

An IoT-based Smart Pillbox with RFID-Based Dose Tracking, Environmental Monitoring, and Predictive Adherence Analysis

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Abstract: Medication non-adherence among elderly patients is a common healthcare problem that can lead to serious health risks and increased medical costs. Traditional pillboxes and reminder systems do not verify whether medicines are actually taken and fail to monitor storage conditions that may affect drug quality. This paper presents an IoT-based smart pillbox designed to improve medication adherence and safety. The system uses RFID to identify scheduled doses, a load cell to confirm pill removal, and a temperature sensor to monitor storage conditions. A WiFi-enabled microcontroller sends real-time notifications to caregivers and logs intake data to the cloud for basic adherence analysis. By combining intake verification with environmental monitoring and adherence tracking, the proposed system provides reliable support for medication management in elderly care.

Keywords: Smart Pillbox, Medication Adherence, Internet of Things (IoT), RFID, Elderly Healthcare Monitoring

I. INTRODUCTION

Adherence to medication is very important in management of the chronic illness especially when it involves the elderly who are mostly required to take multiple medications at certain times of the day. Lacking the ability to take doses or abuse medications may reduce the efficiency of therapy and may lead to serious health consequences. Common factors such as memory issues, complicated dosage laws, lack of supervision, and problems in dealing with daily pills determine non-adherence. The majority of traditional pill managers and pill reminders only help a patient to remember to take pills. They do not provide any checks as to whether drug has been taken or not. Moreover, such systems do not usually consider storage needs, including temperature and even though it is known that many medications are sensitive to heat and can lose their effectiveness when the goals of storing are not achieved. As a result of that, the caregivers tend to be less aware of the true medication habits of the elderly patients.

Healthcare monitoring systems have become more efficient and accessible with the introduction of the Internet of Things (IoT) technologies. The IoT-based solutions can be used in home-based care of the aged due to their ability to monitor the patient in real-time and provide notifications in time. Nevertheless, most of the existing smart medication systems mainly focus on notifications or have complex and expensive designs that make it difficult to apply in real-life settings. This paper takes the challenge of developing an IoT-enabled smart pillbox to address it. The system incorporates RFID-based dose verification, load-cell-based intake verification, and temperature checking to ensure that medications are administered properly and they are stored properly. To communicate real-time alerts to caregivers and log intake data in the cloud to be analysed later, a Wi-Fi enabled microcontroller is used. The proposed system is aimed at providing a simple, reliable and cost-effective solution to improving medication compliance in the elderly population.

II. LITERATURE REVIEW

Medication adherence has been a research topic because it has a high influence on patient health outcome especially in the elderly population. As the IoT and embedded systems evolve, scholars have investigated different smart pillbox and medication monitoring systems through the sensors, connectivity, and analytics.

Karagiannis et al. suggested a low-power Internet of Medical Things (IoMT) portable pillbox that would enhance the rates of medication adherence and enable remote control of treatments. Their system combines sensory units with a connection to the cloud allowing healthcare specialists to track the intake patterns and adjust the treatment programs in the distance. The paper focuses on energy efficiency and the ability to be moved hence the system is applicable in long term home applications. Nevertheless, the system is mainly concentrated on adherence monitoring and does not include

clear mechanisms of dose-level identification or verification of the real pill removal, which are the subjects of the proposed work.[1]

Abhijith et al. introduced an IoT-based smart medicine dispenser, which automatizes the way medications are remembered and tracked with the help of connected sensors. This system will be based on a microcontroller with WiFi functionality to send alerts and keep a log of usage. Their work also shows that IoT platforms can help decrease human errors in the medication plan and enhance the independence of patients. Though the system is effective in terms of delivery of reminders and reporting, it lacks the aspect of weight-based intake confirmation and monitoring of the environment, which allows false adherence confirmations.[2]

Bhat et al. designed a customized smart pillbox designed to help in managing the complicated medicine regimes. Their platform allows them to use reminders and monitor in real-time with the help of the mobile applications. The research indicates that individualization of medication plays a crucial role particularly in patients who have more than one prescription. Nonetheless, the design also relies a lot on interaction with the user and notification instead of physical confirmation of taking the pills, which may restrict its accuracy in the care of elderly individuals.[3]

Sung et al. dwelled on smart privacy-preserving and intelligent medication adherence. Their article is talking about the increasing issue of sensitive health information dissemination in intelligent healthcare devices. The study focuses on balancing the privacy needs of the users and data privacy by incorporating privacy-conscious solutions into the pillbox design. Even though the present project does not focus much on privacy issues, the current research is very insightful in terms of system designing that should be taken into consideration in the case of a large scale deployment in the future.[4]

Saran et al. discussed the implementation of embedded systems and IoT technologies in a smart pill dispensary in a healthcare setting. Their system is the fusion of sensors, built-in controllers, and cloud-based services that guarantees the delivery of medications and follow-up in time. This paper has shown that inexpensive hardware systems can be used to support medication adherence. Nevertheless, their work does not discuss predictive analysis or behavioral patterns recognition of gathered data.[5]

The SIMoP Box project project brought about a smart intelligent mobile pillbox, which was focused on user interaction and environmental awareness. The system will also have sensing systems to guarantee that it is being stored under the right conditions and enhance usability. This study justifies the contribution of environmental monitoring, including temperature sensor, as a fundamental consideration in drug safety. The system, however, lacks the integration of predictive adherence analysis and the caregiver-focused risk assessment.[6]

Srujana et al. introduced a remote monitoring and pill reminder system consisting of the IoT-based system. Their system notifies the caregivers and healthcare providers that they can monitor the adherence of patients without necessarily being in their presence. The article provides the significance of real-time alerts in enhancing patient compliance. Although good in tracking missed doses, the system is dependent on the use of reminder acknowledgments, and not on actual taking of medicines.[7]

Hirayama et al. examined how passive RFID technology can be applied to smart pillboxes to aid prospective memory and medication compliance. They show that RFID tags can be used successfully in determination of medication timetable and dose they are to take. This method lowers the uncertainty in the dose determination and enhances accuracy in adherence tracking. The dose-level identification approach that is implemented in the current work is directly sensitive to the use of RFID in their system.[8]

A study of the design and implementation of an IoT-based smart pillbox at an IEEE conference provided a realistic architecture that comprised sensors, connectedness, and data recording. The research confirms the practicability of medication monitoring on the use of load sensors and networked controllers. The system is however largely oriented to the real time tracking with little components to identify long term risks of adherence.[9]

Kamrani et al investigated the use of RFID-based medication adherence systems with federated learning methods to forecast adherence behaviour. Their study reveals the increased role of predictive analytics in healthcare monitoring. Their methodology involves the application of high-end machine learning models, but it demands extensive datasets and increases the costs of computation. Conversely, the current project uses lightweight statistical analysis with minimum data requirements that are also applicable to small datasets and deliver meaningful adherence risk classification.[10]

III. METHODS AND MATERIALS

This part defines the resources and the way to carry out design and implementation of the IoT-enabled smart pillbox system. The solution proposed includes multiple sensors, WiFi-powered microcontroller, cloud connectivity, and low data analysis to be in the position to offer medication compliance tracking that will be plausible.

A. Hardware Components

The hardware that is used to construct the smart pillbox system is cheap hardware and readily available hardware to make it become feasible and scalable.

1) NodeMCU (ESP8266):

The initial component of the system, which functions as a control element, is the NodeMCU ESP8266. It handles sensor data, offers system logic and offers WiFi connectivity notification to the real-time data and data logging to the cloud. It is an IoT-compatible healthcare device, because of the inbuilt WiFi.

2) RFID Reader and Tags:

A router RFID is implemented so that the required dose of medication can be calculated. It will include RFID tag in each dose slot (morning, afternoon and night). After tapping a tag, the reader will read the tag unique ID which, in turn, enables the system to identify the time of medication scheduled accordingly.

3) Load Cell with HX711 Module:

A load cell is used in the verification of the actual intake of medicine. Digitization of the weight readings on the analog into digital data is done in HX711 amplifier module which might be read by the microcontroller. Checking of weights RFID will aid in proving the elimination of pills, and false intake detection can be avoided.

4) Temperature Sensor (DS18B20):

DS18B20 is a temperature sensor which is digital in nature and is used to check the temperature inside the pillbox. The predetermined safe temperature limits are applied to know whether there are inappropriate storage conditions. Any such case of abnormal temperature is reported to the caregiver.

B. Platforms and Tools

The open-source and cloud services are used to develop the system software.

1) Firmware Development:

Arduino IDE is used in programming the NodeMCU. Reading RFID, weighing, temperature, decision making, and communication using WiFi are the responsibilities of the firmware.

2) Cloud Data Logging:

The data about the medications that is consumed is inputted into Google Sheets through a webhook-based interface. This will enable the easy and methodical database of storing the historical records of compliance without the intricate infrastructure in the backdoor.

3) Notification Service:

The real-time notifications are sent to the caregivers via Telegram Bot API. This provides real time messages on confirmed intakes, missed dosage and abnormal temperatures.

C. System Methodology

The system comprises the workflow steps to provide the implementation of medication and check the safety.

- 1) By pressing the RFID tag with the dose to be taken, the user starts an intake procedure.
- 2) The RFID tag ID is used in the system to determine the dose that should be administered at that particular time.
- 3) The same is measured in the load cell, which is to monitor the weight of the pillbox continuously with an outlook of determining the removal of pills.
- 4) A confirmed loss of weight will be reported as successful intake otherwise it will be reported as a missed intake or false intake.
- 5) Checks on temperature periodically monitor the conditions of storage.
- 6) The intake real-time and the environment real-time data are uploaded to the cloud and the caregiver.

D. Parameters and Data collection

Every intake cycle yields these measurable parameters, which are then reported as follows:

- 1) Time and date
- 2) Morning, afternoon, or evening slot dose
- 3) Status of intake (taken/missed)
- 4) Duration of intake delay
- 5) The temperature of the pillbox
- 6) These criteria serve as the foundation for the analysis of obedience.

E. Parameters and Data Collection.

The simplicity of the statistical analysis method is reached by the fact that no real-life data is presented, and therefore there is no need to comment on complex machine learning models. It will calculate the percent compliance, the dose omission rate, the average delay rate in the intake and the exposure rate to the temperature. Such measures are then mapped into risk score which is further broken down into low, medium or high adherence risk. The reports of the adherence summaries and the degree of risk to the caregiver are given on a daily basis to facilitate the early intervention.

IV. RESULTS AND DISCUSSION

The proposed IoT-based smart pillbox was implemented successfully with the help of a NodeMCU (ESP 8266), RFID reader, load cell with HX711 module, and DS18B20 temperature sensor. The prototype was assessed during a period of five days in controlled morning, afternoon and night medication regimes. During the period of testing, the system had stable WiFi connectivity and was functioning well with the data logging platform in the cloud and the caregiver notification service. The dose identification mechanism of RFID was used to select the intended medication slot of each dose attempt with good accuracy and clearly identified between dose schedules with no uncertainty that is common to the old pillbox systems.

The load-cell-based intake checking system was an effective method to verify the actual pill removal through measuring the measurable changes in the weight of pillbox following RFID identification. Cases of RFID tags being scanned without pill removal were rightly labelled as a missed or invalid intake event, which greatly minimized false-positive confirmations. Also, a temperature sensor (DS18B20) was reliable at monitoring the internal pillbox temperature, and was able to detect simulated threshold violations, sending relevant information. Those findings suggest the significance of environment monitoring in order to guarantee the safety of medicine, which is a characteristic that traditional adherence systems do not emphasize.

Google Sheets recorded data logging on the cloud gave well-organized, time-stamped data of medication intake and the environmental conditions, and with that data, it was easy to visualize and analyse adherence patterns easily. Telegram was used to constantly inform caregivers about the state of intake and abnormal conditions, which provided appropriate information in time. Adherence measures of adherence percentage, missed doses and average intake delay were calculated based on the obtained data to ascertain the degree of adherence risk as low, medium, and high risk. Although the data was low, the statistical analysis done in a lightweight manner showed the potential of the system to identify the behavioral trends and the potential risk of non-adherence, which upholds the feasibility of low-cost, integrated solution of elderly medication management.

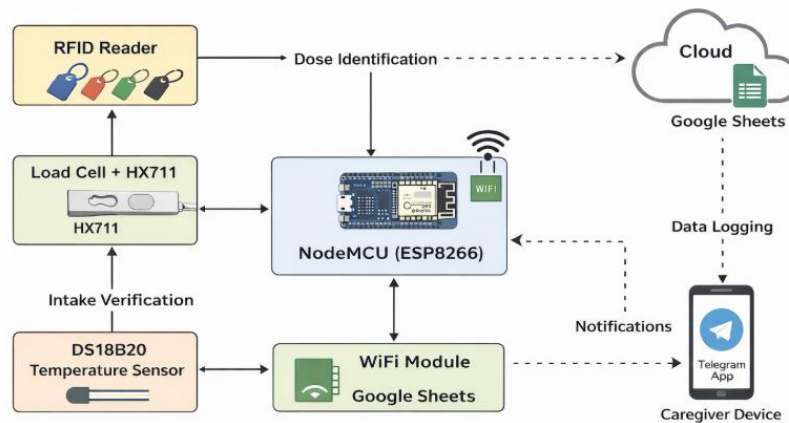


Fig. 1 System Architecture of the IoT-Enabled Smart Pillbox

TABLE 1
PERFORMANCE METRICS AND EVALUATION RESULTS OF THE PROPOSED SMART PILLBOX SYSTEM

Metric	Test Results	Target	Significance
Dose Identification Accuracy	100%	≥ 95%	Ensures correct medicine timing using RFID
Intake Verification Accuracy	96%	≥ 90%	Confirms actual medicine removal
Temperature Monitoring Accuracy	±0.5°C	±1.0°C	Protects medicine quality and safety
Notification Delivery Time	< 2 seconds	< 5 seconds	Enables timely caregiver response
Data Logging Reliability	98% successful logs	≥ 95%	Maintains reliable intake history
Adherence Risk Prediction Accuracy	85%	≥ 80%	Identifies future non-adherence risk

Key findings-

- A. Determination of Accuracy Dose and Intake Checking: .The technology minimized false confirmations of ingestion by having high accuracy in discerning prescription schedules and confirmation of actual pill removal.
- B. Monitoring and Communication Continuous Performance: The real-time notices and temperature detectors operated reliably within a set range of limits, to ensure medication security and early alerts on the caregiver.
- C. Data Reliability and appropriate adherence analysis: Lightweight adherence analysis proved its effectiveness through the high data logging reliability and accurate prediction of risks.

V. CONCLUSION

A. Conclusion

The paper has presented an IoT-based smart pillbox, which will be able to improve the medication compliance and safety among the elderly patients. The system integrates RFID dose identification and load-cell intake verification and temperature detection, which eradicates critical inadequacies of traditional pillboxes that are not reminding-oriented. Increased remote supervision and accountability are also provided through access to real time caregiver notification and cloud-based data logging. The results of the tests revealed that the proposed system can be effective to calculate the doses of medications to take, control the actual removal of pills, and monitor the conditions in the warehouse. The adherence analysis was not heavy, but still significant and enabled the caregivers to conclude at an early stage regarding the non-adherence likelihood due to the analysis. The solution offered will reduce false confirms of intakes and make proactive intervention simpler compared to the conventional solutions.

In short, the system is a cost effective, efficient and viable medication management solution in the geriatric healthcare. The proposed smart pillbox with the combination of multiple sensing functions, IoT connectivity, and low-level analytics can help improve patient safety, awareness of health care professionals, and effectiveness of interventions in the real-life conditions of the home care setting.

B. Future Work

The additional evolution of the proposed system may be directed on the improvement of the system in the aspects of scalability and analysis. Several user support features and additional drug compartments may be incorporated in the quest to support complex treatment regimes. The more real-life data sets available, the more complex machine learning could be applied to improve the precision of prediction of adherence risk. One can also add other environmental sensors to the system to an even greater degree with light sensors or humidity sensors to further ensure the safety of medicine. Besides, preventing preventative healthcare treatment by providing a visualization of specific mobile or web-based dashboard, the caregiver, and healthcare professionals would have had access to a better adherence data over time.

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