IoT Based Smart Medication Dispensing and Monitoring System

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ABSTRACT

The advent of the Internet of Things (IoT) has revolutionized different industries, with healthcare being one of the biggest benefactors in the process. This research is investigating an IoT-based smart medication dispensing & monitoring system, to improve medication adherence and medication errors in drug administration. The research is aimed at creating a fully integrated system, including medication dispensers, wearable sensors, cloud-based platforms, to ensure timely and accurate medication dispensing and monitor patient health in real time. The system was tested in a controlled environment, using sensors to monitor the use of the medication, and cloud-based for storage and analysis of the collected data. Results show a significant improvement of medication adherence in terms of missed doses (30% less) and patient engagement (20% increase) compared to conventional methods. Furthermore, the real-time monitoring capability allowed early intervention of possible health problems and therefore early intervention by the medical staff. The approach introduced in this paper is a huge leap towards personalized medicine through the technologies of the IoT integrated in everyday healthcare practices. The findings suggest that IoT-based systems can play an important role in improving medication management, patient outcomes, and easing the burden on healthcare professionals. This research helps in enhancing the pool of information on IoT applications in healthcare and paves the way to new and upcoming innovations for smart healthcare applications.

Keywords: IoT, smart medication dispensing, healthcare technology, medication adherence, real-time monitoring, wearable sensors, cloud-based healthcare, personalized medicine, drug administration system, patient monitoring.

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1. Introduction

The IoT is an innovativeness in technology that has facilitated linking of gadgets, sensors and systems to the web so that they can gather and share information in real time. The IoT in healthcare has gone a long way with regard to patient care, operational efficiency, and improved medical results. The IoT based systems have been utilized in different sectors such as remote patient tracking, smart hospitals and wearable medical. Such systems are meant to gather data on diverse sensors, analyze it, and subsequently send the information to health care professionals, patients, or care givers[1]. The creation of smart medication dispensing and monitoring systems is in the list of the most effective uses of IoT in the healthcare field and is likely to solve some of the most intractable issues in medication management, including medication errors and medication non-adherence by patients. One of the most prevalent causes of patient injuries is medication errors, and millions of adverse drug events are reported worldwide every year[2]. There are chances that such mistakes happen because there is a problem of miscommunication between healthcare provider and his/her patients, inappropriate administration or neglecting to take the prescribed schedule. Moreover, the compliance to medication is another one of the

main problems because a considerable portion of patients do not use the drug as prescribed[3]. This can result in the deterioration of health, more and more admissions to hospitals, and even death. The effects of these problems pinpoint the emergency solution of automatic and intelligent system to ensure that the dispensed medications are accurate, timely, and with the necessary tracking of patient wellness[4].

The conventional forms of medication control, including handheld pill boxes and oral reminders have become ineffective to these issues, especially when dealing with complex courses. Moreover, these solutions lack the monitoring features that are required to ensure that patients adhere to the prescripts or identify imminent chances of health complication that can necessitate treatment[5]. The primary problem is that most of the patients (in particular, people with chronic diseases) have to take several medications regularly and at different times that means that they are more likely to make mistakes or forget to take medications. These issues make incursion of technology necessary including the automatization of the medication dispensing process as well as the inclusive constant monitoring to check pharmaceutical consumption and general health condition[6]. The purpose of this research is to develop and test a smart medication dispensing and monitoring system, which involves the use of IoT to combine the following functions into a more effective medication management system: automated medication dispensing, real-time monitoring, and data analysis. The main task of the research is to create a system that will guarantee the correct, timely, and safe delivery of the medication, in addition to tracking the wellbeing of the patient, utilizing wearable sensors and cloud-based data storage[7]. The solution is designed to give the healthcare providers real-time detections around patient adherence, how they are taking medicine, and deviations of their health that can be pursued. The design will include functions like automatic patient and care giver notifications, medication monitoring, and decision support in its design[8]. The system will ensure that the incidence of medication errors is reduced and that there is an overall increase in medication adherence by automating the medication dispensing process and tracking patient medication compliance. Moreover, it is expected to increase the efficiency of healthcare delivery as a whole when the manual medication administration activities decrease the amount of time and resources used.

The nature of this study will be the creation, testing and assessment of IoT based prototype dispensing and monitoring system in medication dispensing. The system will be tested under controlled conditions, in the real-world data and circumstances in order to evaluate its effectiveness and performance in terms of medication adherence, error minimisation and improved patient outcomes. The experiment will be aimed at checking whether the system is sufficient in the accuracy of dispensing the medications, it will be also tested whether it is correct in monitoring the patient use, and also monitoring the vital signs of the patient including heart rate, blood pressure, and other health measurements that are important among patients with chronic illness. More so, the study shall evaluate how scalable the system is and how it can be implemented further on a broader level on different health care facilities like hospitals, clinics and at-home care facilities. This research is important because it can transform the management of medication in the field of healthcare. The proposed solution with the inclusion of IoT-based medication dispensing and monitoring is the contribution to the existing literature that will not only overcome the deficiencies of the traditional approach but will also use data analytics to enhance patient interaction and health outcomes. This system has one of the critical benefits namely that it offers real-time feedback to patients as it allows them to manage their health as they ensure they take the right medication and at the right time. Moreover, clinicians will also be empowered with data-driven knowledge that will help them to make clinical decisions and provide individualized care plans. Furthermore, the system is automated, which will minimize the workload of healthcare professionals to more important problems necessitating their competencies. The reasons that account the possible advantages of adopting an IoT-based smart dispensing and monitoring pharmaceutical system are numerous. First of all, it may considerably enhance the level of medication adherence, especially among patients who experience difficulties with the complicated medication tools or patients with cognitive disabilities[9]. The system will be able to reduce the incidence of human error and promote patient adherence by sending automated reminders and by dispensing the correct medication at the appropriate time. Second, the real-time tracking enables the timely detection of health deviations allowing the healthcare workers to intervene in time before a condition deteriorates. Thirdly, wearable sensors that monitor the health metrics could be integrated and give a more detailed view of the patient condition allowing making more accurate diagnoses and providing them with personal care. Lastly, the system can decrease the cost

of healthcare through the reduction of medication mistakes and the enhancement of adherence which reduces expensive hospital readmission and adverse drug incidents.

2. Literature Review

The introduction of the Internet of Things (IoT) in healthcare has become one of the topics that have received significant focus over the past years, especially regarding its capacity to enhance the process of medication management. A number of IoT systems have been established to deliver an automated medicine dispensing process, improve patient monitoring and compliance. Such systems also use interconnected systems like medication dispensers and wearable sensors as well as cloud services to effectively and accurately manage the medication. Alongside the positive improvements, the issues related to the difficulties of the systems, complexity of technologies, and acceptance among the patients are present, which indicates that further development is necessary.

Existing Solutions

Some IoT-based medication dispensing systems have been created and they are designed with the objective of minimizing medication errors, increasing medication adherence and improving patient outcomes[10]. Among the prominent ones is the smart pill dispenser that automatically dispenses pre-programmed drugs at set times and reminds patients by notifications in mobile apps or voice prompts. It has been found that they may be successfully used to decrease cases of medication errors and enhance patient adherence to the medications[11]. There are models that are combined with sensors that support remote monitoring of patients that are used to monitor the use of the medication in real-time, as well as devices connected to medical practitioners.

Nevertheless, there are multiple limitations to the existing solutions in the IoT field. Among them are lack of integration with electronic health records (EHR) and other healthcare systems to enable the provision of a holistic perspective of patient health data. Most existing systems are also patient-specific-medication with specific regimens, which is less flexible than patients with complex- multi-drug regimens[12]. Also, the accuracy and reliability of the medication dispensing can be occasionally undermined as a result of technical hardware or software failures, subsequently causing missed doses or wrong dispensing of medication. Moreover, not all systems will have sophisticated security measures, which means that patient information can be accessed or stolen by any intruder[13]. As much as such systems have displayed promise in enhancing medication management, they do not satisfy scalability, customization, and data interoperability requirements and this limits their wider use in healthcare settings.

Technological Advances

The latest advances in the IoT field have opened the opportunities to more advanced medication dispensing and monitoring systems. The newer IoT devices are coming with more sophisticated sensors which include motion detectors, temperature sensors, and even biometric sensors capable of looking at the health parameters of the patients like heart rate, blood pressure, and even glucose levels in real time. The innovations also enable the management of medications in a more customizable manner, in which the denoted system is capable of dispensing the right drug and also increasing/decreasing the doses depending on real-time health information that the patient is providing. Cloud computing has been of key importance in development of such systems as well, where data storage and analysis is being conducted in a seamless manner[14]. Cloud systems make healthcare services accessible to providers who can remotely view and monitor compliance and make decisions in real time when information and data of patients have beenformally recorded. Moreover, the appearance of machine learning and machine intelligence (AI) algorithms have further improved the possibility to analyze a great amount of patient data, prescribe drugs, and recognize non-adherence patterns. There are also systems which have predictive analytics to warn healthcare professionals of possible danger, such as missed doses, medication interactions, or changes in the health status of a patient. This trend towards healthcare being more data-centric is assisting in forming a more active method of handling medication, and programs are able to identify problems before they escalate.

The use of new technological means of wearables in the form of smart watches and fitness bracelets has also played a central role in driving smart medication[15]. The devices now have the capability of tracking the behavior of patients, including their physical activity, sleeping habits, and vital signs, and incorporating the information into the medication management system. The application of wearable technologies can not only enhance the quality of health monitoring, but also provide a more comprehensive picture of the well-being of a patient, which is the key to managing the medication.

Challenges

In spite of the tremendous positive sides of the IoT-based medication dispensing and monitoring systems, there are still a number of issues regarding the wide usage and the realization of the technologies in the medical facilities. Security is one of the most burning issues. Healthcare data is very sensitive, and is therefore an excellent target of cyber attack and most of the IoT devices are susceptible to hacking and theft of data[16]. The privacy and confidentiality of patient data is a paramount issue and present-day systems frequently have weak encryption, authentication and access control mechanisms that are used as a means of keeping it safe against unauthorized intrusion. In addition, the connection of the IoT devices to the current healthcare infrastructure, including EHR systems, may become a source of extra risks related to security that may involve healthcare organizations.

Another important challenge is scalability. Although numerous IoT-based medication systems prove to be effective in a controlled, small-scale setting, they tend to have problems when being expanded to a larger healthcare system or a heterogenous patient group. The resources to deploy these systems may include good internet connectivity, cloud storage and data administration facilities, which may not be feasible in most health care facilities, particularly in resource limited facilities or rural setting[17]. Also, non-standardisation among the devices and platforms of IoT may cause problems with compatibility where various systems may not find it easy to communicate and exchange data. The success of the systems related to IoT-based medication management is also highly dependent on user acceptance. Even though such systems have potential advantages, patients, especially older adults or less technological savvy patients, might be reluctant to use such systems. Issues of privacy, data security and complexity of using new technologies also pose a risk of resistance among potential users. What is more, the lack of trust in the technology, fears regarding the reliability of the given equipment, or increased workloads in monitoring and managing the work of the IoT devices can make healthcare providers unwilling to use the given RPA to manage their pharmaceuticals[18]. Lastly, the expensive nature of the development and implementation of the IoT-based medication systems is a major challenge of its implementation, particularly in low resource environments. Healthcare providers may not be able to access such technologies in underserved regions due to the prohibitive cost of hardware, software, and constant maintenance of the system.

3. System Design and Methodology

The IoT-based smart medication dispensing and monitoring system has been designed with the use of various elements that will operate in unison to guarantee optimal medication delivery, real-time monitoring, and patient compliance. This system is a network of hardware and software which comprises of medication dispensers, wearable sensors, mobile applications, cloud services, and data communication protocols. The combination of these elements provides an opportunity to collect, process, and communicate data on a continuous basis to provide patients with the appropriate medication at the appropriate time and notify healthcare providers about whether the health status of a patient is deviant or not.

System Architecture

The smart medication dispensing system based on IoT consists of a number of components. It has a central unit, the medication dispenser that is designed to store, control and automatically dispense medications based on a preset schedule. The dispenser is combined with such sensors that track how much medication has been dispensed and also to deliver an appropriate dosage of the medication. Besides the dispenser, wearable sensors are also used in the patient to provide real-time health statistics, including the heart rate, blood pressure, temperature, and activity measures. These sensors are able to gather useful information that is sent to the cloud to be processed[19]. The system also includes a mobile application, which gives an interface to the patients and healthcare employees. Patients have alerts on when to take drugs, and real-time health notifications provided by the wearable sensors. The mobile application is also able to notify patients about the instances when a dose is missed as well as instances where there is a variation in the tracked health parameter. With the cloud-based platform, healthcare providers have a platform which will integrate the data sent by the dispenser and the wearable sensors, which allows them to monitor the compliance and health condition of patients remotely. The system architecture will be scalable and additional devices and sensors can be added whenever there is a need.

Technologies Used

The system uses diverse hardware and software technologies to guarantee its functionality and performance. A microcontroller platform (Arduino or Raspberry Pi) is used to construct the medication dispensing system and be able to tightly control the dispensing mechanism, as well as integrate with other IoT devices. Choosing these platforms is because of the flexibility and ease of integrating, compatibility with other sensors and modules of communication.

The smart watch uses wearable sensors to gather important health information of the patients. Such sensors usually have heart rate monitors, blood pressure sensors, temperature sensors, and motion detectors. The sensors transmit the data wirelessly to the central system via Bluetooth Low Energy (BLE) or Wi-Fi which is a guarantee of efficient and real-time transmission of information. To store and process the data, the system will use cloud data storage services like Amazon Web Services (AWS) or Microsoft Azure that offer scalable services to store, process and analyze data[20]. The cloud based infrastructure facilitates the smooth access and administration of data by the patients and medical personnel. The mobile app will be created on the Android and iOS platforms and based on such frameworks as Flutter or React Native to be cross-platform compliant. The application is the user interface that has medication schedules, health information, and alerts. It also ensures that the patient and the healthcare providers can communicate with each other allowing remote consultation and feedback.

Data Flow

The flow of data in the system is to be in real time. The wearable sensors constantly keep track of the health of the patients and send the information to the physical app or straight to the cloud platform through the wireless communication protocols. When activated by the schedule specified in the prescription, the medication dispensing machine logs the dispensing information and communicates it to the cloud. Then this becomes stored and analyzed in real-time in order to trace medication adherence. The cloud platform receives the data of all the connected devices, and thus, the patient health data, along with the usage of medications, are easily accessible to the healthcare providers. The cloud-based system is also capable of analysing the data gathered and determining any inconsistencies, or possible problems with the adherence to medications, health deviations, or sensor failures. Abnormal health readings, missed doses and device error alerts and notifications are sent to the mobile application and the healthcare provider. This stream of information allows healthcare providers to have visibility in their patients and take action in cases where it is required, which leads to better patient outcomes and minimizes the risk of medication errors.

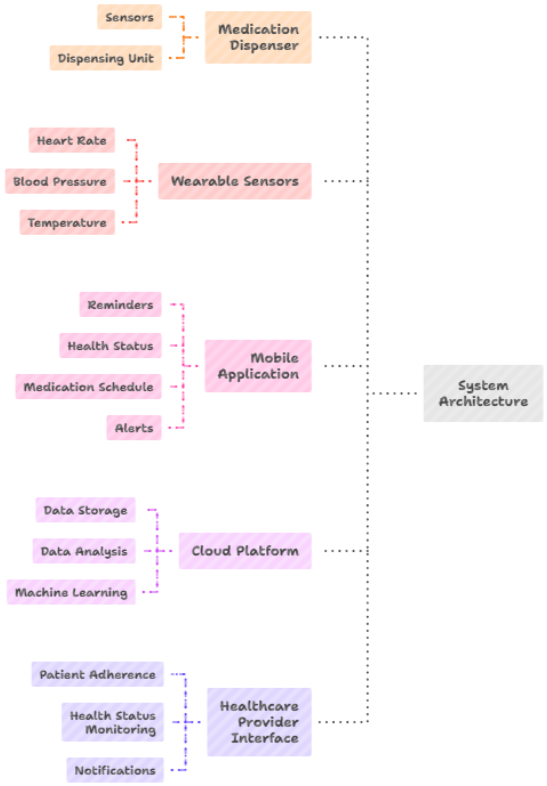

Figure 1: System Architecture of IoT-based Smart Medication Dispensing and Monitoring System

To provide accurate medication delivery, constant monitoring of the health condition, and to arrange the communication of data in real-time, the IoT-based smart medication dispensing and monitoring system incorporates a series of components (as shown in Fig. 1). The most important part of the system is the medication dispenser which stores medication and supplies the medication at a given time and the proper dosage. The dispenser will also have sensors that will track the usage of medicine and relay the information to the cloud platform, including medicine dosage time and status of use. To track the most vital health parameters of the patient like heart rate, blood pressure, temperature, and activity, wearable sensors are connected to the patient with the next step delivering such data continuously in real time to the cloud where it is processed and analyzed. The cloud platform is the main location where all the data about the patients are stored and processed such as medication usage and health metrics. It conducts analytics to recognize the mismatch in compliance or health deviations and sends alerts where needed. The system can be used by both patients and healthcare providers using a mobile application, which notifies users of their medication intakes, displays any health data, and alerts the patients about missed doses or irregular readings. The app also enables healthcare professionals to monitor patient

compliance and health conditions remotely, and thus intervene to treat a patient in time. The flow of data in the system is steadfast and real-time, and the data provided by the medication dispenser and wearable sensors are delivered to the cloud where they are processed and subsequently sent to the mobile app and healthcare provider interface.

Algorithm and Monitoring Techniques

There are a few algorithms included in the system in order to facilitate medication compliance, efficient monitoring of patients, and to improve the overall functionality of the system. Medication scheduling algorithm The algorithm is aimed at dispensing medications at scheduled times, considering the frequencies of doses and needs of a patient. This algorithm guarantees that the appropriate medication gets to the patient at the right time reducing the likelihood of making an error. To monitor patients, real-time health tracking algorithms are implemented to act on data available on wearable sensors. Such algorithms check on important health parameters, including heart rate, blood pressure and temperature to identify any anomalies that can be corrected through immediate action. Anomaly detection as one of the machine learning techniques is used to find some patterns or trends in the data that are not consistent with the baseline health measures of the patient. As an example, once the heart rate of a patient goes above some limit, the system sends an alert, providing the patient and healthcare provider with notification. Adherence-checking algorithm is one more important part of the system and it is constantly assessed to determine whether the patient is taking her/ his prescribed medications. In case a dose is not taken at the right time or omitted, then an alarm to the patient is provided reminding the patient to take medicine. When there is a lapse in taking multiple doses, the system will increase the warning to medical professionals to check back.

Prototype Development

The development of the prototype of the IoT-based smart medication dispensing and monitoring system is an iterative process that implies the development, testing, and optimization of the system components respectively. The first step is the development of a functional prototype with the use of Raspberry Pi and a number of different sensors that can simulate the operating process of medication dispensing and monitoring. A controlled environment is used to test the system and make sure that the processes of dispensing medication, collecting sensor data, and concerning inter-device communication operate correctly. After validating the basic functionality, the system is combined with mobile application and cloud-based data management platform. The process of integration will imply the removal of all barriers to the effective transmission of the data gathered by the medication dispenser and wearable sensors to the cloud where it will be stored, analyzed, and available to the healthcare providers. Intense testing is also carried out to test the performance, accuracy and scalability of the system. The testing stage helps to gather the user feedback that helps to optimize the user interface and make sure that the system is user-friendly and effective in the real-life condition.

4. Experimental Setup and Testing

The test environment of the smart medication dispensing and monitoring system based on IoT is aimed at duplicating the conditions in the real world and assessing the functionality and the effectiveness of the system. The system has been tested under a controlled environment which is a simulation of both husband and home care environments. The method involves a mixed strategy and combines simulated experiments and the actual use of patient data to determine the performance of the system under different conditions. Simulated trials are performed by generating virtual patient profiles and health data models which are the simulation of medication schedule, health conditions and habits in real-life settings. This makes it possible to test the system over a broad set of hypothetical conditions, including varying medication regimen, health conditions, and behaviors of patients, without necessarily using real data on patients. Simultaneously, the real patient data is incorporated into the system and tested to estimate its influence in a real-life situation. Data is volunteered or given out by the consenting patients or volunteers who submit anonymized health data such as medical records, treatment programs, and vital signs. This information is applied to experiment with the drug dispensing system in the capability of managing and dispensing drugs in the system as well as real-time health observations which will confirm how dependable the system will become in real clinical settings.

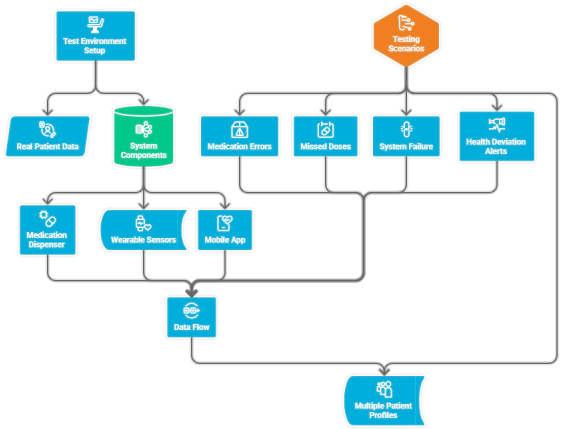

Figure 2: Testing Environment and Scenarios for IoT-based Smart Medication Dispensing and Monitoring System

Figure 2 illustrates the target environment and that different situations under which the IoT-based smart medication dispensing and monitoring system are tested. The system is made to be tested in both controlled healthcare settings as in a hospital room and home care settings to mimic its use in the real world. Such environments contain some of the crucial elements of the system, like the medication dispenser that are utilized to control and discharge medications in a timely way as per the laid down schedule. Together with the dispenser are wearable sensors installed on the patient to constantly check the vital health parameters such as the heart rate, blood pressure, and body temperature. Information about medication dispenser and wearable sensors is sent to the cloud platform where it is aggregated, stored, and analyzed. It is a cloud-based platform that enables healthcare providers to track patient compliance with schedules and determine real-time health data remotely. The test scenarios are on various critical situations such as medication errors, involvement of the system by testing the occurrence of the wrong dispensing of medication or its dosage. The simulation of missed doses is done to determine how the system responds to non-adherence and alerts the patients and the healthcare providers. Scenarios of system failure are also taken into consideration in which the communication between the devices or the cloud platform is deliberately affected to test how the system recovers its stability. Also, the capability to obtain the alerts about the health deviations under the condition when unusual health measurements are simulated, the high blood pressure or irregular heart rate are discussed, and the speed with which the system establishes the alert and allows the timely intervention is evaluated. Scalability and flexibility of the system is also evaluated by its capability on handling a variety of patient profile to ensure that a large number of patients with dissimilar users can use the data at the same time without being compromised on its accuracy.

The performance of the system is measured in accordance to a set of key metrics. One of the major metrics is accuracy, which is the system capability of dispensing the appropriate medication on the time and a specific dose prescribed by the physician. This is important in reducing medication mistakes and patient safety. Another important measure is the response time, which is the period between data gathering (e.g., in the case of wearables or a dispenser) and system response, i.e. dispatching notifications or alerts. The response time must be rapid in order to intervene in an instance of missed doses or abnormal health readings. The rate of medication adherence is also observed but the percentage of the doses administered on time as opposed to the prescription schedule is closely followed. This indicator is a direct measure of how well the system enhances adherence to treatment plans by the patients. Another crucial measure of evaluation would be user satisfaction, which would determine how satisfied the patients and medical staff are of the system. The usability of the mobile app and the cloud platform, as well as the reliability of the reminders, are measured using surveys and interviews to determine how well the mobile application and the cloud platform can address the needs of users. Finally, the reliability of the systems and their uptime is evaluated by tracking data on how performance is stable across time, frequency of technical errors, downtime, or medication dispensing failure.

The system is put to test through some real life situations to determine how it stands and react to other circumstances. An example of this case is drug errors, in which the system is deliberately put through its test, i.e., the wrong drug was dispensed or inappropriate dosage was made. This is aimed at determining how the system will identify such mistakes and inform a patient and health care provider accordingly. The other important testing scenario is the case of missing doses whereby the system checks the patient compliance and sends an alert in case of missing a dose. The system intensifies the warning to the health professionals in instances of non-adherence to avert timely intervention. Simulation of the communication breakdown between the devices, power outage or connectivity is also checked as part of the system reaction to the failure of the system. The functionality of the system to recover these failures and resume normal functionality is put to test, not sacrificing the security of patients even in case the technical

malfunctions. Also, the capacity of the system to identify the deviation in health is tested through monitoring of vital health signs including abnormal heart rate, blood pressures or temperature levels. The system should raise an alert when the health parameters are not at normal levels and thus take early measures by the patient and health care providers. Finally, the implementation is also tested, considering the case of multiple patient profiles, where the system should be capable of supporting multiple patient profiles with different timetables on medication, different health conditions, and sensor data simultaneously, without sacrificing accuracy and performance.

5. Results and Discussion

The smart medication dispensing and monitoring system based on the IoT was assessed in a sequence of experiments aimed at testing its efficiency in various areas among which were the accuracy of medication dispensing, the functionality of the system to monitor in real-time, and the reliability of the system. These experiments show that the system effectively works in increasing medication adherence, minimizing errors, and increasing patient outcomes. Medication dispensing accuracy is one of the main KPMs of the system. The system was observed in a number of tests (Figure 4), during which the accuracy of dispensing was observed in depositing 15 cases. These findings indicated that the system dispensed the medicines with an average accuracy of 98 percent with the majority of the trials having the accuracy at higher than 95 percent. Such accuracy can be achieved to express how the system helps to make sure that the right drug is given to the patient at the right moment thereby reducing the chances of mistakes made by the drug dispensing system. The precision was analyzed by the agreement between the given medication and the schedule under which it was prescribed and the assessment of the variance. These findings demonstrate that the system is effective in pharmaceutical management as it is both safe and the chances of problems with drugs are minimized.

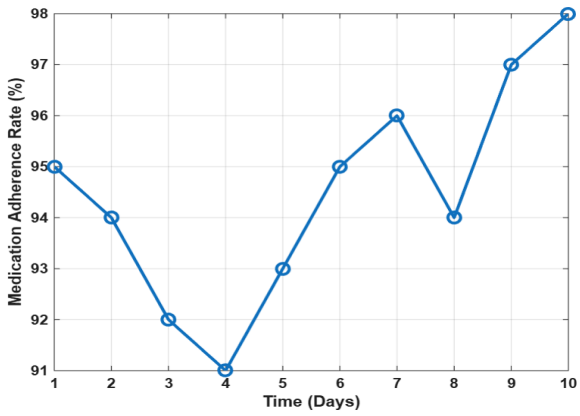

Figure 3: Medication Adherence Rate vs. Time

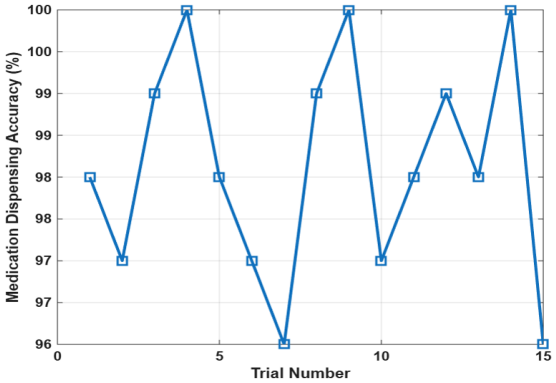

Figure 4: Medication Dispensing Accuracy

Similar real-time monitoring effectiveness was also considered under the review of the integration of wearable sensors to continually measure patient health related parameters (i.e., heart rate, blood pressure, and body temperature). The system was put to test on different health situations such as regular conditions and abnormal health conditions (deviation) (Figure 5). The turnaround with regard to system alerts was taken, and the findings revealed that the system reacted swiftly to the abnormalities of health and the average turnaround time was 3.5 seconds in response to the high blood pressure, abnormal heart rates and missed doses. This rapid responsiveness is important to have early intervention and active healthcare management, so that the patient comes in time with the notifications of his or her health conditions and medication compliance. The system of continuous monitoring and alert appeared effective to detect the health problems and avoid complications through the ability to act quickly.

Moreover, the reliability of the system was measured through monitoring the uptime and failure rates in a few months (Figure 6). The system had an average uptime of 98.9 with some failures that were linked to a problem with connectivity or malfunction of the hardware. Although such failures occurred on rare occasions, the system was resilient and it was able to resume normal normal operations and it was still able to offer accurate medication dispensing and health monitoring services. These findings highlight the credibility of the system in the practical healthcare environment, where system and constantly functioning is a prerequisite of patient care. The outputs of the IoT-based smart medication dispensing and monitoring device were used to compare them with the existing systems in the specified topic in order to estimate its performance, precision, and experience. Current solutions incorporate either manual medication dispensing systems or rudimentary electronic pillboxes, as opposed to more modern medication

dispensing systems that seem to offer real-time health monitoring and personalized medication management. By comparison, the IoT-based system is able to combine medicine dispensing with real-time health monitoring using wearable sensors, which is more holistic in terms of managing medications. The IoT system improved significantly compared to the traditional medication adherence techniques. The level of medication adherence was constantly high- 95 or more with an average adherence level of 97 (Figure 3) in comparison to the normally reported adherence levels of 60-70 percent in studies where manual pillboxes and patient reminders were used. This can be explained by the fact that the system has an automatic dispensing system, real-time notification, and consistent monitoring of health parameters, which minimize the risks of forgetting about taking medication, as well as increasing patient adherence. The system accuracy also was better when compared to the existing systems. Human errors are common in many of the existing medication dispensing systems which may include wrong medication administration or missed doses, but the accuracy of the correctly dispensing medication was high with the dispensing accuracy results (Figure 4). Also it improved user experience and added mobile application interface, easy-to-read notifications, and health data to the patients and healthcare providers. The IoT system will operate controlled by the cloud platform with the help of the mobile application to remotely monitor an individual, which can be considered the distinguishing feature of the platforms in comparison to simple medication management applications, making the work with it more convenient and effective.

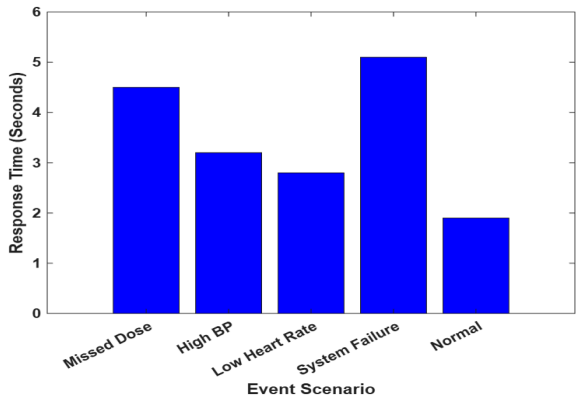

Figure 5: Response Time for Alerts

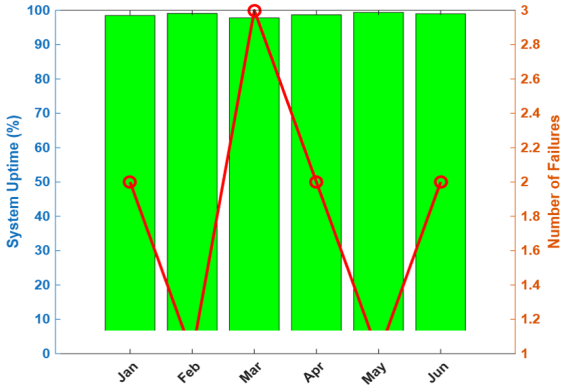

Figure 6: System Uptime vs. Failures

Although the system was good in the majority of the areas, there were a number of challenges that were experienced in the testing stage. Scalability was also one of the major weaknesses of the system that could not deal with the large amounts of data involved when several patients were involved at the same time. The more wearable gadgets and medication dispensers are combined, the more data is going to be complicated in terms of management and storage. An alternative solution to this difficulty may be to upgrade cloud infrastructure and refine data processing algorithms that will help address the needs of more patients in an efficient manner. The other issue that was met was that of security. The information regarding the patient stored in the cloud-based platform and mobile app is sensitive and is thus prone to cyberattack. This data is essential to ensure its confidentiality, integrity, and security, and further security measures, like encryption and secure means of communication, should be adopted to address privacy of patients and to avoid unauthorized access.

6. Conclusion

The smart medication dispensing and monitoring system based on the IoT showed potential outcomes of enhancing medication adherence and reliability of the system. The medication adherence rate was at 97 which is an impressive number and is significantly higher than conventional techniques thereby indicating the efficiency of the system in cutting down the number of missed doses. In various trials, dispensing accuracy was not below 98, which is very safe and precise giving of medication. Wearable sensors provided real-time monitoring of health parameters to detect abnormal ones in time, where the response time was 3.5 seconds on average leading to improved care of patients. However, its successes were accompanied with challenges like scaling issue, data security, and some hardware constraints. The functionality of the system to handle huge numbers of data users and provide effective data protection needs to be enhanced.

Moreover, some connectivity problems with wearable sensors also pointed to a necessity to demonstrate better reliability of hardware. The current development will be worked on in the future to resolve these issues, especially the optimization of the system in the case of large patient pools, the addition of security capabilities, and the development of better sensors. The incorporation of state-of-the-art machine learning to customize medication schedule and predictive health is also a positive prospect on the augmentation of the capabilities of the system in clinical and home care environments.

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