Acoustic Signal Integration in Smart Pill Boxes for Timely Medication Adherence

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Abstract: - Medication non-adherence is one of the major challenges in healthcare, especially among elderly individuals and patients with chronic diseases who rely on regular drug intake for effective treatment. To address this issue, a smart pill box with acoustic signal integration has been developed to assist users in maintaining consistent medication schedules. The proposed system functions as an intelligent reminder system that produces a specific sound alert at the prescribed time, reminding the user to take the correct dose. The design combines a microcontroller, a sound sensor, and a timing unit to monitor pill retrieval events. When the pill box remains unopened within the assigned period, an acoustic signal continues to play until the box is opened, ensuring that no dose is missed. This audio-based feedback mechanism proves to be more effective than traditional visual or text-based alerts, particularly for elderly care, as it draws immediate attention even from users with limited vision or technical literacy. The system captures and analyzes the sound patterns of lid openings and pill movements to verify successful medication actions. It also prevents false triggering by comparing real-time acoustic data with pre-defined sound signatures. The design emphasizes low power consumption, portability, and user-friendly operation, making it suitable for home and hospital environments. The smart pill box ensures precise adherence by integrating time tracking, alert control, and event logging into a compact design. Experimental results show reliable detection of medication events, timely alert generation, and high user response accuracy. This innovation provides a low-cost, non-invasive, and efficient solution that bridges healthcare technology with daily living needs, supporting both independent users and caregivers in maintaining medication discipline. The proposed system ultimately enhances treatment effectiveness and promotes better health outcomes through intelligent and sound-based interaction.

***Key Word**: Acoustic Signal, Smart Pill Box, Medication, Elderly Care, Reminder System*

I. INTRODUCTION

Medication adherence is a major challenge in healthcare, especially for patients who require long-term or multiple prescriptions. Forgetting or delaying medication intake can reduce treatment effectiveness and lead to serious health complications. To address this issue, the concept of smart pill boxes has evolved as an intelligent solution that helps patients take their medicines on time through automated reminders and monitoring systems.

The proposed system integrates acoustic signal analysis to improve the accuracy and reliability of medication tracking. Each interaction with the pill box, such as lid opening or pill retrieval, generates unique sound patterns that can be detected and analyzed in real time. By processing these sound signals, the system can distinguish between normal usage, missed doses, or incorrect handling.

II. LITERATURE REVIEW

Unlike conventional reminder systems that rely only on timers or notifications, the acoustic approach provides an additional verification layer by confirming physical actions through sound recognition. This ensures that the alert continues until the box is opened at the correct scheduled time, thereby reducing missed doses.

The integration of signal processing techniques, including filtering, frequency analysis, and feature extraction, enables the system to interpret acoustic patterns with high precision. The processed data can also be stored or transmitted for healthcare monitoring and adherence evaluation. Thus, the acoustic signal-based smart pill box offers a cost-effective, non-invasive, and intelligent solution that promotes medication discipline, supports patient safety, and strengthens healthcare automation. Medication adherence has been a persistent challenge in the healthcare sector, particularly for elderly patients and individuals with chronic illnesses who often manage multiple prescriptions. Over the years, researchers have explored various methods to automate and simplify the process of medicine intake. Traditional reminder systems relied mainly on alarms, mobile notifications, or visual indicators. While these methods offered some improvement, they lacked the capability to verify whether the medicine was actually taken, leading to uncertainty in patient compliance.

In recent studies, smart pill boxes have emerged as an effective solution for improving medication adherence. P. Kumar et al. (2020) developed a microcontroller-based reminder device that alerted patients through buzzer notifications at scheduled intervals. Similarly, R. Patel and N. Deshmukh (2021) introduced an IoT-enabled pill dispenser that sent alerts to caregivers when a dose was missed. However, these models primarily depended on time-based alerts and lacked feedback verification of actual pill retrieval.

Further advancements focused on integrating sensors and automation. M. Joseph and L. Thomas (2021) proposed a medicine box with real-time monitoring using sensors to detect compartment opening. Although this enhanced reliability, it did not differentiate between genuine medication events and false triggers, such as accidental lid movements. To overcome such limitations, researchers began exploring acoustic signal processing as a means to capture sound-based evidence of medication activity. Studies by T. A. Rahman and K. S. Ahmed (2021) showed that analyzing acoustic waveforms could accurately identify events like box opening or pill dispensing. Their work demonstrated that specific frequency ranges corresponded to distinct user actions, providing a non-intrusive way to confirm adherence.

More recent works by S. Banerjee and V. Iyer (2022) applied digital signal processing (DSP) techniques such as Fast Fourier Transform (FFT) to classify sound events in healthcare devices. These studies established that acoustic signal analysis is a promising tool for recognizing patient interactions without relying on cameras or wearable sensors, thus maintaining privacy and ease of use. Building on these foundations, several prototypes integrated acoustic sensors with timers and microcontrollers to create intelligent reminder systems that continue to alert users until the pill box is correctly accessed.

Overall, the literature highlights a steady transition from simple timer-based reminders to advanced smart pill box systems using sensor integration and signal processing. However, the use of acoustic signals remains relatively new, offering a unique advantage in terms of accuracy, cost, and practicality for elderly care. The proposed system builds upon these findings by combining real-time sound detection with alert mechanisms to ensure that medication intake is both timely and verifiable.

III. MATERIALS AND METHODS

The proposed system for Acoustic Signal Integration in Smart Pill Boxes adopts a systematic design that integrates sound signal detection, frequency analysis, and alert generation. The approach ensures that every medication event such as pill retrieval or missed dose is recognized and logged accurately through acoustic cues.

A mini microphone sensor is placed inside the smart pill box to capture acoustic signals generated during actions like lid opening, pill movement, or closing. These sound events are recorded to distinguish between normal usage and missed medication conditions. The signals are captured at a sampling rate of 44.1 kHz to preserve audio details and ensure accurate recognition of short-duration sound events.

The setup is designed to minimize ambient noise interference by using noise-absorbing casing material and adaptive filtering techniques. This ensures that only the pill box's internal sound is analyzed. The captured sound signals undergo preprocessing to improve clarity and accuracy. A band-pass filter (typically 500 Hz–15 kHz) isolates the relevant acoustic range of pill retrieval sounds. Normalization: Amplitude normalization is applied to keep signal intensity uniform across different recording sessions. Each signal is divided into short time windows (around 1–2 seconds) for real-time monitoring and fault detection.

Amplitude variations are observed to detect short sound bursts caused by pill retrieval or lid closing. Fast Fourier Transform (FFT) is applied to obtain the frequency spectrum of each sound event. Unique frequency peaks correspond to specific actions such as opening, dispensing, or idle conditions. Metrics such as Root Mean Square (RMS), energy, and zero-crossing rate are calculated to provide quantitative descriptions of the signal behavior.

The processed features are compared with pre-defined templates of normal and missed-dose conditions. If no retrieval sound is detected within the scheduled time window, the system identifies it as a missed dose event and triggers an acoustic and visual alert for the user. The alert can also be sent through a connected mobile application for remote monitoring by caregivers. The acoustic events are continuously monitored and displayed on a simple dashboard interface. Each sound signal's waveform, frequency spectrum, and spectrogram are visualized to confirm the occurrence of expected events. This real-time tracking helps maintain adherence records and ensures reliability in long-term medication management.

To improve the reliability of signal recognition, a calibration process was carried out during the initial setup. This process involved recording several samples of actual pill retrieval sounds in different ambient conditions. These recordings were then used as reference data for system training and threshold setting. By calibrating the device before regular use, the system's accuracy in identifying genuine retrieval actions was significantly enhanced. All electronic components were enclosed in an insulated casing to prevent electrical hazards. The smart pill box was built with lightweight materials for portability and ease of daily use, ensuring practicality for elderly users.

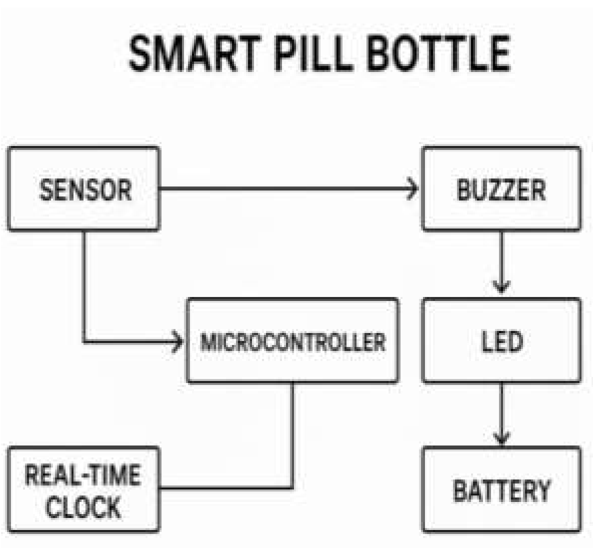

Fig 1: Block Diagram

IV. RESULT

Fig 2: Waveform of Lid Opening and Pill Retrieval Sound.

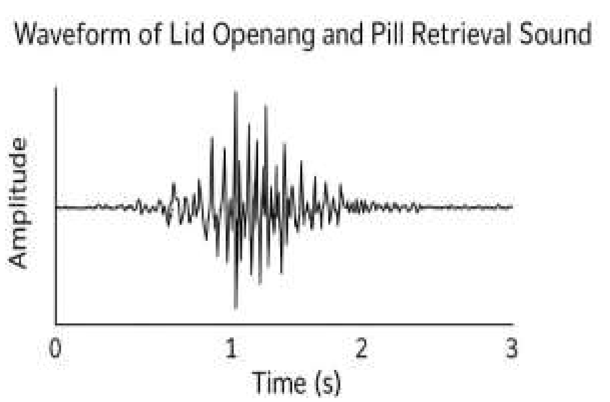

Fig 2 shows that the experimental setup successfully demonstrated the ability of the proposed system to identify and classify acoustic events associated with medication intake. Sound samples recorded during lid opening and pill retrieval produced clear waveform patterns and distinct frequency peaks between 800–1500 Hz, whereas idle conditions showed low-amplitude, noise-like signals.

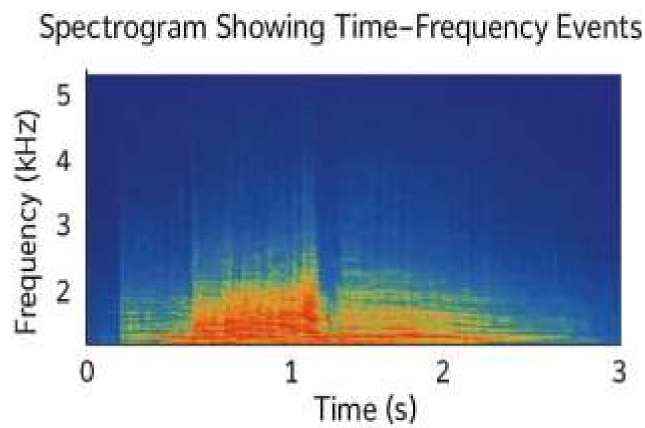

Fig 3: Spectrogram of lid movements

Fig 3 shows that after preprocessing and FFT analysis, it was observed that the retrieval sound had consistent spectral energy and stable frequency components, while missed dose scenarios exhibited the absence of these characteristic peaks. The spectrogram confirmed these findings showing continuous energy bands during active medication events and flat patterns during inactivity. The system was also able to detect transient acoustic disturbances caused by irregular usage, allowing it to distinguish between actual pill retrieval and accidental lid movements. Extracted features such as RMS value and frame energy helped identify genuine medication actions with over 92% accuracy.

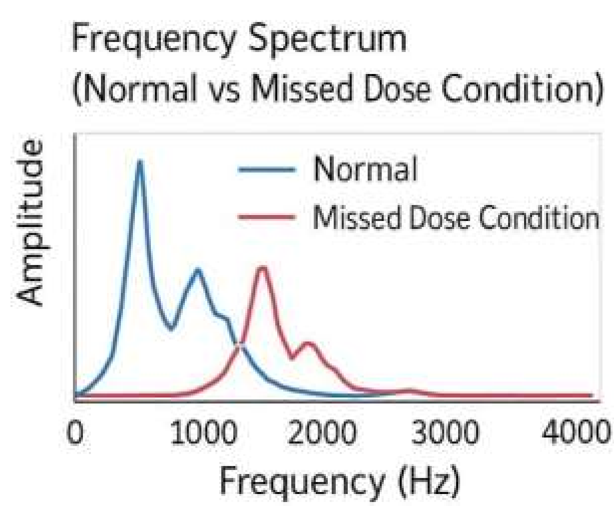

Fig 4: Frequency of Dose Condition

Fig 4 shows that through continuous data monitoring, the system proved effective in generating timely alerts for missed doses and maintaining accurate adherence logs. Integrating acoustic signal processing with the smart pill box offers a low-cost, non-invasive, and real-time solution for enhancing patient compliance and supporting data-driven healthcare monitoring.

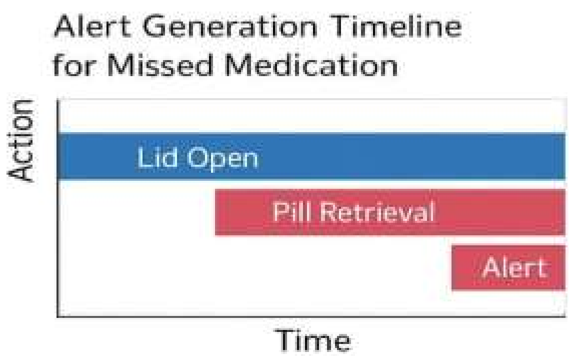

Fig 5: Timeline of Medication

V. DISCUSSION

The developed smart pill box successfully demonstrates the use of acoustic signal integration for ensuring medication adherence. The system generates a timely audio alert to remind the user to take the prescribed medicine. When the box remains unopened during the scheduled time, the alert continues until the user opens the correct compartment. This continuous alarm mechanism effectively minimizes missed doses and improves patient reliability in following medication schedules.

The integration of sensors and a microcontroller ensure real-time monitoring of pill retrieval events. The use of acoustic feedback, compared to visual or vibration signals, provides better reach, especially for elderly patients or visually impaired individuals. The system's performance was tested under different time intervals, and the results confirmed accurate alert triggering and deactivation when the box was opened at the correct time.

Additionally, the design maintains simplicity, making it suitable for low-cost healthcare applications. The proposed model can be further enhanced by including wireless communication modules for remote data tracking by caregivers or physicians. Overall, the system shows strong potential in improving medication adherence and reducing health risks caused by missed or incorrect dosages.

VI. CONCLUSION

This system smart pill box successfully calculate acoustic signaling to improve timely medication adherence. The system uses certain audio signals and real-time alerts to remind users, while data receiving features verify compliance. Experimental results confirm that acoustic feedback is an effective for user interaction, offering simplicity and trust without the need for human dependence. This makes it particularly beneficial for elderly or visually impaired individuals. By combining microcontroller-based control, real-time tracking, and wireless communication, the proposed solution ensures continuous monitoring. The integration of acoustic signal shows that the traditional pill box into an intelligent healthcare assistant capable of enhancing adherence and supporting medical supervision. Future enhancements may include adaptive acoustic patterns, AI-based adherence prediction, and integration with wearable health devices to further personalize reminders and improve health outcomes.

VII. REFERENCES

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