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A Review of Features and Characteristics of Smart Medication Box

Islam M. Ibrahim, Kerolus Fareed, Hager Yasser, Omar Gamal, Mohamed Tarek, Rawan Mahmoud, Rawan Rajab, Rahma Nady, Patrick Mekhail, and Iyad Abuhadrous*

Software Engineering Department, Faculty of Engineering and Technology, Egyptian Chinese University, Cairo, Egypt
**iyad.mohammed@ecu.edu.eg*

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ABSTRACT

The increasing complexity of medication management among the elderly presents significant challenges, including missed doses and medication errors, which can lead to serious health complications and increased healthcare costs. This review examines recent advancements in IoT-based smart medicine boxes designed to enhance medication adherence and improve healthcare outcomes for elderly patients. These innovative devices utilize various technologies, such as microcontrollers, sensors, and mobile applications, to provide timely reminders, secure medication dispensing, and remote health monitoring. Key features include automated alerts for medication schedules, real-time health tracking, and caregiver notifications, ensuring patient safety and caregiver support. The integration of user-friendly interfaces ensures accessibility for elderly users, accommodating their specific needs, while data storage capabilities allow healthcare providers to monitor adherence patterns effectively. By combining advanced technology with practical functionality, IoT-enabled smart medicine boxes represent a promising solution to address medication non-adherence and improve the overall quality of care for vulnerable populations.

1. Introduction

The increasing elderly population presents significant challenges in healthcare, particularly in medication management, as evidenced by the high incidence of medication errors among seniors who often forget or mismanage their prescriptions, underscoring the need for innovative solutions like a smart reminder medicine box [1]. The integration of Internet of Things (IoT) technologies into home healthcare services can enhance connectivity and improve medication adherence, with intelligent medicine boxes offering features such as email alerts and real-time monitoring to ensure patients take the correct medications on time [2]. As life expectancy rises, especially among those over 65, the development of effective medication management systems becomes crucial, with IoT providing a promising approach to reducing healthcare costs and improving patient outcomes through real-time monitoring and better resource management [3]. The implementation of smart pillboxes specifically designed for IVF patients addresses the unique challenges they face, as these devices facilitate medication adherence through reminders and tracking, thereby improving treatment success rates [4]. A smart pill case system aims to assist the elderly and disabled

by providing a user-friendly interface for medication management, which is vital given the increasing number of medications taken daily by this demographic [5]The design of intelligent medication boxes is essential for chronic disease management, as they can sort and dispense medications while monitoring patients' health parameters, thereby improving medication adherence and patient safety [6]. With the aging population projected to increase year by year, the development of an IoT-based smart medication device is critical for ensuring that older adults can manage their medications effectively and maintain their health [7]. Addressing the need for smart medicine boxes is crucial, as proper medication adherence can prevent complications related to chronic diseases prevalent among the elderly [8]. The design and development of automated pill dispensing systems are increasingly important in the context of rising elderly populations, as these systems help manage complex medication schedules efficiently [9]. Finally, the IoT ecosystem offers a transformative solution to healthcare challenges by enabling remote monitoring and data management, ultimately improving patient care and resource allocation in medical settings [10].

2. Methodology: Conducting a Systematic Review

2.1 Purpose and Scope of the Systematic Review

This systematic review aims to examine and synthesize the existing research on IoT-based smart medical boxes for elderly care, specifically focusing on their design, functionality, and efficacy in pill dispensing and health monitoring. The scope of this review includes studies related to IoT technologies, healthcare solutions, and elderly care, with particular attention to the integration of machine learning and AI for improving the usability and effectiveness of smart medical boxes. The review also covers the design methodologies, technological stacks, and system evaluations in the context of elderly healthcare.

2.2 Adherence to PRISMA Guidelines

We adhered closely to the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines to ensure transparency and maintain high standards in our systematic review. [11] A standardized checklist provided by PRISMA makes it possible to report the systematic review process understandably and comprehensively. This includes choosing studies, creating a search strategy, establishing the study focus, extracting data, and synthesizing findings.

2.3 Research Scope and Keywords

In this systematic literature review, we precisely outlined our research focus and utilized a core set of keywords, including IoT, medical box, AI, healthcare, and elderly care. Additionally, we incorporated related terms such as “smart medicine planner for visually impaired people,” “automatic pill dispensing,” “health monitoring systems,” and

"IoT-based patient monitoring systems." Our search strategy aimed to include studies focusing on the role of IoT and AI in improving the quality of life for elderly individuals through innovative healthcare solutions.

2.4 Search and Selection Process

2.4.1 Initial Manuscript Selection

The preliminary selection of manuscripts was conducted through a thorough evaluation of their titles and abstracts, prioritizing those that explicitly referenced IoT-based smart healthcare systems, smart medicine boxes, health monitoring for elderly people, and related topics. We used multiple platforms, including Google Scholar, PubMed, Scopus, and ResearchGate, to identify the relevant studies. To include the most relevant and current information, our search was limited to articles published from 2018 to 2024.

2.4.2 Manuscript Identification

Our initial search resulted in 120 relevant studies. To ensure the integrity and relevance of our analysis, we applied a filtering process. This involved removing duplicate studies across platforms, resulting in 100 unique studies. We then selected papers based on pre-established inclusion criteria, including their alignment with the research objectives and relevance to the scope of our study. This systematic approach ensured that the final set of studies represented high-quality and directly relevant contributions to the topic.

2.4.3 Rigorous Review and Inclusion Criteria

- **Inclusion Criteria:**
  - Relevance to Research Focus: Studies that addressed the design, functionality, or effectiveness of IoT-based smart medical boxes for elderly people, including pill dispensing and health monitoring, were included.
  - Methodological Rigor: Studies with clear methodologies, such as controlled trials, user testing, and data on system performance, were prioritized.
  - Publication Date: Only studies published between 2018 and 2024 were considered to ensure the incorporation of the most recent research on IoT healthcare systems.
- **Exclusion Criteria:**
  - Irrelevance to Research Focus: Studies that did not specifically address IoT-based smart medical boxes or focused on unrelated healthcare technologies were excluded.
  - Methodological Flaws: Studies that lacked clear methodologies, such as uncontrolled trials, or those with insufficient data on the system's effectiveness, were excluded.

- Outdated Research: Studies published before 2018 were excluded due to outdated technology and the rapid advancements in IoT applications for elderly healthcare.

2.4.4 Final Selection and Exclusion Statistics

After applying the inclusion and exclusion criteria, a total of 52 studies were selected for the final review. An additional 48 studies were excluded due to factors such as methodological limitations or the use of outdated information.

2.5 Data Extraction Process

2.5.1 Addressing Limited Directly Related Papers

Due to the limited number of directly related papers, we broadened our search criteria to include studies on related technologies and subtopics. We considered IoT-based health monitoring systems, wearable IoT devices, and automated pill dispensers to supplement the available research. This helped us gather relevant insights from studies that, while not specifically focused on smart medical boxes for elderly people, offered valuable data on similar technologies and systems.

2.5.2 Data Extraction

For each study included in our review, we systematically extracted data related to methodologies, technologies used, findings, and outcomes. Through our collaboration, we were able to construct **Table 1**, where we collectively evaluated the complex and challenging papers.

Table 1: Literature Review on IoT-Based Healthcare Solutions.

Author(s)	Year	Type of Study	Problem	Explanation/Solution/Conclusions
Zara Nasiret et al . [9]	2023	Proceeding Paper	Mismanagement of medication schedules, especially for elderly patients, leads to health risks and potentially fatal outcomes.	A smart medical box was designed with automatic pill dispensing and health monitoring features, using Raspberry Pi and biometric security for user identification. It monitors health metrics (temperature, oxygen level, heart rate) and notifies patients via SMS. The cost-effective prototype successfully addressed adherence but was limited to oral medications.
Zarlish Ashfaq et al. [10]	2022	Review of IoMT Technologies	Inefficiency of traditional healthcare systems in providing timely care and managing large data sets.	Reviewed IoMT technologies, including sensors, machine learning, and communication protocols. Highlighted their role in enhancing remote healthcare, improving data security, and enabling predictive analytics for better healthcare outcomes.

Archana Chaudhari et al. [12]	2024	IoT-based Healthcare Study	Elderly patients and individuals with Alzheimer's often forget their medication schedules, especially when alone. Modern lifestyles and health challenges also make it difficult for various demographics to adhere to medication routines.	A smart medicine box powered by NodeMCU, with a DS3231 RTC module, dual infrared sensors, and integration with a Blynk app. The system provides real-time notifications to caretakers, uses LEDs and buzzers for reminders, and ensures patients take medications on time through IoT connectivity.
Vinay Peddisetti et al. [13]	2024	IoT-based Healthcare Study	Poor medication adherence, characterized by incorrect timing, dosage, and discrepancies between prescribed and consumed medications, poses a major healthcare challenge. Vulnerable demographics such as the elderly face higher risks.	Development of IoT-based solutions, including a Smart Pill Dispenser powered by Arduino Nano RP2040 for precise dispensing, a Smart Cup with sensors for consumption verification, and an Android app for real-time notifications. Communication is streamlined via Bluetooth Low Energy.
J.Ramkumar et al. [14]	2020	Case Study	Ensuring timely medication for patients while reducing human error	Introduced an IoT-based automated pill dispenser to enhance medication adherence through scheduled dispensing and monitoring. Highlighted challenges like data security and cost implications.
A.AngelNancy et al. [15]	2022	Predictive Analytics Study	Lack of accurate and timely prediction of heart disease risk using IoT and cloud systems	Proposed a smart healthcare system using Bi-LSTM and IoT for heart disease prediction, achieving 98.86% accuracy. Emphasized the system's potential for future enhancements, particularly with fog/edge computing, to further improve prediction accuracy and real-time performance.
Vaidik Bhatt et al . [16]	2021	Literature Review	Integration of AI and IoT in healthca real-time monitoring.	The study proposes that AI-enabled smart healthcare systems can enhance patient monitoring and service orchestration, providing timely interventions and improving overall care delivery.
Mazin Asharani et al. [17]	2021	Survey	Limited efficiency in healthcare due to population growth and technology barriers.	Proposed the integration of IoT and AI in remote healthcare monitoring (RHM) to improve efficiency, lower costs, and enhance patient care. The study emphasizes the potential of smart city frameworks and data analytics for addressing healthcare challenges.
Manoj Kumar Shukla et al.[18]	2023	Development Study	Medication errors, missed dosages, and lack of reliable tracking methods in healthcare.	Developed an IoT-based smart medicine box integrating STM32 board, IR sensors, servo motors, and Wi-Fi modules. The system automates medication tracking and delivery, connects to mobile apps for real-time monitoring, and sends reminders, improving patient adherence and safety while reducing healthcare inefficiencies.
Disha Agarwal et al.[19]	2023	IoT-based Healthcare Solution	Elderly patients often miss or improperly manage their medication, leading to health risks.	Proposes a MEDIBOX using IoT and cloud to automate medication tracking, temperature monitoring, and inventory management

Hangxing Huang et al. [20]	2024	Research Study	Patients with chronic conditions have poor medication adherence, leading to suboptimal treatment outcomes.	Developed an intelligent medication reminder system using a universal medication schedule (UMS) to improve adherence. The system integrates drug interaction data, personalized schedules, and a patient-facing application to guide medication timing and monitor adherence. It supports better compliance, reduces adverse effects, and enhances treatment efficacy.
Diaa Salama Abdul Minaam et al.[21]	2018	Prototype Design	Errors in medication due to improper timing, manual pill sorting, and the elderly forgetting to take medications.	Designed a "Smart Pill Box" integrating IoT and wireless technologies. Features include automatic reminders, pill dispensing, and tracking via a mobile app. The system uses sound and light notifications, reducing errors and improving medication adherence. Suitable for elders and hospitals, the device aims to alleviate caregiver burden.

This thorough methodology strengthens the precision, transparency, and reliability of our study by adhering to best practices in systematic literature review methodologies. Based on compelling and convincing arguments, the inclusion and exclusion criteria were meticulously developed and implemented. A thorough summary of the research framework used in this paper is given in Figure 1. It includes every step of the work plan, from the preliminary planning stage to the literature review study's selection and exclusion criteria, and finally the evaluation and discussion of the results. This graphic also illustrates the extent of future research and provides a visual depiction of the methodical methodology used in this study. This method guarantees the calibre, applicability, and timeliness of the included studies. This approach guarantees the quality, relevance, and timeliness of the studies included in our systematic review, thereby strengthening the reliability of our research findings.

3. IoT-Based Smart Medical Boxes for Elderly Care

The integration of IoT technologies into healthcare offers critical solutions to the challenges faced by elderly individuals, particularly in medication adherence and health monitoring. One of the primary concerns among the elderly is medication non-adherence, which can lead to serious health complications. Li et al. developed a smart reminder medicine box to help elderly individuals take their medications promptly and in the proper dosage, incorporating mechanical designs for easy medication insertion and microcomputers for time-based reminders and dosage control. This system monitors medication usage in real time, allowing doctors to track medication intake, adjust prescriptions, and analyze patient behaviour to provide more personalized care [1]. Shukla et al. proposed an IoT-powered smart medicine box with automation features, including an STM32 microcontroller, IR sensors, servo motors, and wireless communication modules, which allows caregivers to remotely monitor medication schedules, receive notifications about missed doses, and access medication histories, improving patient safety and adherence [2]. Al-Mahmud et al. Highlighted the importance of wireless-connected smart medical boxes in lowering healthcare costs by incorporating sensors that track health metrics like temperature, blood pressure, and oxygen levels. These metrics are transmitted to a centralized server for remote access by healthcare providers, enabling timely interventions and reducing the need for in-person visits [10]. Wadibhasme et al. also developed Saathi, a smart pill reminder system

designed for women undergoing In Vitro Fertilization (IVF) which helps patients track medication schedules, receive reminders, and communicate directly with doctors to ensure adherence to strict regimens [4]. Śniady and Królak proposed a smart pill case system using a 3D-printed box and Arduino board to help elderly and disabled individuals organize medications, track environmental conditions, and log medication intake, offering a user-friendly solution for medication management, particularly for those who struggle with complex regimens [5]. These IoT-based smart medical boxes significantly enhance elderly care by ensuring medication adherence, enabling real-time health monitoring, facilitating smooth communication between patients, caregivers, and healthcare providers, and ultimately enhancing the quality of life for elderly individuals while reducing the risks linked to manual medication management.

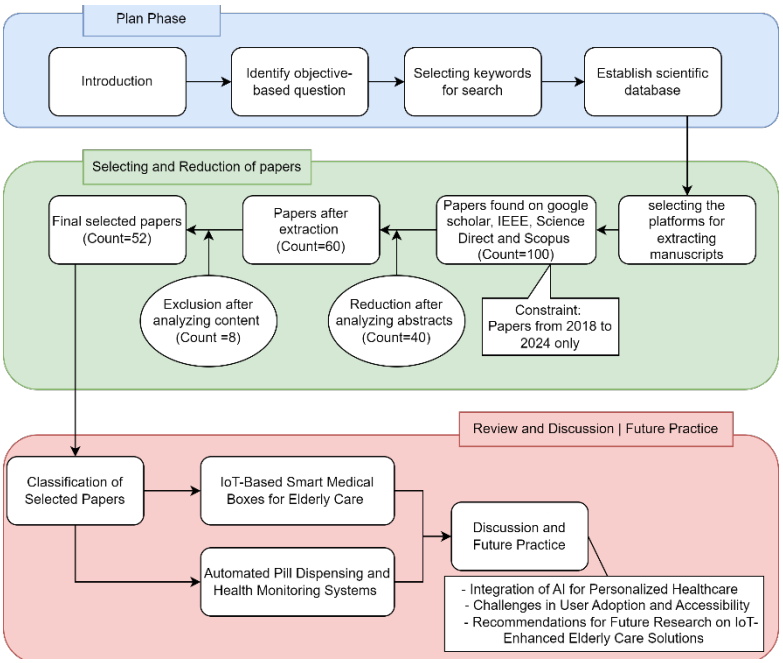

Fig. 1. Overview of the research framework: A visual depiction illustrating the research process, from initial planning through selection criteria, review, and the scope for future work.

4. Automated Pill Dispensing and Health Monitoring System

Automated pill dispensing systems have become essential tools for managing medications and monitoring the health of patients, especially for elderly individuals who may have complex medication regimens. Nasir et al. developed a smart medical box created to offer more than simply dispensing medications according to prescribed schedules but also includes health monitoring features such as tracking vital signs, including temperature, oxygen levels, and heart rate, to ensure continuous health monitoring. The system integrates biometric recognition to ensure medication is dispensed to the correct patient, and users are notified when medication is dispensed, providing an effective solution for elderly care and reducing the risk of medication errors [9]. Ayshwarya and Velmurugan introduced an intelligent medication box designed to organize six different pills and incorporate biosensors for monitoring vital signs such as temperature and heartbeat. The system also provides timely medication reminders via

an Android app, which can be used by caregivers to ensure medication is taken as prescribed. Additionally, this system includes authentication processes to prevent overdosage or improper intake, ensuring both patient and caregiver safety [6]. Talmale et al. developed a low-cost IoT-based pill dispenser that utilizes LEDs and alarms to assist patients in taking the appropriate medication at the proper time., addressing issues like memory loss or confusion with long prescriptions. This simple yet effective system helps patients avoid missing doses or taking the wrong medication, which is common among elderly patients with cognitive difficulties [8]. Ashfaq et al. reviewed technologies that make the Internet of Medical Things (IoMT) possible, highlighting their application in home-based healthcare systems. By integrating IoT and cloud technologies, these systems allow for remote patient monitoring and prediction of critical health conditions using real-time data, improving medication management efficiency and reducing the burden on traditional healthcare systems, thus making healthcare more accessible and personalized [10]. Additionally, Yigit et al. explored combining machine learning (ML) with IoT devices to create smarter healthcare systems. These systems can predict health anomalies, optimize medication schedules, and provide personalized treatment plans based on real-time data, thus enhancing the quality of care for elderly patients and improving their medication adherence [22]. These automated pills dispensing and health monitoring systems ensure accurate medication management while continuously monitoring patient health, offering real-time data for healthcare providers to make informed decisions and enhancing the overall care experience.

5. Technological Approaches

After reviewing the studies, we found that the methodologies from various research on IoT-based smart medicine boxes can be synthesized, with a focus on data collection, sensor integration, user interaction, and system design. These methodologies are commonly categorized as follows:

- **Data Collection and Logging:** IoT-based smart medicine boxes emphasize sensor data logging and integration with mobile applications to enhance medication adherence and environmental monitoring. Studies have implemented systems for tracking parameters such as temperature and humidity to ensure proper medication storage and provide actionable insights for caregivers. For example, [1] introduces a system that collects medication data to assist doctors and monitor market needs, while [2] employs IoT-enabled sensors to automate medication schedules and integrate real-time monitoring through mobile apps.
- **Sensor and Microcontroller Integration:** Effective integration of sensors (e.g., infrared, photoelectric, and biometric) with microcontrollers such as STM32 or Arduino is critical for real-time processing and alert management. Connectivity is achieved using Wi-Fi and Bluetooth Low Energy (BLE) modules, enabling remote monitoring and control. For instance, [2] employs STM32 boards and IR sensors to manage medicine dispensing, while [23] uses LEDs and alarms to guide users in taking the correct medications. These systems demonstrate the importance of reliable connectivity and sensor integration in modern designs.
- User Interaction and Reminder Systems: Reminder systems, implemented through app notifications, LED indicators, and sound alerts, are evaluated for their effectiveness in ensuring medication adherence. Studies

such as [14] highlight the role of user-friendly interfaces, customizable reminders, and real-time alerts in improving patient compliance. Usability assessments further emphasize the significance of accessible designs, particularly for elderly users or patients with cognitive impairments.

- Data Analysis Techniques: The analysis of adherence data is often conducted using statistical tools and visualization techniques, with advanced studies exploring machine learning (ML) to predict user behaviour. [5] describes the application of ML in analysing medication adherence patterns, although challenges such as low-sample scenarios persist. These techniques provide valuable insights into user behaviour and system effectiveness.

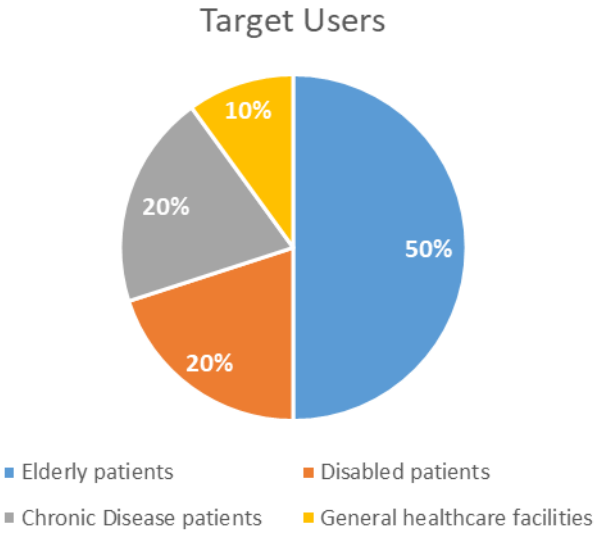

Fig. 2. Illustrates the target users' groups for the smart medication system.

6. Limitation

This review highlights the key limitations in IoT-based smart medicine box studies, focusing on challenges in data accuracy, sensor reliability, user adaptability, and system scalability. By categorizing these constraints, we aim to clarify the main hurdles in current methodologies and suggest areas for improvement in smart medicine technology, which are:

- **User Feedback Bias and Usability Constraints:** Studies often rely on limited or non-representative samples, leading to biases in usability assessments. For example, [4] emphasizes the need for inclusive designs to accommodate elderly individuals with varying levels of digital literacy.
- **Sensor and Connectivity Reliability:** Inconsistent performance of sensors, such as IR and BLE modules, can compromise system functionality. Issues related to ambient lighting, power disruptions, and interference have been noted in studies like [3], underscoring the need for robust sensor designs and improved connectivity protocols.

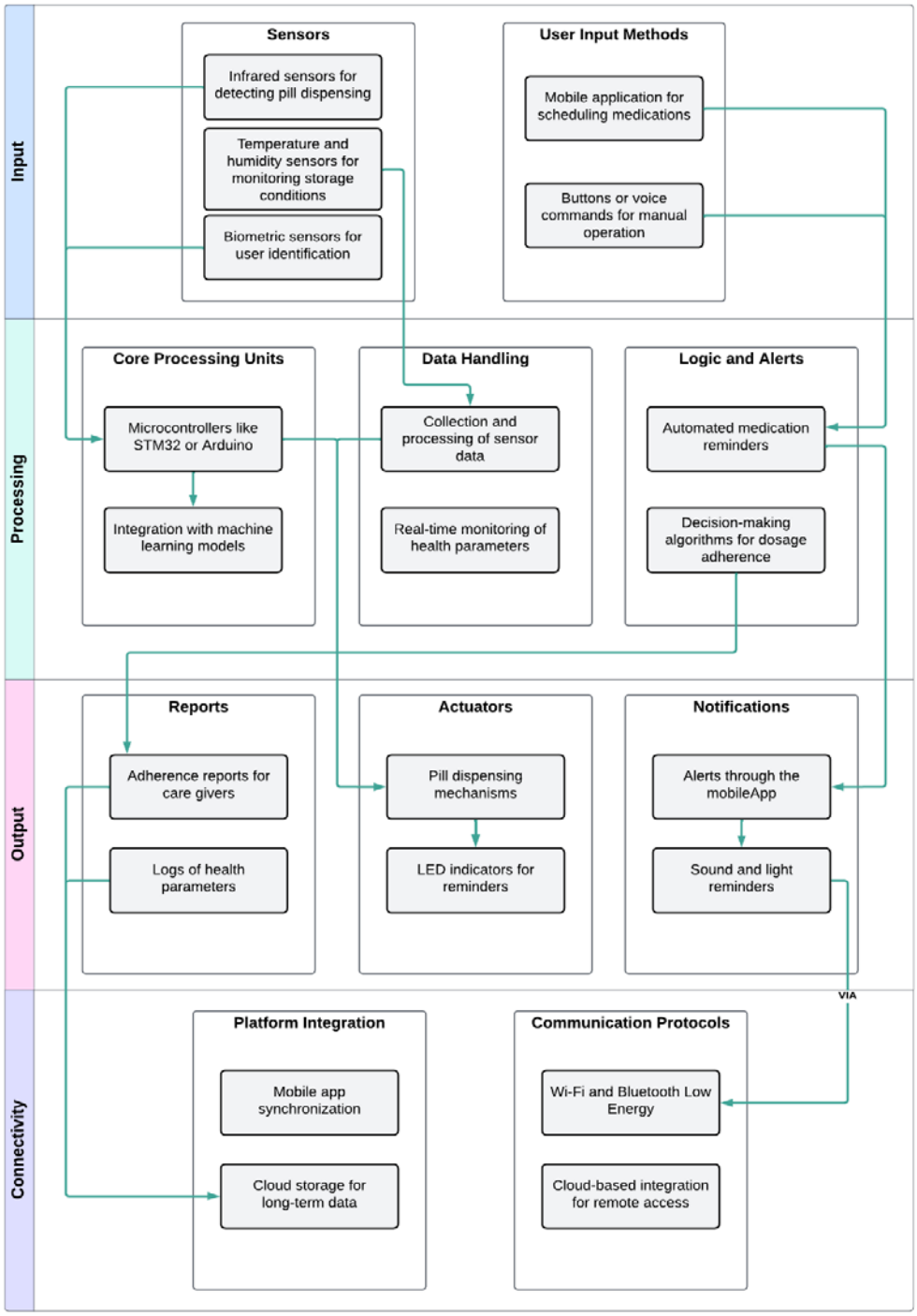

Fig. 3. A general block diagram illustrating the system structure of IoT-based smart medication boxes as synthesized from the literature review.

- **Data Security Concerns:** The protection of sensitive patient data remains a critical challenge. Many studies lack comprehensive mechanisms for encryption, authentication, and access control, leaving systems vulnerable to breaches [2]. Compliance with privacy regulations and the implementation of advanced security protocols are essential for fostering user trust.
- **Complex Data Management:** The synchronization and processing of real-time data from multiple sensors remain significant hurdles.[6] highlights the challenges of managing cloud-based architectures and integrating robust analytics frameworks to ensure system reliability and responsiveness.
- **Scalability and Integration:** Most systems are standalone solutions with limited scalability and compatibility with broader healthcare ecosystems. The lack of interoperability standards, as noted in [14], hinders integration with electronic health records (EHR) and other medical devices.

These limitations underscore the need for interdisciplinary collaboration in addressing technical, usability, and security challenges. Future research should prioritize inclusive design, robust connectivity, enhanced data protection, and seamless integration into existing healthcare infrastructures to improve the reliability and adoption of IoT-based medication adherence systems.

7. Discussion

Future research in IoT-based medication systems should focus on a holistic approach to addressing the existing gaps in design, usability, and scalability. This includes conducting comprehensive longitudinal studies that evaluate the real-world effectiveness of these systems across diverse populations, ensuring insights into long-term adherence, adaptability, and overall impact. Integrating advanced machine learning models can enable predictive analytics to identify potential non-adherence risks, allowing for tailored interventions and more personalized medication management. Additionally, systems must prioritize user-centric designs, incorporating features like voice-assisted interfaces and ergonomic layouts to ensure accessibility for elderly users and those with disabilities or low digital literacy. Security and privacy must be prioritized, incorporating strong encryption, secure authentication methods, and adherence to regulations like HIPAA to protect sensitive health information. Finally, scalability and interoperability must be addressed by developing modular architectures and standardized protocols to facilitate smooth integration with electronic health records and various healthcare systems, promoting widespread adoption and enhancing the overall impact on healthcare. Figure 3 shows a general block diagram illustrating the system structure of IoT-based smart medication boxes as synthesized from the literature review. This diagram outlines the main system components, the functional flow of data, and the key features discussed in the review.

7.1. Improved Adherence and Patient Outcomes

IoT-enabled medication systems demonstrate substantial improvements in medication adherence, particularly among elderly individuals managing complex regimens. By providing timely reminders and limiting access to

medications outside of prescribed times, these systems mitigate the risks of missed or incorrect dosages. Enhanced adherence is essential for effectively managing chronic conditions, minimizing complications, and improving overall health outcomes [1], [2]. Additionally, many systems incorporate health monitoring features, such as temperature, heart rate, and oxygen level sensors, which complement adherence strategies by tracking patient conditions and flagging deviations in health status [6], [14].

7.2. Support for Preventive Care Through Health Monitoring

IoT medication systems include sensors that track essential health metrics such as temperature, pulse, and oxygen saturation. These functionalities allow for the early identification of possible health concerns, enabling timely interventions before conditions deteriorate [3],[4]. Real-time data collection and analysis enable caregivers and healthcare providers to make informed and prompt decisions, transforming healthcare from a reactive model to a preventive one. Such functionality is particularly beneficial for elderly patients and those with chronic illnesses, emphasizing the role of IoT in enabling continuous and effective healthcare monitoring [23].

7.3. Reduction in Caregiver Burden

The automation and remote monitoring capabilities of IoT-enabled medication systems reduce the workload and stress for caregivers. These systems provide automated alerts for missed doses, medication intake updates, and notifications about patient health metrics. By minimizing the need for constant physical supervision, caregivers can focus on other responsibilities while maintaining high standards of care for their dependents [5], [8]. Moreover, some systems incorporate accessibility features like voice prompts and app-based interfaces to ensure ease of use for both patients and caregivers [10], [17].

7.4. Integration of Health Data for Holistic Patient Care

IoT medication systems enable seamless data logging and sharing through cloud-based platforms, promoting a more coordinated approach to healthcare. Data on medication adherence and patient health are accessible to caregivers, patients, and healthcare providers, facilitating adjustments to treatment plans and medication regimens based on real-time adherence trends and health patterns [15],[24] . This integration creates a unified and comprehensive patient health record, improving the quality and continuity of care while supporting data-driven decision-making [25].

7.5. Accessibility and Affordability Challenges

Despite their advantages, widespread adoption of IoT-based medication systems faces barriers related to affordability and accessibility, particularly for underserved populations and regions with limited healthcare infrastructure. While some studies highlight cost-effective prototypes, additional refinements are necessary to make these systems scalable and affordable for low-income users [22],[26]. Furthermore, incorporating user-friendly interfaces tailored to elderly users and individuals with disabilities can enhance usability and inclusivity

[4].

7.6. Privacy and Security Concerns

The sensitive health data collected by IoT-enabled medication systems raise concerns about privacy and security. Many systems lack robust measures for secure data storage, encryption, and user authentication, exposing patients to potential data breaches [27]. Addressing these concerns through improved security protocols is crucial for building user trust and ensuring compliance with healthcare data regulations. Furthermore, given the systems' focus on vulnerable populations, robust security frameworks must be prioritized to safeguard their data [28].

By addressing these challenges, IoT-based medication systems can achieve broader adoption, enhance patient outcomes, and further integrate into comprehensive healthcare strategies.

8. Conclusion

The existing literature highlights the transformative potential of smart medicine boxes in addressing the critical challenge of medication adherence, particularly among elderly individuals and patients with complex therapeutic regimens. These devices leverage IoT-enabled technologies—such as automated reminders, real-time monitoring, and remote caregiver access—to enhance adherence, reduce health risks from missed doses, and alleviate the strain on healthcare systems by minimizing hospital visits and optimizing resource utilization. However, significant challenges persist. Current designs often lack adaptability to meet the needs of diverse user groups, such as individuals with cognitive impairments or disabilities, and are insufficiently integrated with broader healthcare ecosystems. Additionally, the scarcity of longitudinal studies limits a comprehensive understanding of their long-term effectiveness in real-world applications.

To bridge these gaps, future research must prioritize the development of adaptive design features for diverse populations, the integration of predictive analytics to preempt non-adherence risks, and extensive user studies to refine usability and facilitate deployment across varied healthcare settings. This work builds on the methodologies presented in foundational studies [6], [8], and [9] with targeted enhancements to address their limitations. Specifically, we will adopt the methodology and framework outlined in [5] and [6] as a foundation for our work, introducing improvements to achieve better outcomes. Proposed enhancements include implementing advanced IoT protocols to ensure greater precision and reliability in real-time monitoring, applying machine learning algorithms to personalize reminders and optimize adherence strategies, and integrating wearable health monitoring devices for a more holistic, interconnected approach to patient care.

Through the advancement of these innovations, this research seeks to transform medication management, promoting a more inclusive and intelligent solution that improves patient outcomes and contributes to a more efficient healthcare system.

9. References

[1] J. Peng, Y. Jing, and Z. Liu, "Structure Design of Smart Reminder Medicine Box," *J. Phys. Conf. Ser.*, vol. 1802, no. 3, p. 032127, Mar. 2021, doi: 10.1088/1742-6596/1802/3/032127.

[2] "Internet of Things Based Smart Medicine Box for Monitoring Medications. | IEEE Conference Publication | IEEE Xplore." Accessed: Dec. 08, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/10428295

[3] O. Al-Mahmud, K. Khan, R. Roy, and F. Mashuque Alamgir, "Internet of Things (IoT) Based Smart Health Care Medical Box for Elderly People," in *2020 International Conference for Emerging Technology (INCET)*, Jun. 2020, pp. 1–6. doi: 10.1109/INCET49848.2020.9153994.

[4] P. Wadibhasme, A. Amin, P. Choudhary, and P. Saindane, "Saathi—A Smart IoT-Based Pill Reminder for IVF Patients," in *Information and Communication Technology for Intelligent Systems*, T. Senjyu, P. N. Mahalle, T. Perumal, and A. Joshi, Eds., Singapore: Springer Nature, 2021, pp. 697–705. doi: 10.1007/978-981-15-7062-9_70.

[5] M. Śniady and A. Królak, "Smart Pillcase System to Support the Elderly and the Disabled," in *The Latest Developments and Challenges in Biomedical Engineering*, P. Strumiłło, A. Klepaczko, M. Strzelecki, and D. Bociąga, Eds., Cham: Springer Nature Switzerland, 2024, pp. 365–379. doi: 10.1007/978-3-031-38430-1_28.

[6] "Intelligent and Safe Medication Box In Health IoT Platform for Medication Monitoring System with Timely Remainders | IEEE Conference Publication | IEEE Xplore." Accessed: Dec. 08, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9442017

[7] D. Ramesh Reddy, K. Bikash, K. P. Vivek, U. Z. Sadek, and P. Kodali, "Design and Development of an IoT-Based Smart Medication Device," in *Soft Computing for Problem Solving*, A. Tiwari, K. Ahuja, A. Yadav, J. C. Bansal, K. Deep, and A. K. Nagar, Eds., Singapore: Springer, 2021, pp. 77–88. doi: 10.1007/978-981-16-2712-5_7.

[8] R. Talmale, A. Agrawal, A. Khokle, N. Pahade, and P. Khadgi, "Mediminder: IoT Based Smart Medicine Box," vol. 09, no. 04, 2022.

[9] Z. Nasir, A. Asif, M. Nawaz, and M. Ali, "Design of a Smart Medical Box for Automatic Pill Dispensing and Health Monitoring †," *Eng. Proc.*, vol. 32, no. 1, Art. no. 1, 2023, doi: 10.3390/engproc2023032007.

[10] Z. Ashfaq *et al.*, "A review of enabling technologies for Internet of Medical Things (IoMT) Ecosystem," *Ain Shams Eng. J.*, vol. 13, no. 4, p. 101660, Jun. 2022, doi: 10.1016/j.asej.2021.101660.

[11] D. Moher, A. Liberati, J. Tetzlaff, and D. G. Altman, "Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement," *Int. J. Surg.*, vol. 8, no. 5, pp. 336–341, Jan. 2010, doi: 10.1016/j.ijsu.2010.02.007.

[12] A. Chaudhari, R. Mane, P. Madnurkar, R. Lonikar, T. Jain, and D. Limbhore, "IoT Based Portable Medicine Box," in *2024 2nd International Conference on Intelligent Data Communication Technologies and Internet of Things (IDCIoT)*, Jan. 2024, pp. 163–167. doi: 10.1109/IDCIoT59759.2024.10467433.

[13] V. Peddisetti, P. K. Kandregula, J. A. John, S. Poomdla, K. George, and A. Panangadan, "Smart Medication Management: Enhancing Medication Adherence with an IoT-Based Pill Dispenser and Smart Cup," in *2024 IEEE First International Conference on Artificial Intelligence for Medicine, Health and Care (AIMHC)*, Feb. 2024, pp. 137–144. doi: 10.1109/AIMHC59811.2024.00032.

[14] J. Ramkumar, C. Karthikeyan, E. Vamsidhar, and K. N. Dattatraya, "Automated Pill Dispenser Application Based on IoT for Patient Medication," in *IoT and ICT for Healthcare Applications*, N. Gupta and S. Paiva, Eds., Cham: Springer International Publishing, 2020, pp. 231–253. doi: 10.1007/978-3-030-42934-8_13.

[15] A. A. Nancy, D. Ravindran, P. M. D. Raj Vincent, K. Srinivasan, and D. Gutierrez Reina, "IoT-Cloud-Based Smart Healthcare Monitoring System for Heart Disease Prediction via Deep Learning," *Electronics*, vol. 11, no. 15, Art. no. 15, Jan. 2022, doi: 10.3390/electronics11152292.

[16] V. Bhatt and S. Chakraborty, "Real-time healthcare monitoring using smart systems: A step towards healthcare service orchestration Smart systems for futuristic healthcare," in *2021 International Conference on Artificial Intelligence and Smart Systems (ICAIS)*, Mar. 2021, pp. 772–777. doi: 10.1109/ICAIS50930.2021.9396029.

[17] M. Alshamrani, "IoT and artificial intelligence implementations for remote healthcare monitoring systems: A survey," *J. King Saud Univ. - Comput. Inf. Sci.*, vol. 34, no. 8, Part A, pp. 4687–4701, Sep. 2022, doi: 10.1016/j.jksuci.2021.06.005.

[18] B. S. Kumar, S. Dhanasekar, L. N. Kumar, T. Naveenkumar, S. Raghul, and R. R. Celecia, "Integration Of AI and IoT In Medminder and Dosette Box," in *2023 International Conference on Next Generation Electronics (NEleX)*, Dec. 2023, pp. 1–5. doi: 10.1109/NEleX59773.2023.10421271.

[19] D. Agarwal, R. Agarwal, D. K. Choubey, and V. Shukla, "Design and Implementation of IoT-Based Medicine Dispensary Box," in *Microelectronics, Communication Systems, Machine Learning and Internet of Things*, V. Nath and J. K. Mandal, Eds., Singapore: Springer Nature, 2023, pp. 339–351. doi: 10.1007/978-981-19-1906-0_31.

[20] H. Huang *et al.*, "Construction and application of medication reminder system: intelligent generation of universal medication schedule," *BioData Min.*, vol. 17, no. 1, p. 23, Jul. 2024, doi: 10.1186/s13040-024-00376-y.

[21] D. S. Abdul Minaam and M. Abd-ELfattah, "Smart drugs:Improving healthcare using Smart Pill Box for Medicine Reminder and Monitoring System," *Future Comput. Inform. J.*, vol. 3, no. 2, pp. 443–456, Dec. 2018, doi: 10.1016/j.fcij.2018.11.008.

[22] Y. Yigit, K. Duran, N. Moradpoor, L. Maglaras, N. Van Huynh, and B. Canberk, "Machine Learning for Smart Healthcare Management Using IoT," in *IoT and ML for Information Management: A Smart Healthcare Perspective*, S. Namasudra, Ed., Singapore: Springer Nature, 2024, pp. 135–166. doi: 10.1007/978-981-97-5624-7_4.

[23] K. Balamurugan, J. A. A., V. B., R. V. S. K., and S. S. N, "Design of an Intelligent and Smart Pill Box Using Arduino and Sensors," in *2023 4th International Conference on Smart Electronics and Communication (ICOSEC)*, Sep. 2023, pp. 258–263. doi: 10.1109/ICOSEC58147.2023.10276212.

[24] H. ZEIDAN, K. KARAM, R. A. Z. DAOU, A. HAYEK, and J. BOERCSOEK, "Smart Medicine Box System," in *2018 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET)*, Nov. 2018, pp. 1–5. doi: 10.1109/IMCET.2018.8603031.

[25] "Smart Healthcare in the Age of AI: Recent Advances, Challenges, and Future Prospects | IEEE Journals & Magazine | IEEE Xplore." Accessed: Dec. 08, 2024. [Online]. Available: https://ieeexplore.ieee.org/abstract/document/9565155

[26] P. A. Harsha Vardhini, M. S. Harsha, P. N. Sai, and P. Srikanth, "IoT based Smart Medicine Assistive System for Memory Impairment Patient," in *2020 12th International Conference on Computational Intelligence and Communication Networks (CICN)*, Sep. 2020, pp. 182–186. doi: 10.1109/CICN49253.2020.9242562.

[27] "An IoT-Based Health Care Solution: A Smart Medical Box | Proceedings of the 2023 4th Asia Service Sciences and Software Engineering Conference." Accessed: Dec. 08, 2024. [Online]. Available: https://dl.acm.org/doi/abs/10.1145/3634814.3634844

[28] "Real-Time Remote Health Monitoring System Driven by 5G MEC-IoT." Accessed: Dec. 08, 2024. [Online]. Available: https://www.mdpi.com/2079-9292/9/11/1753

[29] R. Achammal.S *et al.*, "Development of Smart Automatic Drug Dispenser for Elderly and Disabled People," in *2024 International Conference on Science Technology Engineering and Management (ICSTEM)*, Apr. 2024, pp. 1–5. doi: 10.1109/ICSTEM61137.2024.10560887.

[30] "Smart Pill Dispensers and IoT: Advancements in Medication Administration | IEEE Conference Publication | IEEE Xplore." Accessed: Dec. 08, 2024. [Online]. Available: https://ieeexplore.ieee.org/document/10481624

[31] T. S, T. S. Reddy, Dhanush, T. Krithin, and J. J. J. Kumari, "A Smart Pill Container for Improved Medication," in *2024 5th International Conference on Electronics and Sustainable Communication Systems (ICESC)*, Aug. 2024, pp. 1623–1630. doi: 10.1109/ICESC60852.2024.10689822.

[32] "Design of a Smart Medical Box for Automatic Pill Dispensing and Health Monitoring †" Accessed: Dec. 08, 2024. [Online]. Available: https://www.mdpi.com/2673-4591/32/1/7

[33] A. J. Al-Haider, S. M. Al-Sharshani, H. S. Al-Sheraim, N. Subramanian, S. Al-Maadeed, and M. zied Chaari, "Smart Medicine Planner for Visually Impaired People," in *2020 IEEE International Conference on Informatics, IoT, and Enabling Technologies (ICIoT)*, Feb. 2020, pp. 361–366. doi: 10.1109/ICIoT48696.2020.9089536.

[34] W. A. K. Ahmad, S. Suneel, L. Nanthini, S. S. Srivastava, M. S. Veerraju, and T. T. Moharekar, "IoT based Novel Design of Intelligent Healthcare Monitoring System with Internet of Things and Smart Sensors," in *2024 3rd International Conference on Applied Artificial Intelligence and Computing (ICAAIC)*, Jun. 2024, pp. 1595–1602. doi: 10.1109/ICAAIC60222.2024.10574986.

[35] G. R, M. V, V. M. P, M. R, and M. K M, "Smart Medicine Box Using IOT," in *2023 7th International Conference on Design Innovation for 3 Cs Compute Communicate Control (ICDI3C)*, Nov. 2023, pp. 429–432. doi: 10.1109/ICDI3C61568.2023.00090.

[36] T. A. Prasath, B. Nani Gopala Krishna, S. A. Kumar, G. Karthick, G. Vishnuvarthanan, and S. Sakthivel, "A Smart Medicine Box for Medication Management Using IoT," in *2021 3rd International Conference on Advances in Computing, Communication Control and Networking (ICAC3N)*, Dec. 2021, pp. 647–650. doi: 10.1109/ICAC3N53548.2021.9725727.

[37] J. Poongodi, S. Sathish, and K. Kavitha, "SMB: An Smart Featured Medicine Box for Patient Monitoring," in *2021 International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA)*, Oct. 2021, pp. 1–5. doi: 10.1109/ICAECA52838.2021.9675519.

[38] H. Daoud, M. Daoud, N. Jardak, and C. Albouzidi, "Design and Implementation of Smart Pill Box for Healthcare Applications," in *2023 20th International Multi-Conference on Systems, Signals & Devices (SSD)*, Feb. 2023, pp. 1046–1050. doi: 10.1109/SSD58187.2023.10411150.

[39] A. Rejeb *et al.*, "The Internet of Things (IoT) in healthcare: Taking stock and moving forward," *Internet Things*, vol. 22, p. 100721, Jul. 2023, doi: 10.1016/j.iot.2023.100721.

[40] M. Sarjare, P. Ghutke, and R. Ghosh, "Development of Smart Medicine Box using IoT Environment," in *2023 11th International Conference on Emerging Trends in Engineering & Technology - Signal and Information Processing (ICETET - SIP)*, Apr. 2023, pp. 1–5. doi: 10.1109/ICETET-SIP58143.2023.10151505.

[41] B. Chen, Y. Ma, and J.-L. Xu, "Research and Implementation of an Intelligent Medicine Box," in *2019 4th International Conference on Intelligent Green Building and Smart Grid (IGBSG)*, Sep. 2019, pp. 203–205. doi: 10.1109/IGBSG.2019.8886274.

[42] V. Gaikwad, S. Chakrabarty, S. Jain, S. Bhat, and S. Bisen, "IOT Based Medicine Box: A Step Towards An Easier Life," in *2024 Second International Conference on Advances in Information Technology (ICAIT)*, Jul. 2024, pp. 1–6. doi: 10.1109/ICAIT61638.2024.10690350.

[43] H. Susilawati, A. F. Ikhsan, Y. Y. Prasetia, R. M. Fadilla, T. Yusuf, and N. Ismail, "Smart Medication Box Based on Android Mobile Application," in *2022 8th International Conference on Wireless and Telematics (ICWT)*, Jul. 2022, pp. 1–4. doi: 10.1109/ICWT55831.2022.9935419.

[44] D. Karagiannis and K. S. Nikita, "Design and development of a 3D Printed IoT portable Pillbox for continuous medication adherence," in *2020 IEEE International Conference on Smart Internet of Things (SmartIoT)*, Aug. 2020, pp. 352–353. doi: 10.1109/SmartIoT49966.2020.00066.

[45] C. Yang, Z. Li, and J. Qiao, "Household Intelligent Medicine Box Based on STM32," in *2022 International Conference on Intelligent Transportation, Big Data & Smart City (ICITBS)*, Mar. 2022, pp. 805–808. doi: 10.1109/ICITBS55627.2022.00177.

[46] R. Kiruba, M. Saranya, K. Srinivasan, V. Radhika, P. R. Suraaj, and V. Sneha, "Design and Implementation of Internet of Things - Based Smart Medicine Box for Patients," in *2023 Third International Conference on Ubiquitous Computing and Intelligent Information Systems (ICUIS)*, Sep. 2023, pp. 36–41. doi: 10.1109/ICUIS60567.2023.00014.

[47] L. Rani. D, Bharathi. M, Manohara. M, H. D. Praveena, and P. Geetha, "A Smart Medication Box with Regular Medications and In-Time Refilling," in *2023 2nd International Conference on Edge Computing and Applications (ICECAA)*, Jul. 2023, pp. 1066–1070. doi: 10.1109/ICECAA58104.2023.10212210.

[48] M. Athish, E. Solomon, R. Indumathi, T. Manoj Prasath, and R. Vinodhini, "Online Doctor Consultation and Automatic Medicine Dispensers in Primary Health Care Centres Using Machine Learning," in *2024 International Conference on Advances in Data Engineering and Intelligent Computing Systems (ADICS)*, Apr. 2024, pp. 1–5. doi: 10.1109/ADICS58448.2024.10533555.

[49] D. Meng, W. Shi, X. Fang, and B. Zhang, "Design of a novel low temperature intelligent medicine box with Internet control," in *2022 4th International Conference on Intelligent Control, Measurement and Signal Processing (ICMSP)*, Jul. 2022, pp. 595–598. doi: 10.1109/ICMSP55950.2022.9859036.

[50] A. K. S, N. V, P. S, S. P, and R. R, "AI Health – IoT based Smart Medicine Box," in *2023 2nd International Conference on Advancements in Electrical, Electronics, Communication, Computing and Automation (ICAECA)*, Jun. 2023, pp. 1–5. doi: 10.1109/ICAECA56562.2023.10200103.

[51] R. Al-Shammary, D. Mousa, and S. E. Esmaeili, "The Design of a Smart Medicine Box," in *Iranian Conference on Electrical Engineering (ICEE)*, May 2018, pp. 130–134. doi: 10.1109/ICEE.2018.8472586.

[52] A. I. Siam, A. Abou Elazm, N. A. El-Bahnasawy, G. El Banby, and F. E. Abd El-Samie, "Smart Health Monitoring System based on IoT and Cloud Computing," *Menoufia J. Electron. Eng. Res.*, vol. 28, no. ICEEM2019-Special Issue, pp. 37–42, Dec. 2019, doi: 10.21608/mjeer.2019.76711.