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Implementation of IoT-Based Technology on Patient Medication Adherence: A Comprehensive Bibliometric and Systematic Review

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ABSTRACT

The integration of the Internet of Things (IoT) into various sectors offers promising advancements, especially within healthcare. This transformation in healthcare management aligns with the shift towards more personalised, proactive, and cost-effective treatment methodologies. This review systematically evaluated the existing literature, coupled with a comprehensive bibliometric analysis, to identify potential research avenues and domains for further investigation concerning the IoT's role in patient medication adherence (PMA). A systematic search was conducted across multiple databases, employing stringent criteria to select relevant studies. From an initial pool of 314 articles focused on the IoT's integration into pharmaceutical care, 33 were critically analysed for their contributions to the understanding of PMA. The analysis displayed an upward trend in publication volume over recent years. From the 33 shortlisted articles, robust evidence was found of the IoT's efficacy in enhancing PMA, especially among elderly patients with chronic ailments. The findings were predominantly associated with IoT-based systems that allow real-time monitoring, reminders, and personalised feedback. However, each system had its distinct advantages and associated limitations. The results underscore the pivotal role of PMA in healthcare, suggesting that it should be at the forefront of medical discussions. The demonstrable benefits of the IoT in improving PMA indicate its potential as a cornerstone in future healthcare solutions, especially for populations at higher risk of medication non-adherence. However, the highlighted limitations of current IoT systems represent the necessity of ongoing research. This is crucial not only to address these constraints but to validate the long-term viability and effectiveness of IoT applications in ensuring optimal patient outcomes. In conclusion, while the IoT presents a paradigm shift in healthcare, especially concerning PMA, its full potential can only be harnessed through rigorous research and innovation aimed at overcoming its present limitations.

Keywords: Internet of Things, IoT, patient medication adherence, PMA, sensors, pharmaceutical care services, patient outcomes.

INTRODUCTION

The notion of the Internet of Things (IoT) technology, a revolutionary vision, was first introduced in 1999, expressing a pioneering goal of seamlessly connecting the physical world into an all-encompassing information network (Ashton, 2009). Despite a wide range of interpretations supplied by researchers and business professionals, there is agreement on the fundamental goal of the technology. It is usually considered a system that efficiently mediates communication and data interchange between tangible items and virtual analogues. A foundational study expanded the IoT's definition to expand on this core idea. According to this study (Lynn et al., 2020), the IoT is a complex network infrastructure that allows the bidirectional transfer of information, comprising both the receipt and dispatch of data from physical entities or devices via the internet. Initially, the technology that enabled this ground-breaking interconnection heavily relied on radio-frequency identification or RFID tags. However, the evolution and integration of various complementary technologies have significantly increased the effectiveness. This set of auxiliary technologies includes, but is not limited to, sensor networks, machine learning techniques, artificial intelligence (AI), and cloud computing. These improvements drastically increased the potency and usability of IoT across multiple sectors and businesses (Gubbi et al., 2013; Madakam et al., 2015). Today, the revolutionary influence of these combined technological breakthroughs attests to the IoT framework's continual evolution and adaptability (Akash et al., 2022).

In this age of widespread interconnection, digital networks can chronicle and monitor and manage the interaction of associated entities, paving the way for a better and much more comfortable lifestyle (Mohamed et al., 2020). The IoT technology sector has grown rapidly, presenting many possible applications ranging from smart homes and intelligent cities to efficient transportation systems (Nord et al., 2019). Notably, the healthcare industry is a particularly prospective beneficiary of advances in this technology. Given the evident trend towards more personalised, anticipatory, and cost-effective healthcare paradigms, it makes sense. The IoT can play a critical role in health management systems. When considering the potential of the IoT in supporting personalised treatment planning, enhancing disease prediction and prevention, and optimising resource allocation in the healthcare sector, it becomes clear (Kashani et al., 2021; Kelly et al., 2020). As a result, acceptance and integration of this technology in the healthcare industry is potentially revolutionary, implying a future in which technology is more deeply woven into healthcare service delivery.

The IoT has emerged as a powerful tool for transforming healthcare delivery, reducing costs, and improving the patient experience. It has significantly reduced healthcare expenditures and patient wait times by promoting precise data collecting and supporting workflow automation. It has significantly improved disease management and therapy administration, reducing the likelihood of errors (Albahri et al., 2021; Dwivedi et al., 2022; Javaid & Khan, 2021). A recent thorough mapping research identified neurology, cardiology, and psychiatry or psychology as the domains with the highest prevalence of IoT adoption in healthcare. This adoption trend highlights IoT's potential to support improvements in various disciplines (Ghozali, 2022). In the time of the COVID-19 pandemic, the infection's emergence highlighted the critical importance of IoT in the healthcare sector. Its applications vary, but they range from patient care and data preservation to monitoring patient conditions and ensuring drug adherence, among other things (Chamola et al., 2020; Javaid & Khan, 2021; Otoom et al., 2020; Poongodi et al., 2023; Singh et al., 2020). The adaptability of IoT applications highlights their broad potential for improving healthcare operations and their critical role in influencing the future of healthcare delivery.

Despite the ubiquitous and successful integration of IoT technology across various healthcare sectors, a significant gap in its application within pharmaceutical care services is evident. A slew of studies has begun to explore the possible implications of this technology in improving production efficiency and operational effectiveness in the pharmaceutical care business (Ahmadi et al., 2020; Bader et al., 2023; Mishra et al., 2020; Sharma et al., 2020; Singh et al., 2020). However, this corpus of material needs to be examined concentrating directly on the implications of IoT technology for patient outcomes or medication adherence within the pharmaceutical care spectrum. Addressing this research gap is critical since incorporating IoT devices in these specific circumstances potentially heralds a major improvement in patient outcomes. Furthermore, it can reduce healthcare costs by improving the safety and efficacy of the treatment process. Pursuing this underutilised research route may provide insights that have the potential to transform the landscape of pharmaceutical care while contributing to a more efficient, effective, and patient-centred healthcare system.

PMA is traditionally defined as the consistency with which patients follow the directives and medication protocols prescribed by healthcare professionals (Vrijens et al., 2012). This topic is particularly relevant and concerning when considering demographics such as the elderly or people suffering from chronic medical ailments. Using the World Health Organisation's extensive statistics, it becomes obvious that this problem is widespread, just 50 per cent of persons in the aforementioned susceptible categories adhering to their prescription procedures (Lam & Fresco, 2015). This concerning trend is emphasized further by specific disease occurrences. For example, a previous study found that only 62–64 per cent of those with type 2 diabetes adhere to the recommended insulin dosage (Cramer, 2004). Furthermore, a study concentrating on pharmaceutical non-adherence among patients diagnosed with resistant hypertension found evidence of a pooled non-adherence rate ranging from 27 per cent to 47 per cent, with an average of 37 per cent (Bourque et al., 2023). The consequences of medication non-adherence are profound and significant, potential effects including an increased risk of mortality and a significant increase in healthcare-related expenses (Kleinsinger, 2018). Given these realities, the need to build a deeper understanding of medication adherence and develop ways to support higher compliance cannot be emphasised too much. In turn, it will lead to better patient outcomes and more cost-effective healthcare systems.

The importance of improving medication adherence is becoming increasingly clear, necessitating collaborative efforts to develop and execute numerous techniques to accomplish this goal (Nieuwlaat et al., 2014; Unni & Bae, 2022). Among the numerous options, the application of ground-breaking advances in IoT technology has tremendous potential. A growing body of research supports the effectiveness of IoT-enabled devices and technological solutions in improving medication adherence among patients (Faisal et al., 2021; Orcioni et al., 2021; Pawar et al., 2021; Rane et al., 2023; Sahu et al., 2023). These IoT solutions include various tools, ranging from intelligent pillboxes and wearable technology to mobile health apps, all geared to meet the diverse needs of the patient population. Furthermore, empirical evidence suggests that adopting such IoT technology significantly increases medication adherence, particularly among patients with chronic health conditions (Aldeer et al., 2022; Awotunde et al., 2021; Ghozali, 2023). This meeting of healthcare and technology, utilising IoT as a conduit, is revolutionising patient care and ushering in a new era of medication administration.

Despite the growing interest in this topic, the available literature needs to be more cohesive and organised. Therefore, a systematic review and bibliometric analysis of the literature is critical to identify existing research gaps and prospective areas for future research. This study aims to provide critical insights into the potential of IoT technology to improve medication adherence and outcomes. The systematic literature review addresses the following research questions: (1) What current trends and characteristics describe the IoT research in the context of enhancing medication adherence? (2) Which IoT devices and technologies are most commonly utilised in medication adherence research? (3) What are the important factors determining the efficacy of an IoT technology-based intervention in improving medication adherence?

METHODS

During the first phase, systematic mapping research was carried out using the approach proposed by Petersen et al. (2008). Defining the research objectives, finding prospective sources, selecting relevant resources, extracting relevant data, and undertaking a comprehensive mapping process were all part of this methodology. Subsequently, a systematic literature review was conducted using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) standards (Moher et al., 2015).

Study Question

1) Bibliometrics

The bibliometric questions of this study were: (a) What are the research outputs on the utilisation of the IoT in pharmaceutical care services, including patient adherence monitoring? (b) How has this research subject progressed over the period 2010–2023 in terms of publication outputs, citation records, and country authorship? and (c) What thematic areas (domains) within the pharmaceutical care services have been investigated the most?

2) Literature Review

Regarding the literature review, the questions were as follows: What is the current status of the literature on using IoT technology to enhance patient outcomes regarding medication adherence? (b) What are the various kinds of IoT-enabled devices and technologies that have been employed to improve medication adherence? (c) What are the advantages and drawbacks of utilising IoT technology in the pharmaceutical care services to improve PMA? and (d) What are the gaps in the present literature, and what are the areas for future research?

Study Search

In order to optimise the search results, an investigation was undertaken on two prominent digital databases, Scopus and PubMed. The databases were chosen based on their academic reputation and the breadth of subjects they cover. As shown in Table 1, the search methodology comprised the strategic use of medical subject headings

(MeSH) and keywords related to medication adherence, the IoT, and the pharmaceutical care services.

Table 1

Study Search: Database, Strategies, and Articles Retrieved from Each Database

Database	*Search Strategy*	*Result*
Scopus	*(TITLE-ABS-KEY (“Internet of Things” OR “IoT”) AND TITLE-ABS-KEY (“Medic* adherence” OR “Medication compliance” OR “Medication management” OR “Drug* therapy management” OR “Drug monitor*” OR “Prescript* monitoring” OR “Prescription refill” OR “Prescription adherence” OR “Prescription compliance” OR “Patient* medic*” OR “Pharmac*” OR “Medication couns*” OR “Medication education” OR “Self-medication*” OR “Prescription track*” OR “Medication dos*” OR “Drug regimen management” OR “Drug intake tracking” OR “Drug dispens*” OR “Drug administration” OR “Drug stor*” OR “Medication scheduling”*	*886*
PubMed	*(Internet of Things [Title/Abstract] OR IoT [Title/Abstract]) AND (Medic* adherence [Title/Abstract] OR Medication compliance [Title/Abstract] OR Medication management [Title/Abstract] OR Drug* therapy management [Title/Abstract] OR Drug monitor* [Title/Abstract] OR Prescript* monitoring [Title/Abstract] OR Prescription refill [Title/Abstract] OR Prescription adherence [Title/Abstract] OR Prescription compliance [Title/Abstract] OR Patient* medic* [Title/Abstract] OR Pharmac* care [Title/Abstract] OR Medication counselling* [Title/Abstract] OR Medication education [Title/Abstract] OR Self-medication* [Title/Abstract] OR Prescription tracking* [Title/Abstract] OR Medication dos* [Title/Abstract] OR Drug regimen management [Title/Abstract] OR Drug intake tracking [Title/Abstract] OR Drug dispens* [Title/Abstract] OR Drug administration [Title/Abstract] OR Drug stor* [Title/Abstract] OR Medication scheduling [Title/Abstract])*	*90*

Study Eligibility

1) Inclusion Criteria

The inclusion criteria of this review were: (a) articles related to the implementation and deployment of IoT in medicine adherence improvement; (b) articles discussing medication adherence monitoring technologies; (c) articles from journals, conference papers and proceedings; and (d) articles written in English.

2) Exclusion Criteria

Meanwhile, the exclusion criteria included: (a) articles focused on sensor issues and energy saving in IoT systems; (b) articles related to nursing, nutrition, fall detection, ambient assisted living, drugs, and emergency care; (c) articles discussing intervention application; (d) articles classified as editorials, book reviews, white papers, or newspaper reports; and (e) articles for which the full texts were not available.

Study Selection and Inclusion

The results of a comprehensive keyword search across several scientific digital repositories were methodically incorporated into Mendeley reference management software to ensure efficient and effective organisation. Following the execution of the required queries, a meticulous culling of duplicate entries occurred, acquiring 860 distinct articles. This collection was then subjected to an even more stringent screening procedure divided into two distinct stages. A detailed review of the titles, abstracts, and keywords relevant to the prospective primary documents was conducted first. The rigorous screening process yielded a refined set of 314 articles, which included a wide range of literature such as conference papers, journal publications, book chapters, symposium documents, and other scholarly texts relevant to the input search terms. Notably, the search parameters covered digital repositories from 2000 to 2023, ensuring a wide range of potential sources. As a result, the application of eligibility criteria was used in the second selection round. During this step, the corpus of research was rigorously reviewed to identify relevant papers while removing those deemed discordant or irrelevant to the research objective. Only the most relevant and reliable articles were retained, strengthening the foundation for the subsequent analysis and synthesis stages.

Given the substantial volume of research on the uses of the IoT in the healthcare sector, particularly in the sphere of pharmaceutical care, this study purposely confined its scope to focus solely on PMA. As a result, a plethora of research articles relevant to the application of IoT in pharmaceutical drug discovery, production, and supply chain management were excluded from the scope of this study. Initially, 314 scientific papers were found, each of which was subjected to a rigorous preliminary examination utilising the title and abstract screening process. Following this initial stage of evaluation, all scholarly works were examined further using bibliometric analysis, a method that helped identify discernible patterns, evolutionary trajectories, and emergent topics within the realm of IoT application in pharmaceutical care. The full-text review stage entailed a thorough and meticulous study of each paper—a stated set of inclusion criteria in this procedure. As a consequence of this thorough examination, a collection of 33 articles (Table 2) was created, encompassing both journal publications and conference papers or proceedings that effectively addressed the implementation of IoT in PMA. This collection of scholarly contributions served as the framework for the final systematic review, depicted visually in Figure 1.

Table 2

Characteristics of the Included Studies

Authors	IoT category	Technology used	Task
Roh et al. (2021)	Vision systems	OpenPose	Medication behaviour monitoring system for stable patient monitoring.
Yang et al. (2014)	Combinations	iMedBox, iMedPack, Bio-Patch	In-home healthcare services based on IoT with improved user experience and service efficiency.
Fozoonmayeh et al. (2020)	Sensor systems	Android smartwatch	Smart watch application and cloud-based distributed data storage and processing pipeline for monitoring medication intake.
Challa et al. (2020)	Proximity Sensing	RFID (Arduino UNO and NODEMCU)	Monitor the patient's medication.

(continued)

Authors	IoT category	Technology used	Task
Sohn et al. (2015)	Sensor systems	Pill bottle	Sense the change of medicine bottle.
Roumaissa and Rachid (2022)	Sensor systems, proximity sensing, vision systems	Smart pill dispenser (mobile application)	Medication management for aged individuals.
Karagiannis and Nikita (2020)	Sensor systems	Portable pillbox	Improve patients' adherence during indoor and outdoor activities.
Karagiannis et al. (2022)	Sensor systems, vision systems	3D printed pillbox	Improve medication adherence and detect dangerous interactions with treatment medicines.
Behl et al. (2022)	Sensor systems, proximity sensing	Smart metered-dose inhalers (+ mobile app)	Developed in order to improve lung diseases like asthma and COPD and to improve the efficiency of the prescribed media.
Toh et al. (2016)	Sensor systems	Medication boxes	Monitor medication adherence and detect changes in medication consumption patterns among the elderly.
Kinthada et al. (2017)	Sensor systems	Automated pill dispenser (eMedicare)	Implementation of eMedicare for those who take medications without continuous professional supervision.
Bharadwaj et al. (2017)	Sensor systems	m-Care Box (mobile app)	Assistive device development for people to follow the medicine course properly and give them a good healing experience.
Ishak et al. (2018)	Proximity sensing, sensor systems	Smart medicine cabinet	Medication adherence monitoring for the elderly.
Srinivas et al. (2018)	Proximity sensing, sensor systems	Home-based medicine box (magnetic reed switches)	Medicine box with different compartments, wirelessly connected to the hospital administration.

(continued)

Authors	IoT category	Technology used	Task
Pang et al. (2014)	Proximity sensing, sensor systems	I2Pak, iMedBox	Preventive medication management (real-time reminding, recording, prevention of medication activity, on-site diagnosis and prognosis of vital parameters, and emergency support to users).
Parra et al. (2017)	Proximity sensing, sensor systems	The Intelligent PillBox (Arduino Mega 2560)	Organisation of several medication schedules needed by health disorders presented in the elderly need.
Kumar and Rani Nelakuditi (2019)	Proximity sensing, sensor systems	I2C Protocol (NodeMCU and Blynk app)	Medication assistive system proposed and developed to facilitate medication adherence.
Sherif et al. (2020)	Sensor systems and proximity sensing	LoRa wireless communication technology	Improve medication adherence for elderly patients.
Ma et al. (2018)	Sensor systems	Smartwatch	Medication adherence monitoring system to collect a patient's motion data using an Android smartwatch during medication intake.
Payne et al. (2020)	Sensor systems and proximity sensing	Bottle sleeve	Intelligent sleeve capable of detecting eye drop use, measuring fluid level, and sending use information to a healthcare team to facilitate intervention.
Fathillah and Chellappan (2022)	Sensor systems	Mobile application	Real-time medication monitoring through a multi-sensor alert option in medicinal compartment to ensure adherence integrity.
Silpa et al. (2022)	Sensor systems	Mobile app (medication alarm)	Medication alarm.

(continued)

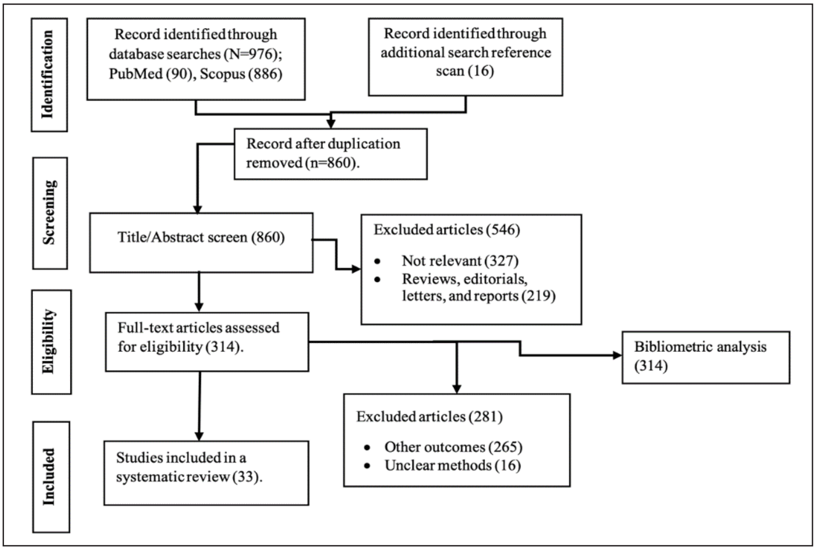
Authors	IoT category	Technology used	Task
Serdaroglu et al. (2015)	Vision systems, sensor systems, and proximity sensing	Watch, mobile app, web server (real time continuous activity recognition)	Medication intake with real-time continuous activity recognition.
So et al. (2021)	Sensor systems	Electronic medication profiles, automated packaging, and electronic records of medication administration	Impact of the medication management programme on medication management efficiency, medication safety, and drug waste in old age home (OAH)s.
Boonnuddar and Wuttidittachotti (2017)	Combinations	A smart pill box (+ mobile application)	Medicine in-take schedules using Android smartphone and Arduino board and load cell sensor to track patient's medication.
Aldeer et al. (2018)	Fusion-based systems	PillSense (medicine bottle)	Medication intake compliance monitoring.
Gu et al. (2020)	Combinations	Smart sharps bin	Medication adherence prediction using machine learning.
Jha and Bhandari (2021)	Sensor systems	Automated medication box	Monitoring and provoking patients.
Chavez et al. (2020)	Sensor systems	Smart pill dispenser	Improve medical adherence in geriatric patients.
Aguilar-Rivera et al. (2020)	Sensor systems	Smart eyedrop system	Eyedrop bottle prototype that can transmit data wirelessly.
Meshram et al. (2022)	Vision systems	Smart medical box (QR code scanning)	Design and development for visually impaired people.
Tan et al. (2018)	Sensor systems	Sensor-based medication boxes	Monitor medication consumption and track adherence.
Silva et al. (2016)	Combinations	Smart environments (UbMed)	Ubiquitous system for monitoring medication adherence.

Data Extraction and Synthesis

To shed light on the increasing patterns and emerging topics within the domain of IoT when incorporated into pharmaceutical care services, a comprehensive bibliometric study was performed first, followed by a precise and complete screening and data extraction process. VOSviewer software, version 1.6.19, facilitated this multidimensional investigation. This strong tool was critical in building extensive cross-national collaboration networks, finding the co-occurrence of crucial keywords, and designating theme regions from an initial collection of 314 articles discovered during the preliminary screening phase. Following that, a second, more stringent screening phase was implemented. As a consequence of the second screening, 33 highly relevant scholarly papers were identified and chosen for inclusion in the systematic review. From these carefully selected articles, detailed information on the adoption of IoT technologies and their subsequent influence on PMA was rigorously gathered, laying the groundwork for a thorough investigation. Collecting and synthesising these precise insights enabled us to develop a solid grasp of the dynamics at work, adding to the existing body of knowledge in this interdisciplinary field of study.

Figure 1

Study Identification, Screening, Selection and Inclusion Flow Diagram



The data extraction and synthesis of this study summarised the information obtained, including each study's title, authorship, year of publication, journal or publication, the IoT technology used, categorization of the IoT system, its intended purpose or function, and an exhaustive summary. The collected data were then classified into separate categories based on the application of the IoT in PMA and the relevant IoT-based systems for PMA investigated in this study. This study focuses on the impact of IoT technologies in medication adherence monitoring systems, which serve as indirect approaches for measuring PMA. As a result, evaluation of the PMA was purposely deleted from the subsequent study, owing to its majority location outside the domain of psychological and social sciences (Aldeer et al., 2022). It is worth noting that most of the IoT technologies mentioned in the selected research are efficient. However, no gold-standard measurement system currently meets the requirements for optimal monitoring (Aldeer et al., 2022; Stegemann et al., 2012).

RESULTS

Bibliometrics

The bibliometric analysis conducted within this exhaustive literature review provides invaluable insights into the emerging trends and evolution of IoT research in pharmaceutical care services. There is clear evidence of a significant increase in related publications in recent years. Figure 2 depicts a significant increase in research endeavours over specific years, especially in 2020, 2021 and 2022, resulting in 480 total publications. A thorough evaluation of the annual publication count reveals that there were 123 publications in 2020, 170 in 2021, and 187 in 2022, indicating a positive growth trajectory. The total number of annual citations displays a more volatile pattern. Notably, the number of citations peaked in 2021 and 2022, with 1,961 citations in 2021 and 2,781 in 2022. These numbers demonstrate the intense academic interest and debate sparked by research publications during these years. The data in Figure 2 provide a more nuanced comprehension of the normalised citation count. This indicator provides a balanced perspective on the impact of research regardless of the number of works published. The years with the highest normalised citation count were 2021 and 2022, with indices of 1,693 and 2,399, respectively. These numbers attest to the substantial influence and significance of the scholarly contributions made during these years, adding another dimension to our understanding of the evolution and significance of IoT research in pharmaceutical care services.

Figure 2

Number of Publications and Total/Normalised Citations Pertaining to the IoT in Pharmacy

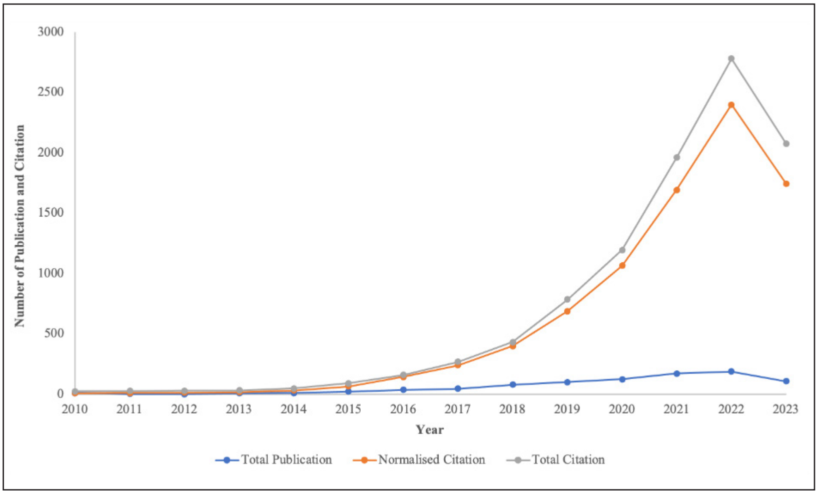
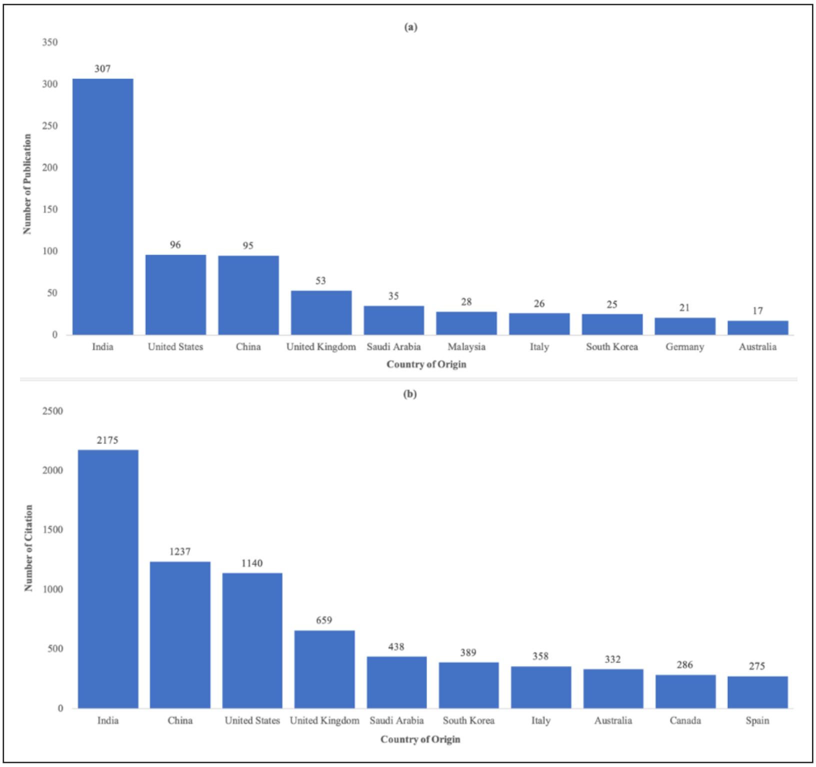


Figure 3 provides a comprehensive overview of publication and citation counts across various nations, thereby identifying the major contributors to this scientific field. It is noted that India is the most prolific country, with an impressive 296 publications. This is followed by the United States with 92 publications, and China with 91 publications. Additionally, an analysis of citation counts places India first, with 2,029 citations. China (1,158 citations) and the United States (1,094 citations) are the next competitors in this category. As expected, an in-depth analysis of the scholarly collaborations between these prominent nations in this research domain reveals intriguing dynamics. Notably, India emerges as the nation with the most extensive co-authorship collaboration network, as Figure 4 demonstrates. This intricate network exemplifies the collaborative spirit that pervades India's academic community, highlighting the country's significant contributions to this field of study.

Figure 3

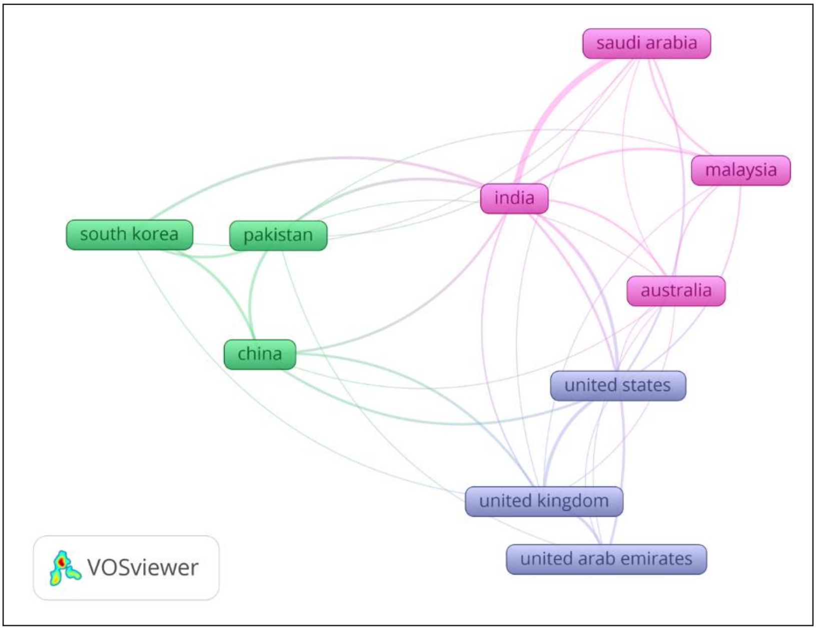
Top 10 Countries With (a) Publications and (b) Citations on The Topic of The IoT in Pharmacy



Following a thorough keyword analysis, three primary topics addressing the intersection of the IoT and pharmaceutical care services emerged. As shown in Figure 5, these include the IoT in healthcare, the IoT in medical records, and the IoT in access control. Notably, the first two themes have no direct relationship to medication adherence. In contrast, the theme of the IoT and medication management includes many keywords emphasising the IoT's utility in augmenting medication adherence, including terms like 'medication adherence', 'medication management', 'RFID' and 'health monitoring'.

Figure 4

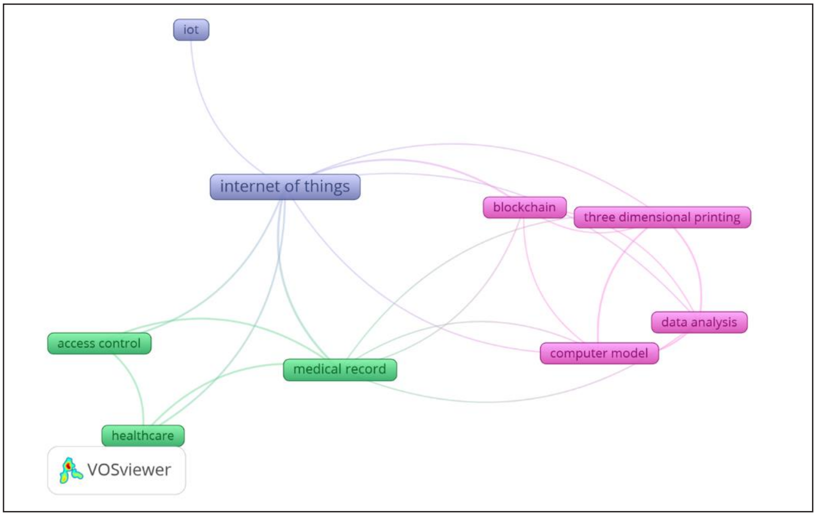
Top 10 Countries Involved in Research Related to the IoT in Pharmaceutical Care



Following the data in Figure 5, a review of recent intellectual trends reveals that 'blockchain', 'three-dimensional printing', 'data analysis' and 'computer model' have become the most widely used keywords in academic research. A median publication year of 2021 was also found, indicating a growing interest in enhancing the security of IoT-integrated pharmaceutical care services. A thorough bibliometric analysis was conducted to assess the burgeoning expansion of IoT-related research in the healthcare industry. Its exhaustive investigation objectively revealed a significant increase in interest in this innovative technology from the healthcare industry. Notable are the emerging themes that continue to gain prominence in the industry: the application of blockchain technology, the development of AI models, the integration of a 5G telecommunications infrastructure, and the advancement of data analytics and computer technology. These elements highlight the healthcare industry's progression towards technological integration and herald a new era of IoT-integrated healthcare services (Rejeb et al., 2023).

Figure 5

Top 10 Keywords' Co-Occurrence and Thematic Areas Related to the IoT in Pharmacy



Role of the Internet of Things in Patients' Medication Adherence

The development and evolution of IoT technology present a significant opportunity to improve patients' adherence to prescribed medications. This enhancement overcomes the inherent limitations of conventional medication management systems. The IoT significantly improves access to prescription data. This increased access improves patients' understanding of their prescribed drug regimens, expediting the acquisition of necessary medications. This combination of factors increases adherence to prescribed medications, improving health outcomes. In addition, it contributes to an overall enhancement of the patient's quality of life. In addition, PMA illustrates the application of IoT technology in the healthcare industry. Diverse mobile applications, such as pill detectors, electronic monitoring systems, and self-report surveys, are widely adopted applications of IoT technology for enhancing PMA. These applications are concrete examples of how IoT technology has significantly transformed PMA, highlighting the technology's potential to enhance patient outcomes (Stegemann et al., 2012).

As alluded to in the introduction, remote monitoring is becoming one of the most prevalent IoT-powered systems designed to improve medication adherence. The foundation of remote monitoring systems is the deployment of sophisticated devices such as complex sensor arrays, advanced peripheral technologies, and user-centric mobile applications. In turn, these systems provide healthcare professionals with a highly effective mechanism for monitoring patients' medication compliance. In addition, they provide real-time updates, enabling immediate adjustments and corrective actions when necessary. This novel arrangement invariably assures adherence to the recommended dosages and administration schedules, optimising the therapeutic effects of medications and minimising the likelihood of adverse events due to overdosing or underdosing. For example, a modern wearable device may be designed to record vital data such as a patient's insulin consumption and concurrent blood glucose levels continuously. The device can transmit these data autonomously to a cloud-based secure system. This procedure significantly improves healthcare providers' capacity for continuous and comprehensive patient monitoring; fundamentally, it enables healthcare professionals to observe, analyse, and take appropriate, well-informed action based on the provided data. Therefore, the remote monitoring strategy is an indispensable instrument for healthcare administration, streamlining patient care and reinforcing the underlying goal of ensuring optimal medication adherence. It is a transformative innovation that combines technology and healthcare, revolutionising patient care in the digital age (Heintzman, 2016; Nasser et al., 2021). Table 3 provides an exhaustive overview of the various components of medication adherence and the role of the IoT in their enhancement.

Table 3

Summary of the Components of Medication Adherence Enhanced with Use of the IoT

Component	Gaps	How IoT can help	Examples
Medication regimen	Patients may forget to take their medication at the correct time or forget to take it altogether.	IoT devices such as smart pill bottles or medication dispensers can send reminders to patients' smartphones or other devices when it is time to take their medication.	Smart medication dispensers (Chavez et al., 2020; Roumaissa & Rachid, 2022); medication reminders and alerts (Ishak et al., 2018; Kumar & Rani Nelakuditi, 2019; Roumaissa & Rachid, 2022; So et al., 2021; Srinivas et al., 2018); mobile applications (Fathillah & Chellappan, 2022; Roh et al., 2021; Roumaissa & Rachid, 2022)
Medication administration	Patients may lose track of whether they have taken their medication, leading to over- or under-dosing.	IoT devices such as smart pill bottles or medication dispensers can track when medication is taken and transmit this information to healthcare providers or caregivers for monitoring.	Smart inhalers (Behl et al., 2022); wearable devices (Roh et al., 2021); connected medical devices (Behl et al., 2022).
Medication refill	Patients may forget to refill their prescriptions, leading to gaps in treatment.	IoT devices can automatically order refills when a patient's medication supply is running low, or send reminders to patients or healthcare providers to refill prescriptions.	Connected pharmacy services (Silva et al., 2016; Yang et al., 2014); automatic refill systems (Parra et al., 2017; Sohn et al., 2015); prescription renewal reminders (Kinthada et al., 2017; Roumaissa & Rachid, 2022; Srinivas et al., 2018; Yang et al., 2014).

(continued)

Component	Gaps	How IoT can help	Examples
Medication monitoring	Patients may experience side effects or other adverse events from their medication.	IoT devices such as wearable sensors or smartphone apps can monitor patients for adverse events and alert healthcare providers or caregivers if necessary.	Digital pill sensors (Aldeer et al., 2018; Chavez et al., 2020; Roumaissa & Rachid, 2022; Silpa et al., 2022); health monitoring systems (Aldeer et al., 2018; Aguilar-Rivera et al., 2020; Fathillah & Chellappan, 2022; Ishak et al., 2018; Ma et al., 2018; Roh et al., 2021; Srinivas et al., 2018; Yang et al., 2014); wearable devices (Roh et al., 2021).
Medication education	Patients may have underlying health conditions that affect medication adherence, such as depression or cognitive impairment.	IoT technology can be used to provide real-time health coaching to patients, encouraging them to adhere to their medication regimen. This coaching can be delivered remotely through smart devices, such as wearables and mobile apps.	Remote patient education (Chavez et al., 2020; Karagiannis et al., 2022; Roh et al., 2021; Yang et al., 2014); interactive patient education (Chavez et al., 2020; Karagiannis et al., 2022; Roh et al., 2021; Yang et al., 2014); mobile applications (Fathillah and Chellappan, 2022; Roh et al., 2021; Roumaissa & Rachid, 2022),

IoT Tech-Based PMA Systems

A considerable body of literature examines and emphasises the development and proposal of various IoT-based systems intended to improve monitoring and tracking mechanisms in the healthcare sector, focusing on medication adherence monitoring. A notable example is a study that conducted a comprehensive scoping review of the adoption and implementation of technology-centric PMA interventions and corresponding measurement components, primarily focusing on mental health and substance use disorders (Steinkamp et al., 2019). The researchers in the study were able to identify a variety of essential measurement components for monitoring medication adherence, including self-reported data, remote direct visualization techniques, advanced fully automated computer vision algorithms, the deployment of biosensors, the use of intelligently designed pill receptacles (also known as smart pill containers), ingestible sensors that are increasingly being integrated into healthcare technology, pill count metrics, and measures that document the utilization patterns of these technologies. These modalities contribute substantially to the effectiveness and efficiency of monitoring systems, thereby highlighting the transformative potential of the IoT for healthcare delivery.

A comprehensive study was conducted to examine the various technology-based techniques and systems used for monitoring medication adherence. This previous study encompassed an extensive review of sensor systems, proximity sensing systems, vision systems, and their potential combinations (Aldeer et al., 2018). In terms of precision, user convenience and battery consumption, a substantial amount of work remains to be done to improve technology-based systems to address current challenges effectively. In addition, a separate systematic review of electronic medication packaging (EMP) devices concluded that, despite their widespread use, additional data collection is required to comprehend and validate their application completely (Checchi et al., 2014). Therefore, this section examines the existing strategies utilised in the design of monitoring systems for medication adherence applications employing emerging technologies.

Table 4

Summary of IoT Technologies Used to Enhance Medication Adherence

Category	Technology	System description	Advantages	Limitations
Sensor systems	Smart pill box (Chavez et al., 2020; Roumaissa & Rachid, 2022)	A pill box equipped with sensors to track medication adherence.	Easy to use, cost-effective.	Unable to prevent medication errors.
	Pill bottle with multi-sensor system (Aldeer et al., 2018; Boonnuddar & Wuttidittachotti, 2017; Chavez et al., 2020; Fathillah & Chellappan, 2022; Karagiannis & Nikita, 2020; Ma et al., 2018; Serdaroglu et al., 2015; So et al., 2021; Srinivas et al., 2018; Toh et al., 2016)	A pill bottle with sensors to track medication adherence.	More accurate than smart pill boxes.	More expensive than smart pill boxes.

(continued)

Category	Technology	System description	Advantages	Limitations
Vision systems	Smart pill dispenser (Chavez et al., 2020; Roumaissa & Rachid, 2022)	An automated pill dispenser that dispenses medication at the appropriate time.	Can help prevent medication errors.	More expensive than smart pill boxes.
	Smart medical box with QR code scanning (Jha & Bhandari, 2021; Karagiannis & Nikita, 2020; Karagiannis et al., 2022; Roumaissa & Rachid, 2022; Srinivas et al., 2018; Yang et al., 2014)	A medical box with a QR code scanner to track medication adherence.	Easy to use, can help prevent medication errors.	QR code scanning can be time-consuming.
Fusion-based systems	PillSense medication bottle (Aldeer et al., 2018)	A medication bottle equipped with a sensor and a mobile app.	Can help prevent medication errors, more accurate than smart pill boxes.	More expensive than smart pill boxes.
Combinations	Smart pill box with mobile application (Aldeer et al., 2018)	A smart pill box connected to a mobile app for medication adherence tracking.	Easy to use, cost-effective.	Unable to prevent medication errors.
	Smart sharps bin (Gu et al., 2020)	A sharps bin equipped with sensors to track disposal of needles.	Can help prevent accidental needlestick injuries.	More expensive than regular sharps bins.
	Smart environments (UbMed) (Silva et al., 2016)	A smart home environment equipped with sensors to track medication adherence.	Can provide a comprehensive picture of medication adherence.	More expensive than other IoT technologies.
Proximity Sensing	Watch (Ma et al., 2018), mobile app (Fathillah & Chellappan. 2022; Roh et al., 2021; Roumaissa & Rachid, 2022; Silpa et al., 2022), and web server (Ishak et al., 2018; Karagiannis et al., 2022; Sherif et al., 2020; Silpa et al., 2022)	A system consisting of a watch, mobile app, and web server to track medication adherence.	Can provide real-time feedback to patients.	Patients need to wear the watch at all times.

This review provides comprehensive summaries of IoT technology and associated configurations. In the meantime, Table 4 summarises information regarding sensor systems, vision systems, fusion-based systems, proximity sensing, and combined technologies. The evaluated articles provide compelling evidence supporting the potential of IoT technology to improve patients' adherence to medication regimens, particularly among elderly patients with chronic diseases. These results are consistent with broader research trends that emphasise the central role of IoT technology in enhancing medication adherence. Despite the use of self-reported measurements, which are frequently viewed as less reliable, a meta-analysis of 13 studies on internet interventions demonstrates the effectiveness of such interventions in enhancing medication adherence (Linn et al., 2011). Similarly, a thorough investigation into the efficacy of a personalised medication management platform (PMMP) revealed significant advances in medication adherence and self-management (Huang et al., 2017). Notably, the study found a significant reduction in long-term medication costs and a remarkable 67 per cent reduction in medication delays. In addition, separate research has demonstrated conclusively that implementing timely and personalised SMS medication reminders positively affects medication adherence. The findings demonstrate the immense potential of personalised interventions to enhance healthcare outcomes (Huang et al., 2017).

DISCUSSION

The rising number of publications and citations demonstrates a growing propensity to employ IoT technology to improve patient outcomes and promote medication adherence. Nonetheless, it is essential to recognise the significant regional differences in research interest, publication rates, and citation frequency. Therefore, additional research is required to determine the dependability and uniformity of outcomes in diverse contexts. Because medication adherence is a crucial predictor of patient safety and treatment efficacy, incorporating the IoT into the topical domain of medication administration is vital to pharmaceutical care services.

Due to their potential to improve medication adherence, IoT-enabled medication dispensing devices have gained widespread popularity and adoption. These devices provide mechanical dispensing of medications according to predetermined dosages and regimens, thereby relieving patients of their burden. In addition, they serve as invaluable reminders, helping patients to remember their medication administration schedules. Certain devices with advanced functionalities, such as facial and voice recognition, ensure that medications are administered only to the intended individual. Medication dispensing can adhere strictly to predetermined schedules using IoT technologies and systems, ensuring patients receive the correct medications at the correct times.

IoT-enabled systems have the inherent capacity to improve and optimise patients' medication regimens through timely notifications and reminders about missed doses. These reminders can be effectively programmed to appear on wearable or mobile devices, ensuring patients are promptly alerted to their medication needs. In addition, the inclusion of replenishment reminders can be judiciously programmed to improve individuals' consistent medication adherence further. The convergence of IoT, gaming, and augmented reality (AR) technologies offers a promising avenue for improving medication adherence. By incorporating gaming principles and incentivizing components into medication adherence programmes, the potential for increased patient engagement and motivation is significantly increased. Recent research on IoT and AR applications in medication adherence supports this notion (Adetunji et al., 2022), thereby validating the practical viability and relevance of IoT, AR and gaming components in optimising medication adherence in the healthcare industry.

The advent of the IoT has ushered in a wave of transformative technologies, especially in mobile applications, which have become pervasive and readily accessible due to the widespread adoption of smartphones and tablets. These innovative tools provide many advantages, such as medication reminders, usage pattern monitoring, and access to educational resources, empowering patients to manage their medication regimens effectively. Utilising these IoT-based mobile applications presents a substantial opportunity to improve patient outcomes by enhancing medication adherence. The ability of these IoT-enabled applications to provide patients with valuable insights into their medication history, refill information, and prescription data is a significant advantage. By leveraging the power of cloud services, these applications provide seamless communication channels between patients, healthcare providers, and pharmacies, thereby fostering better medication management practises. In addition to facilitating the interchange of information, this technology streamlines the continuous monitoring of medication adherence, thereby ensuring that patients adhere to their prescribed treatment plans. A recent study exemplified the potential of this technology by highlighting the development of a mobile application for elderly patients with disabilities (Mohammed et al., 2018). This app effectively bridged the communication gap between these vulnerable patients and their physicians by utilising cloud services. This app empowered older patients to take charge of their healthcare by integrating features such as medication reminders, monitoring tools, and educational materials. The app's seamless integration into these individuals' lives demonstrates its efficacy in facilitating the continuous monitoring of medication adherence, resulting in improved health outcomes (Mohammed et al., 2018). An evaluation of 160 medication adherence applications ranked MyMedSchedule, MyMeds and RxmindMe as the highest-rated options due to their basic medication reminder functions and superior levels of functionality (Dayer et al., 2013).

Consideration should be given to the claim that there may be more effective ways to improve compliance than assessing adherence alone. In order to increase adherence, interventions should focus on multiple factors, including enhancing patients' comprehension of their prescribed medication, enhancing patient satisfaction, enhancing coping mechanisms, mitigating stress levels, simplifying the complexities associated with medication use, and addressing other significant factors that contribute to noncompliance. By emphasising the multifaceted factors instead of relying solely on measurement, interventions may have a greater effect on patients' adherence. The emergence of IoT technology offers a promising avenue for remote patient education, potentially improving medication adherence. This innovative technology provides patients with access to abundant educational resources, such as informative videos, live seminars, and interactive materials. By emphasising interactive patient education, medication regimens can be better understood, thereby encouraging patients to engage in the learning process (Stegemann et al., 2012).

Utilising IoT technology for remote patient education offers numerous benefits. It enables healthcare providers to provide patients with valuable information at their discretion without requiring them to visit healthcare facilities in person. It can be especially advantageous for those who encounter geographical obstacles, lack transportation options, or have limited mobility. In addition, remote patient education allows personalised learning opportunities, as patients can access educational resources tailored to their specific requirements and preferences. In addition, IoT technology enables the monitoring of patients' progress and their interaction with educational materials. By collecting and analysing data, healthcare providers can gain insight into patients' behaviour, identify potential barriers to adherence, and tailor interventions accordingly. This data-driven strategy permits a more proactive and individualised approach to enhancing medication adherence.

In addition to patient education, IoT technology enables remote monitoring of medication usage. Smart pill dispensers and connected medication packaging can monitor when and how the medication is taken, providing healthcare providers with real-time data on adherence. This real-time monitoring capability enables prompt intervention and support, such as reminders or notifications, when noncompliance is detected.

In recent years, there has been a significant increase in the use of IoT-enabled sensing mechanisms to improve patient outcomes in medication adherence. As shown in Table 4, numerous studies have investigated intelligent pill containers, multi-sensor pill receptacles, and intelligent pill dispensers, all of which seek to assist patients in managing their medications effectively. A previous study shed light on the efficacy of an intelligent pill container in enhancing medication adherence among hypertension-affected individuals (Tan et al., 2018). The investigation determined that the intelligent pill container significantly improved hypertensive patients' adherence to medication and blood pressure control. In addition, the study provided insightful information regarding the practicability and acceptability of this technology in a real-world context, thereby highlighting its potential advantages. Similarly, another study investigated the effect of an intelligent pill dispenser on medication adherence among tuberculosis patients undergoing treatment (Chavez et al., 2020). The intelligent pill dispenser was instrumental in substantially increasing medication adherence rates and improving patient treatment completion rates, according to the findings of the study. In addition, the study illuminated the enormous potential of this technological innovation to improve treatment outcomes while simultaneously easing the burden on healthcare providers (Chavez et al., 2020).

With recent advances in computer vision, a thorough investigation was conducted to determine the viability of an innovative medical container equipped with a quick response (QR) code-scanning mechanism (Meshram et al., 2022). The device featured a pill container with multiple compartments for storing medications, each bearing a unique QR code. In order to facilitate the process of monitoring medication consumption, a mobile application was used to detect the QR codes, thereby allowing the precise time and date of ingestion to be recorded. The study hypothesised that QR code scanning offered a highly effective method for monitoring medication adherence. However, it acknowledged that the patient's access to and familiarity with a smartphone and the possibility of human error in failing to scan the barcode could influence its effectiveness. Emerging evidence suggests that combining IoT technology with complementary modalities, such as mobile applications and intelligent environments, can significantly impact medication adherence. These interconnected technologies can address medication adherence's complex and multifaceted nature, resulting in substantial improvements in patient outcomes. Another study investigated using a smart pill container and a mobile phone app to improve PMA (Boonnuddar & Wuttidittachotti, 2017). The investigation's methodology significantly increased medication adherence rates among patients with chronic diseases like diabetes and hypertension.

Following this premise, a comprehensive investigation was conducted to determine the efficacy of using an intelligent container designed for sharps to improve medication adherence among patients with chronic diseases, including diabetes (Gu et al., 2020). The novel system utilised cutting-edge visual and sensor technologies to detect and meticulously document the disposal of sharps, such as needles and syringes. In addition, the system included a user-friendly mobile application that provided patients with constructive feedback regarding their prescription disposal practises and punctual reminders regarding the proper sharps disposal methods. This multifaceted approach successfully improved medication adherence rates among patients with chronic diseases such as diabetes (Aldeer et al., 2018). One study introduced the PillSense medicine container, which utilised an advanced fusion-based system to closely monitor medication adherence by integrating vision-based and sensor-based technologies (Aldeer et al., 2018). The PillSense device was ingeniously designed as a pill container and fitted with a cutting-edge digital sensor capable of meticulously recording and documenting the exact time the bottle was opened. Adding to its functionality, the system incorporated a mobile application that effectively reminded patients to adhere to their prescribed medication regimens while providing an added protection layer by alerting caregivers when the regimen was not followed. This comprehensive approach proved highly effective in substantially increasing medication adherence rates, especially among patients with chronic diseases such as hypertension and diabetes.

In recent years, the application of proximity-sensing technologies in the healthcare industry has garnered considerable interest. By utilising highly sensitive sensors capable of detecting the presence of medication containers or devices close to patients, these cutting-edge technologies detect the presence of medication containers or devices close to patients. This technological advancement is primarily intended to ensure and verify patients' adherence to prescribed medication regimens with greater precision. In contrast to traditional methods such as self-reporting, proximity sensing systems provide more accurate data on medication adherence by actively detecting the opening of medication containers. Notable research utilising a timepiece, a mobile application, and a web server monitored medication adherence among geriatric patients (Serdaroglu et al., 2015). The smartwatch, a state-of-the-art wearable device, was ingeniously designed to detect the exact instant the medication container was opened, capturing vital information regarding medication usage. These data were then seamlessly transmitted to the accompanying mobile application, which acted as an intermediary to facilitate the data transmission to the specified web server. The results of this innovative investigation were nothing short of astounding. Implementing the proximity sensing system resulted in a significant increase in medication adherence rates among senior patients. Patients and caregivers who participated in the study provided enthusiastically positive feedback regarding the system's efficacy. By employing cutting-edge technological advances, the researchers were able to address a significant issue in healthcare effectively and pave the way for improved patient care, particularly in the context of geriatric medication management. These findings have far-reaching implications beyond the domain of geriatric care. Incorporating proximity sensing technologies into medication adherence monitoring can revolutionise healthcare practises, ensuring optimal patient outcomes across all demographics. Moreover, such systems' real-time and accurate data can provide healthcare professionals with invaluable insights into patients' behaviour and medication-taking patterns, enabling them to make informed decisions and interventions.

Challenges and Future Directions

This article identifies and discusses several barriers and limitations endemic to applying IoT technologies to medication adherence. Prior research has highlighted significant data privacy, security, and confidentiality concerns (Rasool et al., 2022; Shahid et al., 2022). In the healthcare industry, where confidential patient information must be protected from unauthorised access or breaches, these concerns are of the utmost importance. In addition, this review emphasises the importance of considering the efficacy of IoT technologies, particularly when implemented among elderly patients or individuals with limited technical proficiency (Coughlin et al., 2007; Moraru et al., 2022). The inability of these demographic groups to implement and utilise IoT devices effectively may result in suboptimal medication adherence rates. In addition, previous research has indicated that energy consumption and user convenience are obstacles to implementing IoT technologies for medication adherence (Nižetić et al., 2020; Perković et al., 2020). Given the reliance on battery-powered devices and the need for user-friendly interfaces, it is essential to address these challenges to ensure widespread adoption and successful integration of IoT solutions in healthcare settings.

Exploring low-energy communication technologies arises as a potential strategy for overcoming the abovementioned constraints. In this context, single-hop communication solutions are a viable option, eliminating the need for resource-intensive handshakes or acknowledgements. An earlier study demonstrated that these methods have the potential to reduce energy consumption significantly during packet transmission. By examining the complexities of such approaches, the potential for achieving significant improvements in energy efficiency within communication systems becomes evident, thereby fostering sustainability and environmental awareness (Khan et al., 2022).

Evaluation of user acceptability and comfort levels is crucial for the successful implementation and widespread adoption of these devices. An investigation of collaborative sensing, a technique that integrates energy-efficient sensors with high-fidelity activity reporting sensors on a single platform, may also provide a viable strategy for extending the lifespan of battery-powered systems. This strategy requires the development of sensor fusion algorithms capable of constructing a comprehensive model from multiple sensed and reported inputs, as illustrated by Bayesian inference (Krishnamurthi et al., 2020). In other words, there is a need for ongoing research and innovation in the field of IoT technologies for medication adherence, emphasising precision monitoring, energy efficiency, and user-centric design.

CONCLUSION

This comprehensive assessment highlights the potential for IoT technologies to improve patient outcomes and increase medication adherence. The bibliometric analysis revealed a growing publication trend in employing IoT technology to improve medication adherence and patient outcomes, emphasizing that medication adherence is of the utmost importance and merits comparable attention to other aspects of pharmaceutical care services. Observations have revealed the applicability of numerous IoT-based systems employing sensor, vision, fusion-based, combination, and proximity sensing technologies, each of which possesses distinct benefits and limitations. These technologies offer advantages such as real-time monitoring, automated reminders, and personalised feedback, which could help patients adhere to their prescribed medication regimen. However, there are limitations associated with these technologies, such as high costs, limited battery life, and privacy concerns. This review affirms that, despite these limitations, IoT technologies have significant potential to improve medication adherence and patient outcomes. Additional research is required to address the challenges and limitations of these technologies and determine their long-term efficacy in improving patient outcomes.

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