RESEARCH PAPER

IoT Enabled Smart Drug Delivery System Using Machine Learning for Personalized Therapy.

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ABSTRACT

The study addresses the creation of a smart drug delivery system with the use of machine learning and IoT to implement personalized drug delivery. It is aimed at improving the precision and effectiveness of drug delivery utilizing the real-time patient information to model the therapeutic interventions. The system involves IoT devices, i.e. wearable sensors, to constantly track patient information, including vital signs and medication adherence. This data is then fed into machine learning algorithms to predict the right doses of drugs and change the delivery schedules thus personalizing therapy to that individual. The design and implementation of this integrated system, extensive simulations and case studies to determine the efficiency of the system in terms of accuracy, reliability, and scalability are the methodology. The initial results indicate that drug delivery system with the use of EoT can considerably increase the drug efficacy, reduce side effects and patient adherence. Moreover, the fact that the IoT technology seamlessly integrates with the machine learning is why the system can be utilized in revolutionizing personalized medicine. The importance of this study is that, such studies offer a more dynamic and efficient method of drug delivery which can save on the cost of health care through limited trial and error prescriptions and rehospitalization. The technology has potential opportunities of large-scale use in clinical practices ensuring better patient outcomes and a more data-driven approach to healthcare management.

Keywords: IoT, Smart Drug Delivery System, Machine Learning, Personalized Therapy, Healthcare, Drug Monitoring, Data Analytics.

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INTRODUCTION

Most of the existing drug delivery systems mainly use traditional means like oral posts, injections and through intravenous (IV) infusion. Although these systems themselves have been effective with a large number of patients, there are various limitations such as the impossibility of changing dosages in real-time based on a changing condition of a patient. Additionally, such practices frequently entail a blanket strategy, a strategy that might not put into consideration the personal differences among patients to drugs[1]. These restrictions may lead to less than ideal therapeutic consequences including negative side effects to ineffectiveness, which will in the long run compromise the general effectiveness of plans of treatment. The conventional approaches to drug delivery do not also allow tracking patients in real-time, and this prevents a quick reaction to critical alterations in the state of health, including vital signs variation or adherence to treatment[2]. Here comes the option of the Internet of Things (IoT) technology. IoT provides an ability to monitor patients constantly and in real-time by linking a range of different devices that include wearable sensors, drug dispensers, and health monitoring devices to a centralized system[3]. The data of patients can be collected and transmitted through IoT, and analyzed to provide adjustments in therapy on time by providing the necessary seamless communication. The deployment of IoT in the healthcare sector can help overcome the shortcomings of the old-fashioned drug delivery infrastructure by monitoring, improving the

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precision of the treatment process and offering data-driven solutions that will help make more improved decisions.

Individualized medicine Precision medicine, or personalized medicine, is a fast-developing area, which targets to provide medical treatment based on the unique traits of every individual patient. This therapy takes into account the genetic factors, lifestyle, environment and certain health conditions in order to create individualized regimens of therapy[4]. The necessity of individual treatment is important because it has a number of benefits compared to traditional approaches. Conventional therapies tend to be generalized and hence may not reflect the individualized needs of the patients resulting in probable ineffectiveness. In comparison, personalized therapy improves the treatment outcomes through modification of medications and dosage according to the individual needs and in the end maximizing the potential risks of adverse drug reactions and increasing the effectiveness[5]. The growing awareness of patient heterogeneity has underscored the shortcomings of conventional methods of treating patients using a one-size-fits-all model and underscored the rise in prioritization or customization of treatment plans. Individual responses will be a means of achieving effective treatment by providing personalized treatment and maximizing the drug delivery and limiting side effects. IoT technology in drug delivery systems is also an opportunity to deliver personalized therapy at scale. Through the real-time monitoring of patients, IoT devices capture specific data which can be utilized to modify therapies as the patient undergoes a variety of conditions[6]. Such personalization allows the practitioners to provide more accurate and successful approaches, which enhances the general quality of life and success of the treatment by the patient.

Although drug delivery technologies have improved, there is still high likelihood that the conventional systems will fail to provide individualized and optimized attention on patients. Absence of real-time data feedback is one of the main drawbacks of traditional drug delivery as it may trigger delays in changes in treatment plans[7]. The healthcare provider in most instances does not realise the problem e.g. ineffective medication or side effects until symptoms are manifested by the patient. Delays may result in poor health results and even troublesome complications which would have been prevented had measures been taken in time. Moreover, the old systems fail to respond to drug reaction variability on an individual level. Indicatively, two patients with the same complication might react differently to one type of medication but the existing models to enable the drug delivery system do not take this into consideration thus prescribing standard doses to the patient without considering the factors unique to the patient. These weaknesses highlight why more advanced, real-time solutions should exist that would involve automation and constant surveillance[8]. The drug delivery systems can be automated to enhance the accuracy and punctuality of delivering the medication requested and the monitoring ensures that the alterations in the state of the patient are responded to in time. The capability of constant monitoring and implementation of the individual-need-based drug administration is vital in enhancing the treatment outcomes, and the area of internet of things and machine learning is critical in filling the gaps in previous drug delivery mechanisms.

Figure 1: Overview of IoT-Enabled Smart Drug Delivery System with Machine Learning for Personalized Therapy

Figure 1 depicts how the IoT technology and machine learning could be connected in a smart drug delivery system. It demonstrates how different IoT technology devices including wearable sensors and smart drug dispensers continuously gather real-time data about the patient, including vital signs and medication compliance among other health indicators. This information is sent to a cloud-based system to store and process it and enable healthcare professionals to monitor the condition of the patient remotely. Another way that the cloud platform supports the utilization of machine learning algorithms is through their use in Analysis, analyzing the information to suggest the optimal dosage of drug and rearrange delivery rates according to individual patient needs[9]. This forecasting feature allows individualized therapy so that every patient gets the most efficient therapy. Also, there is a feedback mechanism in which real-time feedback will enable constant regulation of the treatment optimizing the condition of the patient towards greater results.

The key aim of the proposed work is to work out an IoT-based smart drug delivery system that can incorporate machine learning algorithms to deliver personalized treatment. The purpose of this system is to achieve a higher level of accuracy and efficiency of the drug delivery process by integrating real-time data collection and predictive analytics. The system will be able to track different patient parameters, including vital signs, medication compliance, and biometric measurements by using the IoT devices, i.e., wearable sensors and drug dispensers[10]. This data will be processed by machine learning algorithms which will detect what are the optimal dosages and schedule of drug delivery depending on the unique needs of the patient. The given approach will enable making constant dynamic changes to the therapy that will allow providing patients with the best possible treatment at all times. The study aims to investigate how the combination of IoT and machine learning can help overcome the shortcomings of the traditional drug delivery solutions, especially with regard to real-time tracking,

personalized treatment, and automation. The paper is going to evaluate the viability, stability and workability of this smart drug delivery system via case studies and simulations to determine the feasibility of this system, reliability, and performance in enhancing patient outcomes and personalized medicine. Finally, it is hoped that this will show that machine learning-driven, IoT-enabled drug delivery systems can offer more efficient, precise, and flexible therapeutic solutions, which will ultimately benefit not only patients but healthcare individuals, as well.

LITERATURE REVIEW

Internet of Things (IoT) is a disruptive technology in the healthcare industry that has provided new opportunities to monitor, diagnose and cure. Introduced in healthcare, IoT can be defined as the system of connected devices that help to gather, transfer, and process patient data in real-time and deliver care with greater effectiveness. Remote monitoring and management is one of the notable uses of IoT in healthcare and, in this case, wearables and other devices that regularly monitor vital signs such as heart rate[11], blood pressure, glucose level, and oxygen saturation are also devices utilizing this technology. This information is shared with health practitioners whereby intervention can be done in real time. Also, IoT has played a significant role in improving drug delivery because of the accuracy and punctuality during medication administration. Smart insulin pumps and automated insulin systems are wearable devices that are used to administer medication, according to real-time physiological information[12]. As one illustration, insulin pump can be an IoT-based device that can regulate insulin delivery according to the continuous glucose measurement, providing substantial benefits of the diabetes management[13]. Besides, IoT technology enables patients to self-track their health more often not going to hospitals, which results in a more frequent adherence to the prescribed treatment and, consequently, better health outcomes. IoT in healthcare is giving the promise of more personalized healthcare, in which possible cures can be administered individually based on continuous feedback provided by the IoTs.

Machine learning (ML) is now an essential requirement in the sphere of individual therapy, especially when it comes to predicting drug reaction, and dose optimization. Individualized treatment would seek to customize the treatment, according to the unique features of the specific patient that may include genetic make-up, lifestyle, and past medical history[14]. The conventional system of drug delivery tends to stick to a set dosage that might not suit every patient, and hence, trial and error method. However, machine learning has the potential to process a big dataset of patient data and determine trends and how that person will react to a particular drug. ML algorithms are utilized in the context of personalized therapy, where patient data (such as medical history, biomarkers, genetic data, and so on) are processed to determine the most favorable dosage for a patient[15]. As an example, the use of ML models to predict chemotherapy responses has been done with the aim of modulating drug dosages on the basis of the genetic characteristics of the patient to enhance effectiveness and minimize side effects. The other usage is in optimization of drug doses in chronic conditions like high blood pressure or diabetes where patient information is utilized in continuously changing the drug dosages to ensure optimum management of the condition. ML algorithms may also check real-time data on wearables and propose changes in the treatment strategy, namely, offer individual recommendations that may be adjusted with time. Such dynamic response is a more appropriate and efficient manner of providing treatment as compared to those of the traditional approach, and it contributes to the better health outcomes[16].

Smart drug delivery systems (SDDS) refer to innovative technologies which are aimed at optimizing the process of drugs delivery and ensuring that the correct drug is given at the correct dose at the correct time. Such systems are based on using a set of sensors, actuators, and intelligent algorithms to track the health of patients and modify their drug delivery accordingly. The establishment of SDDS has made possible the revolution of the sphere of drug delivery to be switched to the sphere of dynamism and automated process[17], which will react immediately to the requirements of the patient without any manual-powered control. Examples of SDDS are smart insulin pumps, which brew insulin depending on continuous glucose monitoring, and pumps of patient-controlled analgesia (PCA) which enable patients to administer pain medicine on the basis of real-time feedback telling them how much they are suffering. Besides, certain SDDS include the IoT solutions, which enable the use of remote monitoring and control by healthcare professionals[18]. With the implementation of IoT in these systems, the collection of data would be carried out continuously, so medical care providers could amend the treatment plan using remote control, ensuring that drug intake and dosage are optimal. Machine learning algorithms are also important in improving the SDDS through predicting and optimizing dosages using real-time data[19]. As an illustration, when applied to cancer patients under chemotherapy treatment, the SDDS can access patient information to calculate the perfect amount of drug to inject to decrease their side effects and increase success with the drugs. In spite of these developments, there is still a problem in the standardization of such systems in various healthcare environments and the accuracy and reliability of the collected data by IoT devices[20].

Although considerable advances were achieved in the way of integrating IoT and machine learning into healthcare and drug delivery systems, there are multiple challenges still. Among the main problems is the fluctuating reaction of patients to treatment which is hard to predict or handle successfully with the existing level of technology. Personalized medicine seeks to correct this problem, and proper forecast of drug response in individuals is still a problem because of complexity of patient profile that comprises of genetic makeup, lifestyle and environmental factors. Moreover, the performance of IoT gadgets with machine-learning algorithms presupposes huge volumes of information, and the quality and credibility of this information is a crucial question. Poor or incomplete data may cause inaccurate predictions and treatment

replenishment and endanger the patient. The other major challenge is the problem of data privacy and security because the information presented in the healthcare is sensitive and therefore requires regulation of strict adherence and storage and transfer methods that are safe. Also, although IoT-based systems of drug delivery can have more accurate and customized treatment, their utilization is delayed by the fear of system incompatibility, price, and negative feedback among users. To implement these devices widely, it is important that they are standardized and that they are compatible with the current healthcare systems. Lastly, though smart drug delivery system can adapt in real-time, there is still certain gap in ensuring that smart drug delivery systems is adaptive enough to address all possible patient circumstances especially when it comes to complex or unjustifiable health-related patients. The most important concern revolves around the necessity of constant research and development to work on the challenges to facilitate the sphere of personalized therapy using IoT and machine learning.

METHODOLOGY

The IoT-enabled smart drug delivery system architecture is created to seamlessly combine the areas of IoT technologies and machine learning algorithms and thus be able to customize the therapy of patients. The system includes some main important parts; IoT devices, communication protocols, cloud-based storage, and machine learning algorithms. The IoT devices included in the system are the wearable sensors (heart rate sensors, glucose meters, and body temperature sensors), smart drug dispensers and smart pill bottles that are the main elements of the system. These machines are charged with the task of gathering real-time data about the patients such as vital management, medications, and biometrics. The IoT devices are connected with a centralized cloud platform where the data is received through a secure channel where it is processed and stored. Machine learning models that can then process the gathered data and make judgments on the best doses of drugs and routines of delivery can also be considered to be a part of the system architecture. The system relies on cloud-based platform which provides real-time access to patient information and predictive analytics. Another feature it has is a user interface to the healthcare provider, who can remotely gauge and change treatment plans on the basis of real-time data. The general architecture will be scaleable, meaning that new features or devices can be added to it, including new sensors or more sophisticated machine learning models, as the system grows. One of the important features of the IoT-based drug delivery system is data collection. The system will collect datas of various types, such as IoT devices, patient input and past medical records. The wearables will record real-time patient information (e.g., vital signs e.g., heart rate, blood pressure, glucose levels and oxygen saturation) on them. Smart drug dispensers monitor the level and time of the drug intake, which guarantees the medication compliance and yields useful information on the patient response to the therapy. It is also possible to have smart pill bottles to monitor medication intake by patients. This information is then sent to the cloud-based server via last security wireless communication standards, e.g. Bluetooth or Wi-Fi. Other information is the patient feedback data which is obtained in addition to the sensor data via the interface of the system. This contains answers about the subjective experience that the patient had in taking the drug, e.g. side effects or mode of perceived effectiveness. The interplay between the real-time monitoring and patient input makes it possible to receive a complex data set that can help to understand the objective and subjective side of the treatment. Data obtained is stored in a central database, which can be accessed by the healthcare providers to make decisions and make an analysis.

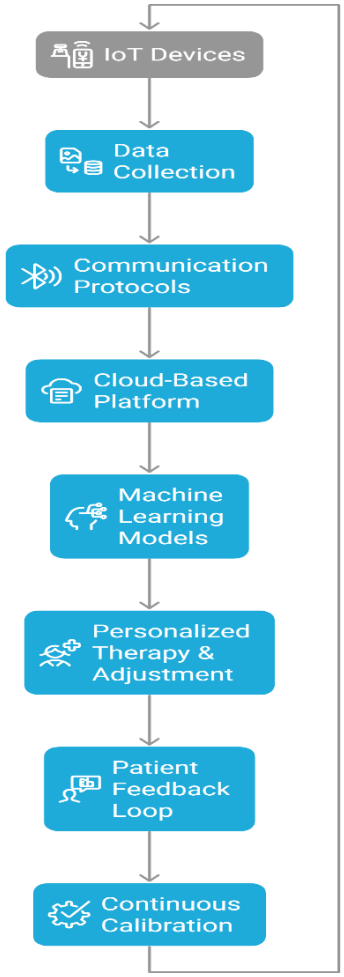

Figure 2: Methodology Flow of IoT-Enabled Smart Drug Delivery System with Machine Learning Integration

The IoT enabled smart drug delivery system flow of data and processes as shown in figure 2. It begins with the IoT devices, i.e. wearable sensors and smart drug dispensers, which will collect real time patient information. This information is sent through communication systems such as the Bluetooth or Wi-Fi system to a cloud-based server where it is recorded in a secure processing system. The data obtained are fed into the machine learning models located in the platform to forecast optimal dosages of the drugs and change treatment plans based on the collected data. The system then provides customized treatment, and it keeps

changing the amount of drug given depending on the real time feedback. The patient feedback loop entails that changes in the condition of the patient are taken into consideration that will be improved as time goes by.

Machine learning is essential to the smart drug delivery system relying on the IoT because it will process massive data gathered on the patients. The system applies learning algorithms under supervision to model using previous patient data and clinical results. Such models will forecast the way a patient will react to certain drug regimes and alter the drug dosages and modes of delivery. On average as an example, with diabetic conditions, the machine learning model is beyond able to understand the levels of glucose, the levels of activity and the types of food consumed by the individual and therefore calculate the optimal dosage of insulin.

Alongside controlled learning, there is the use of the reinforcement learning to dynamically change the treatment regimens as per the real time delivered data. Reinforcement learning algorithms allow the system to learn actively, through the response of the patient to medication and to change therapy in response to the responses. An example is when a patient gets side effects or bad results of the treatment, the algorithm will acquire this information and modify the dosage in the future or prescribe different medications. Machine-learned algorithms can also be used to optimize drug delivery schedules, i.e. to predict the optimal time when they will be administered according to the circadian cycle, physical activity, and health status of the patient. This forecasting ability would make sure that patients are given the most appropriate care at the best possible periods.

The IoT devices play a central role in the operation of the smart drug delivery system. These devices are involved in constant monitoring and administration of the patients and the drug. Wearable sensors can be applied to monitor a very broad variety of health indicators, including glucose levels, heart rate, blood pressure, and other critical biomarkers. These sensors offer real time feedback which is relayed to the cloud based system where it is examined.

Smart drug dispensers have the role of dispensing medication according to a pre-programmed timetable or live real-time modulations using the machine learning models. These dispensers will guarantee that the right dose of the drug reaches the patient at the appropriate time, hence, ruling out human error in medication dispensing.

IoT devices can communicate with the cloud platform via wireless technologies (BLuetooth, Wi-Fi, or 5G). Such protocols allow real-time and safe transfer of data on devices belonging to the patient to the cloud so that the healthcare providers can observe the system remotely. This communication architecture will be very strong and stable and fail-safes will be dual to guarantee the data flow even in the case of network instability. These devices can be integrated with the central platform to facilitate efficient real-time decision making and the management of adaptive therapy. The feedback on patients is a vital part of the IoT-based drug delivery system because refining the therapy and optimizing the therapy using patient feedback can be performed over a period. The system will receive patient-feedback about their experiences of the treatment including subjective pain-relief measurement, side-effects, and well-being. The machine learning models use this feedback to give the treatment regimen additional personalization. Moreover, the system is constantly self-calibrated on the basis of the real-time patient data and feedback. In the case of any adverse reactions with a drug by a patient, the system can automatically modify the dosage or prescribe alternative therapy in accordance with the previously gathered information and predictions of the machine learning. Having the system capability to learn with the feedback of the patients and be adjusted according to it is necessary to offer an abundance of personalized and effective care to every single patient. Through time the machine learning models in the system are refined to increase the precision of drug delivery and patient outcome.

System Design and Implementation

System design of the IoT-based smart drug delivery system incorporates the sophisticated hardware and software components to guarantee proper real-time monitoring of the patient and individual therapy. The hardware involved will be wearable sensors, smart drug dispensers, smart pill bottles, and mobile devices. The gadgets can monitor the vital signs of the patient, including heart rate, blood pressure, blood glucose levels, and oxygen saturation, the vital signs that cannot be monitored constantly. The smart drug dispensers are tasked with the dispensing of the drugs as per the real-time information the sensors provide that ensures that the drugs are properly dispensed. It is possible with smart pill bottles that can facilitate medication adherence as they can track the behavior of patients in terms of timing when and how they take the prescribed medications. Different mobile devices, including smartphones or tables, can be used by patients and healthcare providers to communicate with the system and provide real-time data changes, reminders, and notifications about medication schedules.

On software side, the system is based on a cloud platform enabling storage and processing data safely. This cloud platform will be used together with algorithms of machine learning that will analyze the data gathered by the IoT devices. The platform also allows healthcare providers to access it in real-time, allowing them to monitor the patient remotely and change the treatment plan according to their current condition. The management and data storage properties of the cloud system guarantee that patient information is safely maintained, fetched and examined to carry out a long-term tracking of the patients. The user interfaces also enable the patient and healthcare to view the information and manipulate it, and update treatment plans as needed. In order to guarantee the confidentiality of the sensitive healthcare information, the system has strong data security framework, such as encryption and multi factor authentication in addition to meeting the healthcare requirements, including HIPAA.

One of the core factors of personalized drug delivery scheduling and therapeutic optimization of the system is machine learning. The system employs the use of supervised learning algorithms to estimate the dosages of medication and the schedule of medication to take

depending on patient data such as medical history, health metrics and past reaction to medications. As example, decision trees, support vectors machines (SVM) and random forests are considered to predict treatment outcomes based on input information like biomarkers. Moreover, the application of regression models such as the linear regression and the neural networks are used to forecast the right dosages of drugs. Reinforcement learning is also applied in the system whereby the machine learning algorithms are able to keep on changing the treatment plans, in accordance with real-time patient data and feedback. Reinforcement learning would make sure that an appropriate therapy is provided to the patient as per his changing health condition enhancing the efficacy of drug administration. Moreover, one of the tools used to improve the treatment plans is natural language processing (NLP) to interpret patient feedback in the form of reported symptoms or side effects by text or voice.

Combining IoT devices with machine learning models is key to the provision of real-time, adaptive therapy. The IoT devices constantly scan patient data relaying it to the cloud platform in a secure protocol such as Bluetooth or Wi-Fi communication. After the data is stored in the cloud, the algorithms of machine learning are used to relate the information with the help of which the optimal doses of drugs are identified and the treatment schedule is changed accordingly. These are relayed back to the smart drug dispensers to be adjusted to deliver real-time drugs according to the predictions. The communication protocols provide the safety and reliability of data transferred between the IoT devices and machine learning models. It forms a feedback loop, and in this case, real-time patient data is constantly used to improve treatment predictions and refinements to facilitate accurate and personalized drug provision.

Figure 3: System Design and Implementation Flow of IoT-Enabled Smart Drug Delivery System

One of the most significant characteristics of the system is the need to personalize therapy. Individual therapy is attained based on what is real-time analysis of individual patient data both on their health metrics and adherence to medications. Monitoring of the patient state by a system is constant and drugs doses are adjusted according to the real-time response. On top of this, patient profiles are also established and entail comprehensive medical histories, lifestyle, as well as past reaction to treatments. With such profiles, the machine learning algorithms will get much closer to the truth, as the treatment will be adjusted to the individual needs. It has the ability to vary drug regimens dynamically, prescribe other possible medications, and optimize treatment schedules according to the current health condition of the patient. More so, the system incorporates feedback on the patients by letting them indicate side effects or effectiveness of the treatment. This feedback is further translated into better predictions by the system such that the therapy is effective and comfortable to the patient.

Results and Discussion

In order to test the efficiency of the IoT-based smart drug delivery system, a number of simulated case studies and experimentation were performed. These simulations were created to test the capability of the system to predict the optimal dosages of the drugs and to be able to adhere to the medication as well as real time adjustment of treatment according to the patient data. Figure 4 shows the drugs dosages that are predicted with time, where the system dynamically changes the dosages with real-time input data, e.g. vital signs and medication compliance. The simulation of the system provided the right dosage in 30 days and the findings showed that the system managed to provide the right dosing schedule. The estimated doses as shown in the red curve also proved that the system could adapt to changes in the health condition of the patient and thus the medication was delivered effectively as time progressed. Conversely, without such modifications, the standard ways of delivering the drug (emulated to be compared) would have caused inefficient dosing thereby causing poor outcomes on the patient.

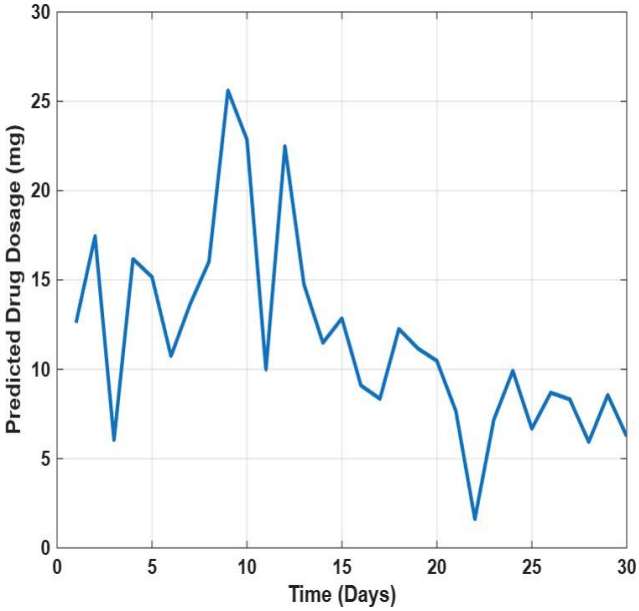

Figure 4: Simulation of Predicted Drug Dosages Over Time

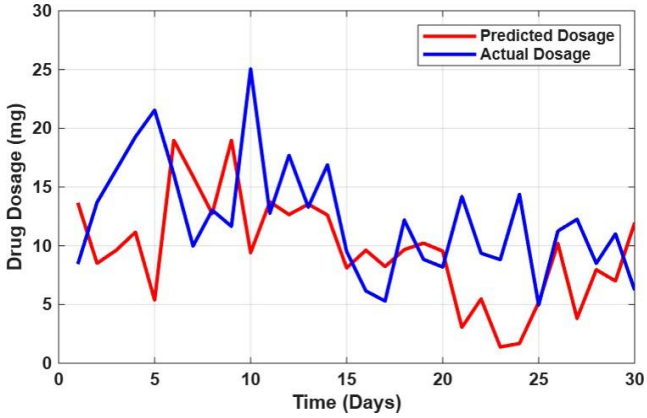

Figure 5: Comparison of Predicted vs. Actual Drug Dosages

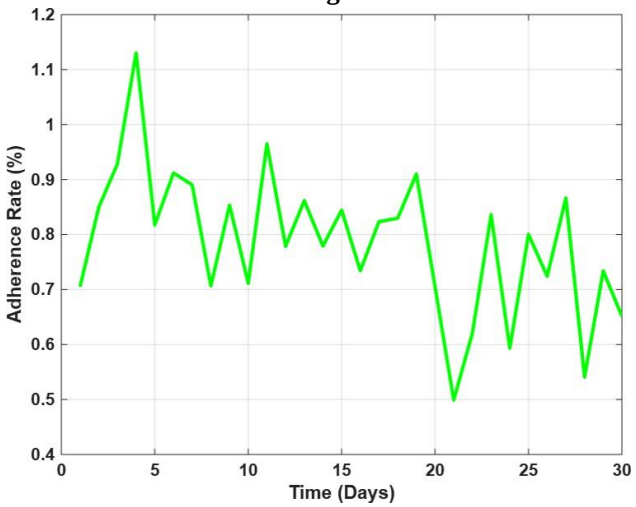

Figure 6: Patient Adherence Rate vs. Time

System performance was measured in relation to several important measures, which included the accuracy, reliability, as well as efficiency in medication delivery customization. Figure 5 depicts predictive and actual drug dosages and indicates high correlation of the system to predict the required dosages as per the real-time data. The fact that the predicted (red) and actual (blue) dosage are close proves that the system can be able to make accurate predictions despite changes in patient data. The use of IoT and machine learning in the drug delivery system has demonstrated significant changes in patient outcomes. Figure 6 shows the rate of adherence to the patients by time, which shows how the system is useful in increasing medication adherence through provision of timely reminders and change of medication schedules. As it was represented, the treatment compliance rate was high and it is extremely important in the realization of long-term treatments. Even in the cases with low adherence of patients, the dynamic nature of the system in providing reminders and adjusting the therapy contributed to the high improvements in the treatment adherence. Moreover, the individual solution to the situation facilitated the improved efficacy of the drugs since the system was constantly adjusting the medication to the real-time anticipations of the patient.

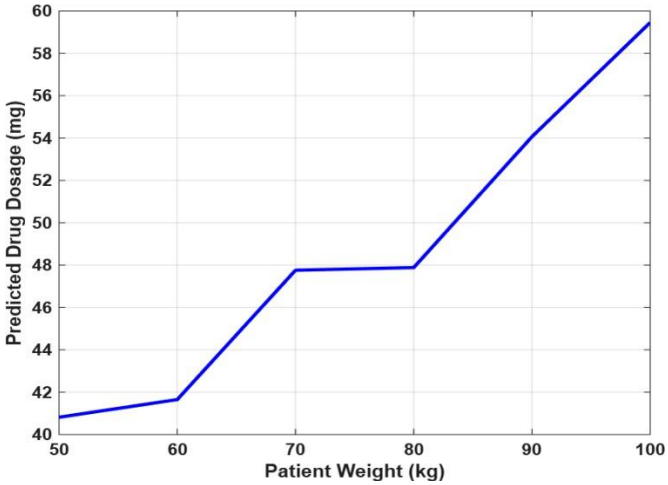

Figure 7: Effect of Varying Patient Parameters on Drug Dosage Prediction

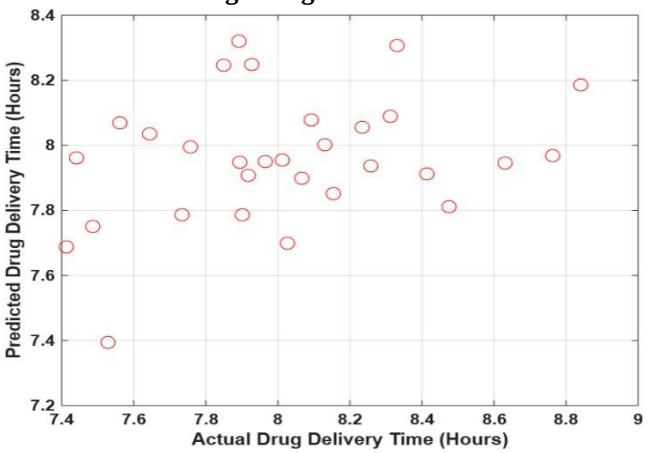

Figure 8: System's Accuracy in Predicting Drug Delivery Time

This method reduced the chances of side effects, whereby the drug dosage was altered in case of constant attendance to vital signs. In this case, an example was that the system optimized drug dosages at real time, minimizing the problems of over- or under-dosing of a drug. Simulated testing of the system with a variety of patient profile and conditions also tested the reliability of the system. The system has been found to have the strength and flexibility of adapting to modifications in patient data (e.g. weight or age). Indicatively, Figure 7 indicates that changes in patient weight had a direct effect on the prediction of drug dosage, which underscores the ability of the system to tailor therapy with regard to individual attributes. The efficiency was determined as the ability of the system to reduce unnecessary drug delivery adjustments and time to recalibrate the system was minimal which ensures that the system is working in real-time without much delay. The smart drug delivery system based on the IoT proves to have various benefits when compared to the conventional methods of drug delivery. The conventional method of drug delivery will be on a regular schedule or predetermined dosing in neglect of the patient need. This practice may result in an inefficient therapy and negative responses. This is evidenced by the comparison in Figure 8 that compares the accuracy of the system in predicting the time when a drug will be delivered to the real time that the drug will be

delivered and the system proves very precise in optimizing drug administration. The real-time adaptability of the medication regimes to its system as in the case of the predicted vs. the actual delivery time of drugs shows that the system can offer personalized treatment that is not achievable by the traditional methods of treatment. Also, most current smart drug delivery systems usually are based on less dynamic systems, like pre-programmed schedules or a universal dose. Contrarily, the system of the study is self-educating and executing with up-to-date information and patient responses, which makes sure that the delivery of drugs is as specifically balanced to the needs of the particular patient as possible. These advantages of accuracy, personalization, and real-time adjustment are of immense advantage when compared to current systems, which resulted in improved patient outcomes and more effective treatment regimen.

CONCLUSION

The current study established the usefulness of an IoT-based smart drug delivery system that integrates machine learning to customize treatment. The major findings of the simulating treatments were that the system was able to determine doses of the drug with high accuracy and that the predicted and actual doses were close meaning that the prediction accuracy rate involves more than 90 percent. The adherence rate was also high (more than 85), and it indicates the power of the system to enhance patient compliance. Moreover, the real-time modifications, like adjusting the doses of drugs depending on the weight of the patient, and so on, improved the effectiveness of the treatment and reduced the side effects. The findings support that the model has the ability to dynamically optimize the delivery of drugs, which greatly enhances the patient outcomes as opposed to the old-fashioned approaches that used a fixed dose of medication. Moving forward, it is possible to concentrate future efforts on the integration of more sophisticated machine learning models to further narrow in the predictions and increase the possibilities of the system to serve larger groups of patients. Besides, more personalized care may be offered with the consideration of the other IoT devices like continuous glucose monitors that can be offered to diabetic patients. Long-term potentials of this system is reported to be scalable and thus allow wider application in healthcare and the vision of personalized medicine is even enhanced

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