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(Review Article)

Smart IoT-based medication adherence system for real-time patient monitoring and alerts

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Abstract

Medication adherence is a critical aspect of effective healthcare management, particularly for patients with chronic illnesses. Non-adherence to prescribed medication can lead to adverse health outcomes, increased hospitalizations, and additional healthcare costs. This paper explores the design and implementation of a Smart IoT-Based Medication Adherence System (SMAS) aimed at improving medication adherence, real-time patient monitoring, and timely alerts. The system integrates wearable devices, mobile applications, and IoT-based sensors to track medication intake, monitor patient vitals, and provide alerts to healthcare providers and caregivers in case of non-adherence or any health anomalies. The system's potential to enhance patient outcomes and reduce healthcare costs is also discussed.

Keywords: Medication Adherence; IoT; Real-Time Monitoring; Smart Devices; Healthcare; Alerts; Sensors; Patient Monitoring; Medication Tracking

1. Introduction

Medication adherence is essential for improving patient outcomes and preventing complications in chronic disease management. Non-adherence is a global issue that leads to increased hospitalizations, prolonged illnesses, and even death. In the United States alone, medication non-adherence is responsible for an estimated $100 billion in additional healthcare costs annually. Traditional methods of tracking medication adherence, such as paper logs and verbal reports, often fail to provide accurate real-time data and rely on patients' self-reporting [1].

The integration of Internet of Things (IoT) technology into healthcare has transformed the way healthcare systems monitor and support patients. IoT-based systems can provide continuous, real-time monitoring and alert systems, making them an ideal solution for medication adherence. The goal of this paper is to design a Smart IoT-Based Medication Adherence System (SMAS) that can monitor medication intake, track patient health status in real-time, and generate alerts for both patients and healthcare providers in case of non-adherence or health anomalies.

This IoT-based system not only tracks medication intake but also continuously monitors vital health parameters, including heart rate, blood pressure, and blood glucose levels. With the help of cloud computing and machine learning algorithms, it can provide insights into patient behavior and health patterns, enabling healthcare providers to take timely interventions. The system aims to reduce the burden on healthcare facilities, improve patient adherence, and ultimately enhance health outcomes [2].

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2. Literature Review

The integration of Internet of Things (IoT) technology in healthcare has gained significant attention in recent years due to its potential to revolutionize patient care, especially in the realm of medication adherence. Medication non-adherence is a pervasive issue that has significant consequences for patient outcomes, healthcare costs, and public health. Various studies have explored the use of IoT devices to monitor and improve medication adherence, as well as the use of wearable health-monitoring devices for patient care. This literature review explores the existing work in the areas of IoT-based medication adherence systems, real-time patient monitoring, and the challenges and limitations associated with these technologies.

2.1. Medication Adherence and its Impact on Healthcare

Medication adherence, defined as the extent to which a patient follows the prescribed medication regimen, is essential for effective treatment, particularly for chronic diseases such as diabetes, hypertension, and cardiovascular disorders. Non-adherence to prescribed medication regimens is a major contributor to poor health outcomes, leading to increased emergency room visits, hospitalizations, and avoidable complications. According to the World Health Organization (WHO), approximately 50% of patients with chronic conditions fail to adhere to prescribed medication regimens, which exacerbates the global burden of disease (WHO, 2003).

Studies by *Chisholm-Burns et al. (2012)* highlight the costs associated with medication non-adherence, estimating that the direct healthcare costs of non-adherence in the United States amount to more than $100 billion annually. The importance of medication adherence has led to a variety of interventions aimed at improving it, including patient education, reminders, and the development of smart medication tracking systems [3].

2.2. IoT-Based Medication Adherence Systems

Several studies have focused on the use of IoT-based systems for medication adherence. These systems typically involve the integration of smart pillboxes, sensors, wearable devices, and mobile applications to track and monitor medication intake. For example, *Mohan et al. (2020)* proposed a smart pill dispenser system that automatically tracks when a patient takes their medication. This system is equipped with a sensor that detects when the pillbox is opened and records the time of the action, providing a real-time log of medication adherence. If a patient misses a dose, the system sends an alert to caregivers or healthcare providers. These types of smart pill dispensers have shown promise in improving adherence by providing visual and auditory reminders [4].

Other studies have explored the use of smartphone apps in combination with IoT devices. A study by *Zhao et al. (2019)* proposed a system in which a mobile application communicates with a smart pillbox to remind patients to take their medication and track their adherence. The application could also send alerts to caregivers and healthcare providers if a dose is missed. The mobile app serves as an effective communication tool between patients, caregivers, and healthcare providers, ensuring that medication adherence is continuously monitored and managed.

2.3. Wearable Devices for Real-Time Monitoring

In addition to medication adherence tracking, wearable devices that monitor physiological parameters such as heart rate, blood pressure, glucose levels, and oxygen saturation have become integral parts of patient monitoring. The combination of IoT-enabled medication adherence tools with wearable devices offers a more comprehensive approach to patient care. Wearables provide real-time health data, which can be crucial for detecting early signs of health deterioration and responding promptly to potential issues.

Patel et al. (2019) explored the integration of wearables such as smartwatches with IoT systems for continuous health monitoring. These devices collect data on key metrics like blood pressure and heart rate, and transmit the data to healthcare providers in real-time. Wearables can detect anomalies in patient vitals, triggering alerts to both the patient and healthcare provider for immediate intervention. This functionality is particularly beneficial for patients with chronic conditions such as hypertension and diabetes, where timely adjustments to medication or lifestyle are necessary to prevent complications [5].

2.4. Cloud Computing and Data Analytics in Healthcare

Cloud computing and data analytics are essential for enabling real-time access to patient data and enabling healthcare providers to make data-driven decisions. IoT devices generate vast amounts of data, and the ability to analyze and interpret this data is vital for providing meaningful insights into patient health.

Liu et al. (2020) highlighted the role of cloud computing in healthcare systems, where data from IoT devices is uploaded to cloud platforms for processing and analysis. The integration of cloud-based systems allows for centralized monitoring of multiple patients, facilitating more efficient management of patient care. In the context of medication adherence, cloud-based platforms enable healthcare providers to monitor patients' adherence history and assess the effectiveness of interventions [6].

Moreover, cloud computing allows for the use of machine learning algorithms to analyze trends in health data and predict potential health issues. For example, *Liu et al. (2021)* used a cloud-based platform to analyze data from wearable devices to predict potential health risks based on changes in patient vitals. The platform could identify patterns in medication adherence and suggest adjustments to treatment protocols, thus offering a personalized healthcare experience.

3. System design and architecture

The design and architecture of the Smart IoT-Based Medication Adherence System (SMAS) are critical for ensuring seamless integration of various components, including wearable health-monitoring devices, smart medication containers, mobile applications, and cloud computing systems. The primary goal of SMAS is to offer real-time monitoring of both medication adherence and patient health, enabling timely interventions by healthcare providers when necessary. This section provides a detailed explanation of the system's design, including its key components, communication protocols, data processing, and storage mechanisms [7].

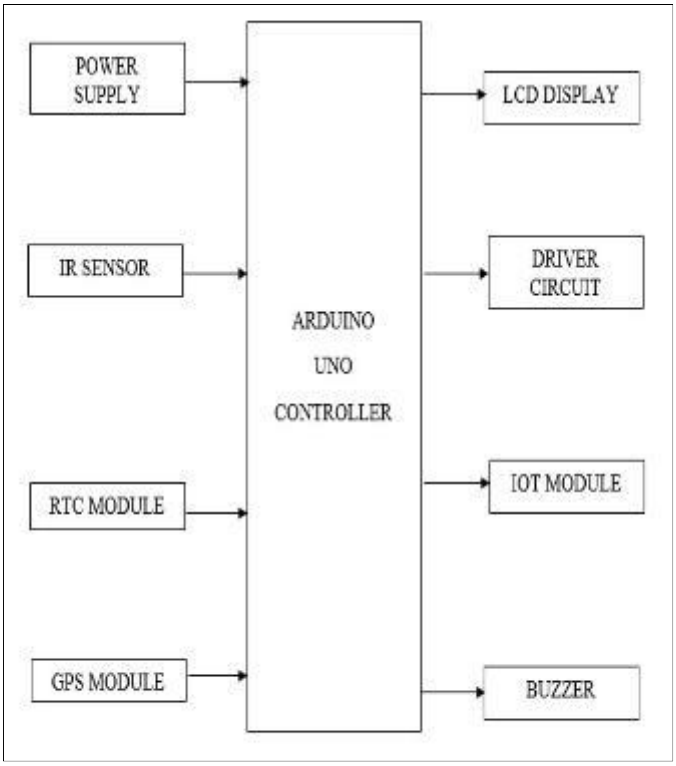

Figure 1 System Architecture

3.1. Overview of the System Architecture

The system architecture of SMAS can be divided into four main components:

- Wearable Health Monitoring Devices
- Smart Medication Containers
- Mobile Application
- Cloud Platform

These components work in harmony to monitor the patient's health status, track medication adherence, and provide real-time alerts and data visualization. The system is designed to be scalable, flexible, and interoperable, allowing for easy integration of additional devices or features in the future.

3.2. Wearable Health Monitoring Devices

Wearable devices play a crucial role in real-time patient monitoring by continuously collecting vital health parameters. These devices are designed to monitor the following key metrics:

- Heart Rate: Useful for tracking patients with cardiovascular diseases or conditions that require close monitoring of heart function.
- Blood Pressure: Essential for hypertensive patients, as it helps ensure medication is effective in controlling blood pressure levels.
- Blood Glucose Levels: Important for diabetic patients, as monitoring blood glucose is crucial for controlling diabetes and preventing complications.
- Oxygen Saturation: Vital for patients with respiratory issues, such as COPD or asthma.

3.3. Smart Medication Containers

The smart medication container is a core component of SMAS, designed to monitor and track medication adherence. The container holds the prescribed medication and has embedded IoT sensors to detect when it is opened or closed. Key functionalities of the smart container include:

- Medication Tracking: The system tracks when the container is accessed (e.g., when a pill is taken) and logs the time and date of this event. This helps create a record of medication adherence.
- Reminder Notifications: If the patient does not open the container at the prescribed time, the system sends a reminder notification via the mobile app, prompting the patient to take their medication.
- Missed Dose Alerts: If the system detects that the patient has missed a dose, it automatically sends alerts to both the patient and their healthcare provider. This ensures that missed doses are addressed promptly [8].
- Secure Lid: Some advanced smart containers are equipped with secure lids that can be locked or opened only with the patient's authentication (e.g., biometric recognition or PIN code). This prevents improper usage or medication theft.

3.4. Mobile Application

The mobile application is a central hub through which patients, caregivers, and healthcare providers interact with the system. The app provides several features that enable real-time communication, monitoring, and management:

- Medication Reminders: The app sends push notifications to remind patients when it is time to take their medication. If the patient misses a dose, the app sends a follow-up reminder.
- Health Monitoring Dashboard: Patients can view a dashboard displaying real-time health metrics from their wearable devices, including heart rate, blood pressure, glucose levels, and oxygen saturation. The dashboard also visualizes trends and alerts the user if any vital signs fall outside of the acceptable range.
- Adherence Tracking: The app logs when the patient takes their medication and provides a history of adherence. Patients can view this data and make adjustments if necessary.
- Alert Management: In case of an emergency, the app can send alerts to caregivers and healthcare providers. For example, if a patient's vital signs go out of range or if a medication dose is missed, the system sends a notification to the appropriate parties for timely intervention [9].
- Communication with Healthcare Providers: Healthcare providers can access patient data via the mobile app to monitor medication adherence and health parameters. The app provides secure communication channels for providers to contact patients or their caregivers when needed.

Table 1 Character LCD pins with 2 Controller

Pin No.	Name	Description
Pin no. 1	D7	Data bus line 7 (MSB)
Pin no. 2	D6	Data bus line 6
Pin no. 3	D5	Data bus line 5
Pin no. 4	D4	Data bus line 4
Pin no. 5	D3	Data bus line 3
Pin no. 6	D2	Data bus line 2
Pin no. 7	D1	Data bus line 1
Pin no. 8	D0	Data bus line 0 (LSB)
Pin no. 9	EN1	Enable signal for row 0 and 1 (1^{st}controller)
Pin no. 10	R/W	0 = Write to LCD module 1 = Read from LCD module
Pin no. 11	RS	0 = Instruction input 1 = Data input
Pin no. 12	VEE	Contrast adjust
Pin no. 13	VSS	Power supply (GND)
Pin no. 14	VCC	Power supply (+5V)
Pin no. 15	EN2	Enable signal for row 2 and 3 (2^{nd}controller)
Pin no. 16	NC	Not Connected

3.5. Communication and Integration Between Components

The communication between the various system components (wearables, smart medication containers, mobile app, and cloud platform) is facilitated by wireless technologies, primarily Bluetooth and Wi-Fi. The communication flow works as follows:

- Wearable Device to Mobile App: Health data collected by the wearable devices is transmitted to the mobile app via Bluetooth or Wi-Fi. The app then processes this data and displays it on the user's health dashboard.
- Smart Medication Container to Mobile App: Data from the smart medication container (e.g., when the container is opened) is sent to the mobile app. If a dose is missed, the app sends an alert [10].
- Mobile App to Cloud Platform: Data from both wearable devices and medication containers is synced with the cloud platform. The cloud processes the data and stores it for future reference, enabling healthcare providers to access the data remotely.
- Cloud Platform to Healthcare Providers: Healthcare providers access real-time data from the cloud platform. They can track patient adherence, health trends, and receive alerts if any intervention is necessary.

4. Real-time monitoring and alert system

The Real-Time Monitoring and Alert System (RTMAS) is a critical feature of the Smart IoT-Based Medication Adherence System (SMAS). This system ensures that both patients and healthcare providers can continuously monitor patient health and medication adherence. By providing immediate notifications, the RTMAS enhances patient care and facilitates early intervention when needed, ensuring that medication adherence is maintained, and that health abnormalities are quickly addressed.

This section describes the components, workflows, and technologies involved in real-time monitoring and alerting, along with the system's capabilities to improve health outcomes [11].

4.1. System Components for Real-Time Monitoring

Real-time monitoring within SMAS relies on a network of interconnected devices, which work together to collect and transmit patient data in real time. These components include:

- Wearable Devices: Devices such as smartwatches or patches that monitor vital health parameters like heart rate, blood pressure, blood glucose levels, and oxygen saturation. These devices collect data continuously and transmit it wirelessly to the mobile app or cloud platform.
- Smart Medication Containers: These IoT-enabled containers track when patients access their medications. The container records each time the lid is opened, indicating when medication is taken, and sends this data to the mobile app or cloud platform.
- Mobile Application: The mobile app serves as the hub for patients and caregivers to view real-time health data, medication logs, and alerts. The app receives real-time data from both wearable devices and medication containers, processes the information, and triggers notifications or alerts based on predefined thresholds.
- Cloud Platform: The cloud platform stores and processes health data from the wearable devices and medication containers. It can run algorithms to analyze the data in real time, looking for trends or abnormalities that indicate the need for intervention. The cloud system sends alerts to healthcare providers or caregivers when necessary.

4.2. Real-Time Data Collection and Transmission

For real-time monitoring to function effectively, it is critical that data is constantly and seamlessly collected from patient devices and transmitted for processing. The data collection process is as follows:

4.2.1. Wearable Devices (Health Monitoring)

- Continuous physiological data, such as heart rate, blood pressure, blood glucose, and oxygen levels, is gathered through sensors embedded in wearable devices (e.g., smartwatches, fitness bands, or specialized patches).
- The devices transmit data to the mobile app via Bluetooth Low Energy (BLE) or Wi-Fi, which ensures low energy consumption for continuous monitoring.

4.2.2. Smart Medication Containers (Adherence Tracking)

- The smart medication containers use sensors to detect when the lid is opened, which indicates that the patient has taken the prescribed medication. The time and date of each event are logged and sent to the mobile app or cloud platform.
- If a dose is missed or delayed, the system can trigger a reminder or alert. This process ensures that medication adherence is accurately tracked.

4.2.3. Mobile Application and Cloud Platform

- The mobile app aggregates the data from both wearable devices and smart medication containers in real-time. It displays health data on a user-friendly dashboard and provides immediate feedback to patients regarding their health and adherence [12].
- Data collected by the mobile app is uploaded to the cloud platform, where it can be processed, analyzed, and stored securely.

4.3. Data Processing and Analysis for Alert Generation

For the alert system to function effectively, the incoming data from wearable devices and medication containers needs to be processed and analyzed in real time. The following steps are involved in the process:

4.3.1. Data Filtering and Validation

- Raw data from wearable devices and medication containers is processed to eliminate noise and ensure that the data is accurate. For example, if a device records a value that is clearly erroneous due to an environmental factor (e.g., an inaccurate heart rate reading caused by device movement), this value is filtered out.

4.3.2. Threshold Monitoring

- The system establishes predefined thresholds for health parameters (e.g., a blood pressure reading above 180/120 mmHg, or a blood glucose level above 250 mg/dL). If any health parameter exceeds or falls below these thresholds, an alert is generated.
- Similarly, medication adherence thresholds are set, such as the prescribed window within which a medication must be taken. Missing the window triggers an alert.

4.3.3. Predictive Analytics

- The system employs machine learning algorithms and predictive models to analyze patient data over time. These models look for trends or anomalies that suggest a future risk (e.g., a patient’s heart rate trending upwards over several days).
- Predictive models can also suggest the likelihood of medication non-adherence based on historical patterns, prompting preemptive interventions.

4.3.4. Immediate Feedback

- As soon as an alert condition is met, the system provides immediate feedback. For example, if a patient’s blood glucose level is dangerously high, the system will notify the patient and healthcare provider, providing actionable guidance such as contacting the provider or adjusting the medication regimen.

5. Data analytics and machine learning

Data Analytics and Machine Learning (ML) play a pivotal role in enhancing the effectiveness and efficiency of the Smart IoT-Based Medication Adherence System (SMAS). These technologies enable real-time insights, predictive analytics, and the identification of patterns that help healthcare providers and patients make more informed decisions regarding medication adherence and health management [13].

In this section, we will explore how data analytics and machine learning algorithms are applied within SMAS to track patient health, predict potential health risks, optimize medication adherence, and facilitate personalized healthcare interventions.

5.1. Importance of Data in SMAS

SMAS generates vast amounts of data through continuous monitoring of patients' health and medication adherence. The primary sources of data in the system include:

- Health Data: Collected by wearable devices that monitor vital signs such as heart rate, blood pressure, blood glucose levels, body temperature, and oxygen saturation.
- Medication Adherence Data: Generated by smart medication containers that record when the patient opens the container to take their medication, tracking whether doses are missed or delayed.
- User Behavior Data: Data from the mobile app that reflects patient behavior, such as interactions with the medication reminders, responses to alerts, and overall engagement with the system.

The ability to process and analyze this data in real time allows the system to detect anomalies, offer predictive insights, and provide personalized recommendations for both health and medication adherence.

5.2. Data Processing and Preprocessing

Before applying advanced analytics and machine learning algorithms, the data collected from various sources needs to be processed and prepared for analysis. This process involves several steps to ensure data quality and consistency:

- Data Integration: Combining data from different sources (wearables, smart medication containers, mobile apps) into a centralized system. This integration allows for a comprehensive view of a patient's health and medication adherence patterns.
- Data Cleaning: Raw sensor data may contain noise, missing values, or errors. For example, a heart rate sensor may give an occasional incorrect reading due to motion artifacts. The cleaning process filters out erroneous data, fills in missing values (e.g., using interpolation), and removes outliers to ensure accuracy.

- Feature Engineering: Creating meaningful features from raw data is crucial for improving the performance of machine learning models. For example, health data may be aggregated into daily averages, or trends in medication adherence can be calculated to detect potential issues (e.g., consistently delayed doses).
- Data Normalization: Health data from different sources may have varying scales (e.g., blood glucose levels vs. heart rate). Normalization ensures that all features are on a similar scale, which is essential for most machine learning algorithms.

Once the data is processed and cleaned, it is ready for analysis using various data analytics techniques and machine learning models.

5.3. Real-Time Data Analytics and Insights

Real-time data analytics enable SMAS to provide actionable insights to both patients and healthcare providers on an ongoing basis. These analytics help in real-time decision-making and intervention, enhancing overall care delivery [14].

- Dashboards and Visualizations: Healthcare providers can access real-time dashboards that display key health metrics, such as blood pressure, heart rate, and glucose levels, as well as medication adherence rates. These dashboards highlight deviations from normal health trends and show the effectiveness of interventions over time.
- Health Trend Analysis: By continuously analyzing data from wearables, SMAS can track long-term health trends and provide alerts for emerging conditions. For example, if a patient's health metrics show consistent deterioration over weeks (such as a gradual increase in blood glucose levels), the system can notify the healthcare provider to intervene before the patient reaches a critical condition.

6. Privacy and security considerations

The Smart IoT-Based Medication Adherence System (SMAS) relies heavily on the collection, transmission, and storage of sensitive personal health data, making privacy and security a critical concern. As such, ensuring the protection of this data is paramount for maintaining patient trust, ensuring compliance with regulations, and preventing breaches that could jeopardize both patient health and the integrity of the system.

In this section, we delve into the privacy and security considerations that must be addressed when developing and deploying SMAS. These considerations cover various technical, regulatory, and organizational aspects necessary to protect sensitive health data.

6.1. Data Privacy Challenges

SMAS generates and handles vast amounts of sensitive data, including personal health information (PHI), medication usage logs, and behavioral data, which makes it prone to various privacy risks. The following are key privacy challenges:

- Sensitive Data Handling: Health data, such as vital signs, medication adherence, and personal health histories, is highly sensitive. Unauthorized access, sharing, or misuse of this data could have severe consequences, including identity theft, medical fraud, and breaches of patient confidentiality.
- User Consent: Since SMAS involves the collection and sharing of personal health data, obtaining informed and explicit consent from users is critical. Patients should have a clear understanding of what data is being collected, how it will be used, and with whom it will be shared [15].
- Data Sharing: One of the core features of SMAS is the real-time sharing of data between patients, healthcare providers, and sometimes family members or caregivers. This sharing, while necessary for effective monitoring and intervention, raises concerns about unauthorized access to sensitive data and breaches of privacy.

6.2. Security Risks and Vulnerabilities

The IoT devices, mobile applications, and cloud-based platforms that form the backbone of SMAS are susceptible to various security risks. These vulnerabilities can be exploited by malicious actors to access or manipulate sensitive health data. Key security risks include:

- Data Interception during Transmission: The transmission of data between IoT devices, mobile apps, and cloud servers occurs over potentially insecure networks, such as Wi-Fi or cellular connections. Without proper encryption, this data can be intercepted by attackers during transmission.

- Device Hacking: IoT devices, such as wearable health trackers and smart medication containers, are vulnerable to hacking. Attackers could exploit weaknesses in the devices' firmware or communication protocols to access, alter, or tamper with health data.
- Cloud Security: Since SMAS relies on cloud-based platforms for data storage and analysis, the security of cloud infrastructure is paramount. Data breaches, unauthorized access, or inadequate security practices on the cloud provider's end could result in massive exposure of personal health data.

6.3. Legal and Regulatory Compliance

SMAS must adhere to a variety of laws and regulations designed to protect patient privacy and data security. Compliance with these legal frameworks ensures that the system operates within the bounds of the law and protects patients' rights. Key regulatory considerations include:

- Health Insurance Portability and Accountability Act (HIPAA): In the United States, HIPAA sets stringent rules for the privacy and security of health information. SMAS must comply with HIPAA's privacy and security rules, ensuring that PHI is protected from unauthorized access, disclosure, and modification. This includes implementing safeguards such as access controls, encryption, and audit trails for health data [16].
- General Data Protection Regulation (GDPR): In the European Union (EU), GDPR governs the processing of personal data, including health data. It establishes strict requirements for obtaining patient consent, providing transparency regarding data usage, and ensuring that data is only retained for as long as necessary. GDPR also mandates that patients have the right to request access to their data, request corrections, and demand deletion.
- Data Protection and Privacy Laws: Other countries have their own laws for data protection and privacy, such as the Personal Data Protection Act (PDPA) in Singapore and the Privacy Act in Australia. These laws regulate the collection, use, and sharing of personal data and require SMAS to implement privacy-by-design and robust data security measures.
- FDA and Medical Device Regulations: If any IoT device within SMAS is considered a medical device (e.g., a wearable that tracks critical health parameters), it must comply with regulations set by authorities such as the U.S. Food and Drug Administration (FDA). This may involve rigorous testing, certification, and ongoing monitoring to ensure device safety and efficacy.

7. Challenges

7.1. Technical Challenges

7.1.1. Interoperability

- One of the primary challenges in deploying IoT-based healthcare systems is ensuring interoperability between diverse devices and platforms. SMAS relies on various IoT devices such as wearables, medication dispensers, and smartphones, each of which may have different communication protocols, data formats, and security requirements. Achieving seamless data exchange between these systems is essential for real-time monitoring and effective medication adherence tracking [17].

7.1.2. Data Accuracy and Reliability

- IoT devices are prone to errors, such as sensor malfunctions, calibration issues, or incorrect readings, which could compromise the accuracy of health data and medication adherence records. Inaccurate data can lead to false alarms or missed interventions, which may have detrimental effects on patient health.

7.1.3. Device and System Scalability

- As SMAS is designed to monitor a large number of patients, scalability of the system to accommodate growing numbers of users, devices, and data volume becomes a significant challenge. The system architecture must be able to handle large-scale data processing, real-time analytics, and cloud storage while maintaining performance and responsiveness.

7.2. Privacy and Security Concerns

7.2.1. Data Protection

- Although significant strides have been made in securing health data, the privacy of patient information remains a persistent concern. SMAS must implement robust security protocols, including encryption, authentication, and access control, to protect sensitive health data from unauthorized access and cyberattacks. Additionally, data storage in the cloud introduces risks of breaches, and ensuring compliance with global data protection regulations (e.g., HIPAA, GDPR) adds an additional layer of complexity.

7.2.2. User Consent and Control

- Ensuring that patients have full control over their data and can give informed consent is essential for building trust in the system. Patients must have the ability to easily manage their data-sharing preferences and know exactly how their data is being used. However, user consent management can be complex, especially in multi-stakeholder systems where data may be shared among patients, caregivers, healthcare providers, pharmaceutical companies, and insurers [18].

7.3. User Engagement and Behavior Change

7.3.1. Patient Motivation

- Encouraging consistent engagement from patients is one of the key challenges for SMAS. Medication adherence depends not only on tracking and reminders but also on motivating patients to take their medication as prescribed. Patients may forget to take their medications, become non-compliant due to side effects, or may not understand the importance of medication adherence for their health. Ensuring that patients are motivated and actively engaged is crucial for the success of SMAS.

7.3.2. Health Literacy

- For SMAS to be effective, patients must have a basic understanding of how to use the system and interpret the data. Low health literacy can result in patients misusing the system or failing to act on alerts. This is especially important for older adults, who may not be as familiar with digital technologies. Educating patients about how to use the system effectively and how it can improve their health outcomes is critical to maximizing its benefits.

8. Future work and opportunities

8.1. Advanced Analytics and AI Integration

8.1.1. Enhanced Predictive Analytics

- Incorporating more advanced machine learning (ML) and artificial intelligence (AI) techniques into SMAS can provide even more accurate predictions of patient health outcomes and medication adherence patterns. For instance, deep learning algorithms could be employed to analyze vast amounts of health data (e.g., from multiple wearables and health sensors) and predict potential health events such as heart attacks, strokes, or diabetic episodes with greater accuracy.

8.1.2. Adaptive Systems for Dynamic Care

- Future versions of SMAS could be designed to adapt dynamically to changing patient needs. For example, as a patient's health condition evolves or as they experience changes in their medication regimen, the system could automatically adjust its reminders and alerts to better suit the patient's current state. Adaptive algorithms could also analyze user behavior over time and recommend alternative treatment options if adherence patterns decline.

8.2. Integration with Broader Healthcare Ecosystem

8.2.1. EHR and Telemedicine Integration

- To increase the impact of SMAS, integration with electronic health records (EHRs) and telemedicine platforms is crucial. By consolidating health data from SMAS with other medical records, healthcare providers can gain a

comprehensive, real-time view of a patient's health and medication adherence. This would allow for more informed decision-making and personalized interventions.
- Telemedicine features could also be added to allow patients to consult with healthcare providers remotely, ensuring continuous care even in rural or underserved areas.

8.2.2. Pharmaceutical and Insurance Partnerships

- Collaborating with pharmaceutical companies and insurance providers could open up new avenues for improving medication adherence. For instance, pharmaceutical companies could use SMAS data to monitor the effectiveness of their medications in real-world conditions, while insurance companies might incentivize patients with lower premiums or rewards for adhering to prescribed regimens.

8.3. User-Centric Innovations

8.3.1. Gamification and Behavioral Nudges

- To improve patient engagement and motivation, SMAS could incorporate gamification elements, such as reward systems, progress tracking, and social sharing. For example, patients could earn points or badges for taking medications on time, which could then be redeemed for rewards. Social support networks could also be integrated to allow patients to share their progress and engage with family members or other patients.
- Behavioral nudges, such as personalized notifications based on the patient's adherence history, could also be used to encourage positive health behaviors.

8.3.2. Voice and AI-Powered Assistants

- With the growing use of voice assistants like Amazon Alexa and Google Assistant, integrating voice-powered features into SMAS could make it easier for patients to interact with the system, especially for older adults or those with limited digital literacy. Voice commands could be used to request medication reminders, check health status, or get advice on medication side effects.

9. Conclusion

The Smart IoT-Based Medication Adherence System (SMAS) represents a significant advancement in healthcare, offering a transformative approach to improving medication adherence and real-time patient monitoring. By integrating Internet of Things (IoT) devices, mobile applications, cloud computing, and machine learning, SMAS provides personalized, timely interventions that can significantly enhance patient outcomes. This system allows healthcare providers to monitor patients in real-time, ensuring they adhere to prescribed medication regimens, leading to better management of chronic diseases, reduced hospital readmissions, and improved overall health. However, the development and implementation of SMAS come with challenges, particularly related to data privacy and security, interoperability between diverse devices and platforms, and the engagement and behavior of patients. Addressing these challenges is crucial for the system's success and scalability. Ensuring robust security measures, compliance with data protection regulations, and seamless integration with healthcare infrastructure are essential to safeguarding sensitive health data and building patient trust.

In conclusion, SMAS offers a promising solution to the ongoing challenge of medication non-adherence. Through a combination of cutting-edge technology and thoughtful design, this system has the potential to revolutionize the way healthcare providers monitor and manage patient care, ultimately improving the quality of life for individuals and reducing the burden on healthcare systems worldwide. However, continued research, development, and collaboration are needed to refine the system and overcome existing challenges, ensuring it delivers optimal benefits for both patients and healthcare providers.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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