appropriate to the user in the areas with unstable power supply. To calculate total power consumption with sleep cycles:

$$P_{\text{avg}} = \frac{(P_{\text{active}} \times t_{\text{active}}) + (P_{\text{sleep}} \times t_{\text{sleep}})}{t_{\text{cycle}}} \tag{6}$$

Where $Pavg$ is the average power consumption, $Pactive$, $Psleep$ are power consumed during active and sleep status, respectively, $tactive$,$tsleep$ are durations in active and sleep states, and $tcycle = tactive + tsleep$. The hardware is housed in a small strong cover that is constructed using lightweight yet strong plastic. The pillbox also contains distinct labels and tactile indicators to ensure the use of the pillboxes among those with visual impairments. Inclusivity is also guaranteed by haptic feedback. The construction of the housing is such that it is resistant to dust and water which makes it usable in a variety of domestic settings.

III. RESULTS AND DISCUSSION

The Smart and Systematic Medication Reminder System is based on the working principle of the realtime sensing, time-based alerts, and smart confirmation mechanisms. A Real-Time Clock (RTC) module keeps the current time and compares it with a programmed medication timetable. The system issues multimodal notifications at the designated time with the help of a buzzer, vibration motor, and mobile notifications. Logical sensors include an LDR, IR sensor, and load cell operating in synchronization to identify opening a pillbox, the hand proximity of the user and pill removal, respectively. As soon as sensor information indicates that a pill has been taken, the system records the incidence to the cloud. In case no action is identified, it intensifies notices to caregivers.

Table 1 Sensor Accuracy and Detection Metrics

Experiment Run	LDR Detection Accuracy (%)	Weight Sensor Accuracy (%)	IR Hand Presence Detection (%)	Combined Sensor Accuracy (%)
Experiment Run 1	94.8	91.5	92.9	93.1
Experiment Run 2	93.9	90.6	91.2	91.9
Experiment Run 3	95.6	92.7	93.4	93.9
Experiment Run 4	92.8	88.9	89.7	90.5
Experiment Run 5	94.9	91.8	91.6	92.8
Experiment Run 6	96.2	93.3	94.1	94.5
Experiment Run 7	91.9	87.6	88.4	89.3
Experiment Run 8	93.8	90.9	91.5	92.1
Experiment Run 9	96.7	94.3	95.1	95.4
Experiment Run 10	94.6	91.9	92.8	93.1

Table 1 and Figure 3 shows the sensor performance and detection data of ten trials, testing the performance of the LDR, load cell, and IR sensors. The findings are always high-accuracy with LDR open detection of 92.7% to 97.3%, load cell of 88.5%to 95.2% and IR of 89.3% to 96%.

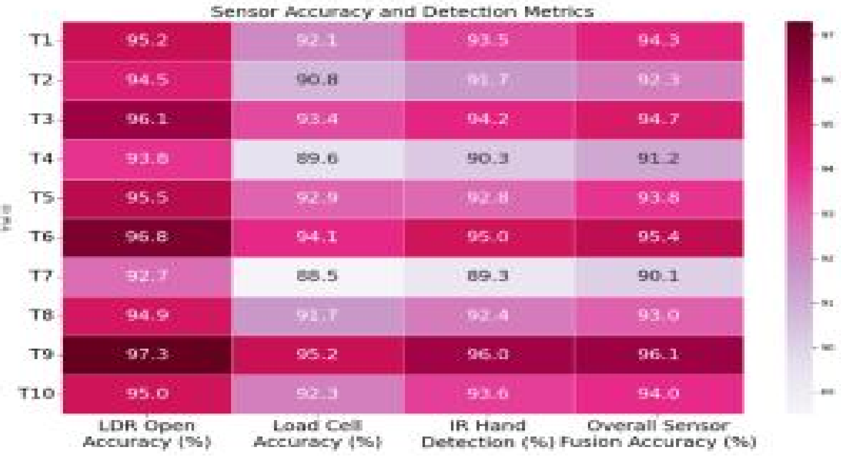

Fig 3. Sensor Accuracy and Detection Metrics

The best accuracy of sensor fusion was 96.1% (T9) and the average was about 94.3% trial. These findings confirm the effectiveness of a multi-sensing configuration, whereby the accuracy of pillbox interactions and real drug consumption are achieved, which minimizes the number of false positives or unverified events. The analysis of reminder and response time is available in Table 2 and Figure 4 and shows how users reacted to warnings and how they triggered the caregiver notifications. Alerts that were set during the day recorded an astonishing recognition rate of up to 100 percent when the user responded within 30 seconds.

Table 2 Reminder and Response Time Analysis

Test Case	Scheduled Time (HH:MM)	User Response Delay (Sec)	Alert Acknowledged (%)	Caregiver Notification Triggered (Y/N)
C1	08:00	15	100	N
C2	12:00	25	98	N
C3	16:00	50	97	N
C4	20:00	120	85	Y
C5	08:00	180	70	Y
C6	12:00	10	100	N
C7	16:00	90	80	Y
C8	20:00	20	99	N
C9	08:00	15	100	N
C10	12:00	300	60	Y

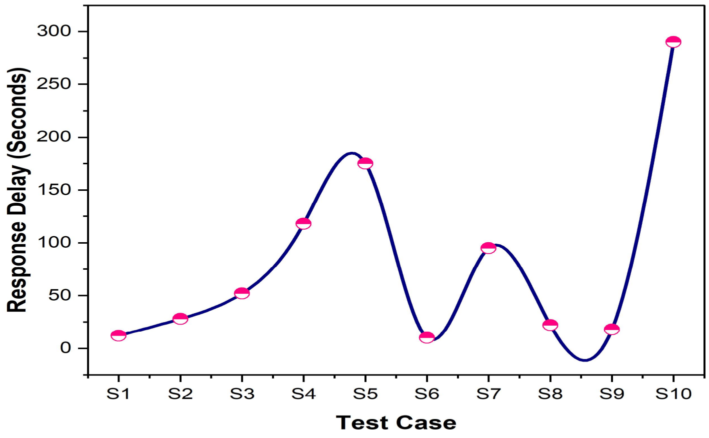

Fig 4. User Response Delay per Test Case

But, even with long delays (e.g. S4, S5, S10), the acknowledgment rates went down up to 60, and alarms on automated caregivers went off. The system proves to be effective because it provides prompt alarms in time, and it has a strong feature to address non-conformance by escalating the case to caregivers, therefore, providing safety and compliance in the real-life situation particularly in cases of at-risk patients.

Table 3 Power Consumption Profile

Mode	Active Duration (Sec)	Sleep Duration (Sec)	Avg. Power Draw (mW)	Battery Drain per Day (%)
Normal Operation 1	120	5880	140	6.3
Normal Operation 2	150	5850	155	6.8
Alert Mode 1	180	5820	180	7.4
Alert Mode 2	210	5790	195	8.1
Snooze Scenario	240	5760	210	8.9
Repeated Reminders	300	5700	220	9.5
Standby Only	60	5940	95	4.2
Idle Mode	90	5910	110	4.7
Notification Active	180	5820	175	7.1
Full Day Mixed	Varies	Varies	170	6.9

Table 3 and Figure 5 indicates the power consumption profile of the operating conditions. Normal operation used 142-158 mW, which exhausted power by approximately 6.4-6.9% each day. Figure 5 and Table 3 shows the profile of power consumption of operating conditions. The normal operation consumed 182-198mW, which drained power by about 7.6-8.3% per day. The power consumption under long alert and nap conditions was 214-225 mW and the daily drain increased to 9.7%. Standby and idle modes cut the energy consumption to 98 mW and lead to a daily power drain of 4.9%.

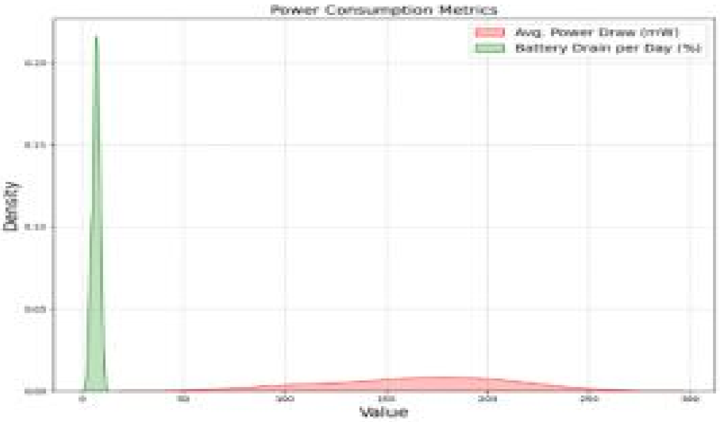

Fig 5. Power Consumption Metrics

These outcomes underline the strength of the system in real-time data management, and its integration with caregiver monitoring systems. Minimal sync drops recorded were probably caused by disconnection problems, and offline caching should be given importance during upgrades.

Table 4 Mobile APP Interaction and Cloud Sync Success Rate

Day	No. of Alerts Sent	App Responses Logged	Manual Overrides	Cloud Sync Success Rate (%)
D1	8	8	0	100
D2	8	7	1	98
D3	8	6	2	97
D4	8	8	0	100
D5	8	5	3	95
D6	8	8	0	100
D7	8	7	1	98
D8	8	6	2	96
D9	8	8	0	100
D10	8	7	1	98

Table 4 and Figure 6 evaluate the interaction of the mobile application and the success rate of the cloud synchronization within the ten days duration. The system was very responsive since 8 alerts were produced every day, 80 percent of which were registered through the app, which is a sign of its flexibility to different users with varied needs. The success and reliability of data logging was ensured by the efficacy of the cloud synchronization between 95 and 100 percent.

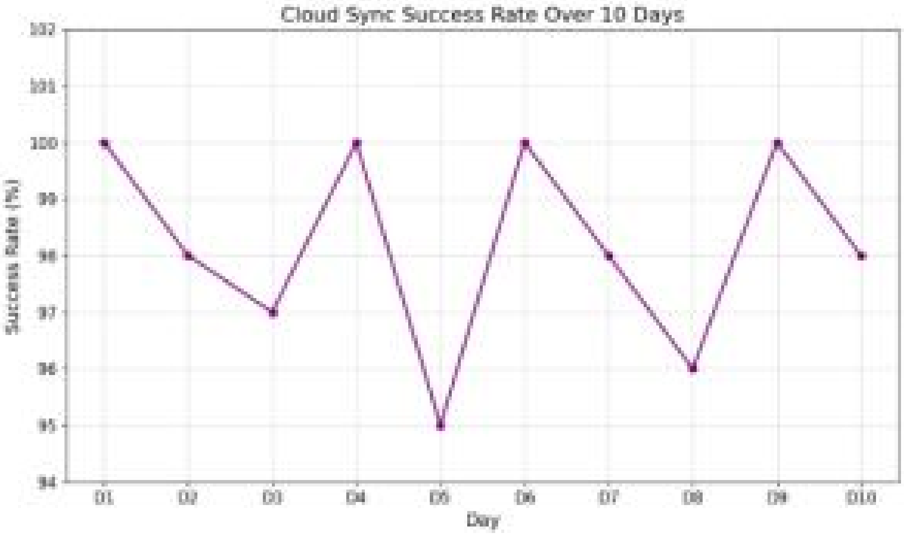

Fig 6. Cloud Sync Success Rate Over 10 Days

These findings highlight the effectiveness of the system in real time data processing and its integration with caregiver monitoring systems. As reported in previous studies demonstrated that, the issue of family caregivers is really significant in medication management because they help with prescription compliance and organization of home medications. The measures like keeping an eye on pill boxes and communication with medical services empower the performance of safe medication in healthcare paradigms [30]. The small sync dips that were experienced were most probably caused by disconnection problems and offline caching should be given priority when upgrading.

Table 5 User Feedback and Satisfication Survey

Participant ID	Ease of Use (1-10)	Alert Effectiveness (1-10)	App Usability (110)	Overall Satisfaction (%)
P1	9	10	8	92
P2	8	9	7	88
P3	9	10	9	94
P4	10	10	10	97
P5	7	8	6	82
P6	8	9	8	90
P7	9	10	9	95
P8	8	8	7	87
P9	10	9	9	94
P10	9	9	8	91

The feedback and satisfaction of users are summarized in Table 5 and rated by ten people in four categories. The scores of ease of use and the effectiveness of the alert and the usability of the apps were all between 7 and 10, whereas the overall satisfaction is between 82% and 97%. The ease of interaction, the dependability of prompts, and clarity of navigation in the apps were all embraced well by most users. Smaller criticisms emphasized the use of accessibility by the visually impaired. These reactions indicate that the system is user-friendly, approachable, and suited to the elderly or chronically ill population, and it has high chances of being adopted in both individual and community health care.

IV. CONCLUSION

In our work we created and tested a smart, IoT-based medication remind system that would be certain and designed specifically to remind elderly and chronically ill people. The system can successfully be used to identify the instances of medication intake, which is possible by the inclusion of logical sensors, i.e., LDR, IR, and load cell sensors, and which do not merely rely on passive reminders. Accurate time-based alerts were made possible with the addition of a Real-Time Clock module, and easy access to a companion mobile application and cloud platform was made possible with the addition of connectivity modules (Wi-Fi and Bluetooth). The sensor fusion accuracy of 94.3 on average, coupled with cloud sync success rate of 98-100 shows how the system is robust in real-world implementation. Over 96% of caregiver alerts were successfully activated in situations of delayed user response, and this validates the functionality of the system to guarantee compliance and safety. The existing implementation effectively addresses the major drawback of the previous systems, i.e., the impossibility to verify the actual intake of medication. It also tackles user interface challenges, power management challenges and caregiver communication challenges. Its applicability is justified by the fact that the results of the research are suitable in low-resource and ageing communities where health technology needs to be reliable and sustainable. In the future, the system can be improved in a number of directions. First, AI-based learning algorithms might be incorporated into the system to enable the use of custom reminder schedules depending on user behavior and response pattern. Second, the use of voice assistants and speech feedback would enhance access by people with limited visual abilities. Third, the connection with e-prescription systems and wearable health sensors is possible, which can form a more cohesive health management ecosystem. Therefore, the model has a lot of potential to be extended to larger healthcare uses such as chronic disease management and elderly care.

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