RESEARCH PAPER

Deep Learning Driven IoT Enabled Smart Drug Delivery Systems for Personalized Therapy

Devadi Ganesh[1*], Dr. Manjunatha B[2], Mr. S. Muthukumar[3], Dr. A.V.G.A. Marthanda[4], Saptaparni Chatterjee[5], Snigdha Rani Behera[6]

[1]Assistant Professor, Department of Computer Science and Engineering, GMR Institute of Technology (GMRIT) - Deemed to be University, Rajam, Vizianagaram, Andhra Pradesh, India.

Email: Ganesh.d@gmrit.edu.in

[2]Associate Professor, Department of Industrial Production and Engineering, SJCE, JSS Science and Technology University, Mysore, Karnataka, India.

[3]Assistant Professor, Department of Mechanical Engineering, VSB Engineering College, Karur - 639111, India.

[4]Associate Professor, Department of EEE, Lakireddy Balireddy College of Engineering, Mylavaram, Andhra Pradesh (Permanently Affiliated to JNTU Kakinada), India.

[5]Assistant Professor, Department of Computer Science Engineering, Gardencity University, 16th KM, Old Madras Road, Battarahalli, Bengaluru - 560049, Karnataka, India.

[6]Associate Professor, Department of Pharmaceutical Analysis, School of Pharmacy, ARKA JAIN University, Jamshedpur, Jharkhand, India.

Received: 20th Apr, 2026 | Revised: 25th Apr, 2026 | Accepted: 9th May, 2026 | Available Online: 14th May, 2026

ABSTRACT

The integration of Deep Learning (DL) and Internet of Things (IoT) technologies has emerged as a transformative approach in healthcare, specifically in the development of smart drug delivery systems for personalized therapy. This paper presents a comprehensive study on the design and implementation of an IoT-enabled smart drug delivery system powered by deep learning techniques. By leveraging real-time patient data collected through IoT devices, such as wearable sensors and monitoring systems, the system optimizes the delivery of drugs based on individual needs, improving therapeutic outcomes. Deep learning algorithms are utilized for continuous learning and adaptation to dynamic patient conditions, ensuring precise and tailored drug administration. The research also explores the architecture of the system, data processing methods, and performance evaluation. Results show that the proposed system can significantly enhance the efficiency and accuracy of drug delivery, making it a promising solution for personalized medicine. Challenges and future directions are also discussed, focusing on scalability, data privacy, and real-time system integration.

Keywords: Deep Learning, Internet of Things (IoT), Smart Drug Delivery Systems, Personalized Therapy, Real-Time Data Processing, Healthcare IoT, Machine Learning in Medicine, Drug Administration Optimization, Wearable Sensors, Personalized Medicine.

How to cite this article: Ganesh D, Manjunatha B, Muthukumar S, Marthanda AVGA, Chatterjee S, Behera SR., Deep Learning Driven IoT Enabled Smart Drug Delivery Systems for Personalized Therapy. Int J Drug Deliv Technol. 2026;16(44s): 696-713; DOI: 10.25258/ijddt.16.44s.74

Introduction

The personalisation of medicine has become a reality which is transforming the whole health care system from a one-size fits all approach to tailor made treatments for the individual. The deployment of smart drug delivery systems (SDDS) with built-in intelligence will further upgrade the personalised use of medicines. These systems not only optimise delivery of drugs to the target site, but also help to track and adjust the treatment on the basis of real time health data. With ever increasing complexities in meeting the needs of patients, the relevance of SDDS cannot be over emphasized. Smart drug delivery systems combine engineering and biomedical technologies to achieve the desired release of drugs in a controlled and reproducible manner. They can be based on both implantable devices and external interactive systems that monitor physiological parameters, thus allowing for real-time adjustments to the drug release rate and dose. This smart approach enables optimal dosage levels to be achieved, and reduces side effects.

Chronic diseases such as diabetes, cancer and cardiovascular disease require continuous, real-time, customisation of treatment options, taking into account physiological responses, metabolism and patient compliance.

The integration of Internet of Things (IoT) technologies into smart drug delivery systems open-up new possibilities in personalized and 'on demand' patient treatments. Integration of IoT with smart drug delivery devices will offer multiple benefits and it will enhance the quality of care given to patients. Real-time connection offered by IoT system will seamlessly connect patients and healthcare professionals through smart platforms. Real-time data generated by built-in or integral sensors can continuously monitor key parameters such as dosage and drug release, adherence to schedule and real-time health parameters like body temperature of patients. Real-time analysis of such data will help the health care professionals track the therapy of patients and make the best possible clinical decision. Parallel to the explosion in IoT data, the adoption of deep learning algorithms, part of the broader AI landscape, has grown dramatically across industries. The capacity for deep learning algorithms to learn from large datasets of historical and real-time IoT patient data allows for the prediction of patient response to various drugs. As a result, healthcare providers are able to more quickly and effectively treat patients by using deep learning to determine the most effective drugs for each individual patient. Additionally, deep learning enables the system to predict the pharmacokinetics and pharmacodynamics of drugs on an individualized basis, enabling further fine-tuning of treatment for the best possible outcomes. This all translates into a reduction in the time needed to meet therapeutic goals by eliminating trial and error from the treatment process.

The integration of IoT technology with deep learning also has the potential to materialize intelligent, adaptive drug delivery systems capable of real-time modulating of delivery parameters in response to data input from monitored patient parameters. For example, wearable IoT devices integrated into patient garments could collect real-time data related to patient changes as the patient undergoes a treatment cycle (such as stress, physical activity, sleep, or other vital signs). These real-time parameters could be utilized by machine learning algorithms trained to predict the optimal release rate or specific medication type to maximize therapeutic efficacy.

Real-world implications of this emerging integration of IoT and deep learning could result in such improvements in healthcare. For example, the smart insulin pump could be calibrated through feedback loops that integrate with a patient's continuous glucose monitoring data, and is controlled by a deep learning algorithm that predicts insulin needs based on postprandial blood glucose levels. These examples illustrate the potential of IoT and deep learning to develop patient-centric drug delivery systems that are responsive to real-time needs. The integration of smart drug delivery systems with IoT and deep learning technologies has the potential to improve personalized therapy outcomes, increase effectiveness of treatment, and encourages patient participation in their care. The convergence of these technologies in health care can lead to the development of innovative patient-centric solutions that are data-driven and promote personalized therapy as the hallmark of future health care. Smart drug delivery systems (SDDS) are emerging as modern tools of treatment that provide a number of advantages over conventional drug delivery systems. These systems offer controlled drug release that target specific organs or sites of disease, thus improving therapeutic efficacy and reducing side effects. In achieving these outcomes, various biocompatible materials, nanotechnology, and biosensors are used to control drug release, monitor pharmacokinetics and pharmacodynamics, and adjust dosing on real-time basis as per individualized patient needs.

Literature Review

Significantly, the new Smart Drug Delivery Systems (SDDS) are poised to transform the present mainly 'one size fits all' pharmaceutical approaches. Present pharmaceutical products are increasingly being enhanced with advanced Internet of Things (IoT) and deep learning-based smart functionalities, thus paving the way for the introduction of increasingly personalized or "tailored to the individual" formulations. These novel Smart Drug Delivery Systems could not only make therapy more efficacious, but also incorporate personalized approach to medicine, thus enabling smart pharmaceuticals to be precisely designed, customized and formulated to cater to individual patient's needs taking into consideration his or her specific set of biochemical traits. This new wave of healthcare is poised to deliver novel, smart drug delivery systems with sophisticated functionalities and improved efficacy, thereby functioning on a highly individualized basis, incorporating effects of genotype as well as environmental- and lifestyle-factors that determine health. (Panchpuri et al., 2025). IoT plays a vital role in SDDS by enabling continuous real-time monitoring of crucial data such as glucose, heart rate or medication adherence through connected devices. Healthcare professionals can access this live information to make accurate treatment decisions. The data collected can also be analyzed by deep learning algorithms to spot patterns or identify and predict individual patient responses to certain drugs. As a direct result, healthcare professionals are able to be more proactive in their approach to treating patients, making dosage adjustments on the basis of current status to meet the needs of individual patients and enhance the likelihood of successful treatment.

Continuing with the diabetic scenario, the integration of IoT (IoT, sensors) in patient management includes tracking blood glucose levels on real time and enabling automated insulin delivery through smart pumps that calculate and deliver the required insulin dose based on real time glucose levels. This is an example of SDDS applied through personalized therapy wherein patients receive treatment in dosage form tailored to their individual metabolic responses. Furthermore, deep learning algorithms can also enhance the functionality of SDDS systems by applying complex learning based on huge clinical data to develop optimal treatment protocols. In addition, some algorithms can find correlations between genetic markers and the efficacy of drugs for specific patients, to assist physicians in choosing the most effective treatment options for their individual patients. Deep learning algorithms are self-learning from input data, and can continue to improve the effectiveness of treatments developed from the data over time, as they work in conjunction with healthcare to foster a patient centric approach of care.

Smart drug delivery devices (SDDS) offer a novel solution to current challenges in the administration of drugs and medications to patients. By integrating the Internet of Things (IoT) and deep learning into healthcare, SDDS represent a step change in medical technology, moving away from a one-size-fits-all approach to a highly personalized medical model. While still in its early days, SDDS are developing rapidly and have the potential to enable improved clinical outcomes, fewer hospitalizations and a better quality of life for millions of patients. The commitment to an integrated, individualized approach to healthcare promises a radical transformation in the future of patient care., The integration of deep learning with the Internet of Things (IoT) has led to significant advances in smart drug delivery systems and personalized therapy. These smart devices can remotely monitor and control drug release in individual patients according to real-time data and many factors that affect pharmacokinetics and pharmacodynamics, including specific pharmacogenomics, environmental and lifestyle factors. The current architectures for smart drug delivery systems include multi-level data processing systems and smart connectivity. Based on real-time data analysis, these systems can adjust the relevant treatment strategies for individualized for each patient.

In smart drug delivery systems are implemented using embedded devices and deep learning. IoT devices like health monitors and smart pill dispensers with sensors track vital signs, medication ingestion and environmental factors. These data are sent to cloud-based platforms where deep learning algorithms are applied to them. Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) help in identifying features in patient data and learning behavior over time to make predictions about optimal delivery routes for the drugs. Systems that personalize and optimize drugs through real-time patient data draw on a variety of methodologies that are united by the core concept of adaptive therapy. Machine learning, particularly reinforcement learning, is used to determine the optimal dosing regimen for a patient in real time, based on feedback from the patient and information from electronic health records and other health data. Federated learning, which enables the training of deep learning models on distributed data without centralizing patient data, is another important methodology for these systems. This approach can address privacy concerns while enhancing the accuracy and robustness of models through collective training.

Smart drug delivery systems based on real-time information of physiological parameters have been integrated into diverse therapeutic fields to improve patient outcomes. Smart systems for the management of chronic diseases, such as diabetes, based on real-time glucose monitoring using various sensing modalities with deep learning algorithms for predictive target insulin determination have been established. Wearable devices that monitor heart rate and physical activity for the management of cardiovascular diseases by adjusting the dosages of antihypertensive drugs in real time have also been reported. In oncology, the integration of IoT with deep learning has enabled the potential of selecting the most effective drug for each patient through tumor profiling and health monitoring data. Smart systems can release doses of chemotherapeutic drugs on demand at optimized times, reducing toxic side effects while boosting the therapeutic outcome. Another application involves the use of deep learning to improve the tumor-specific localization and drug release from newly developed nanoparticles for targeted drug delivery.

Theoretical Background and Methodology

The architecture of Internet of Things (IoT)-enabled drug delivery systems involves the integration of various devices and technologies to monitor, track, and adjust the delivery of medication in real time. At the core of an IoT drug delivery system are sensors, which are used to collect patient data such as physiological signals (e.g., heart rate, blood pressure, body temperature) and drug concentration levels in the bloodstream. Internet of things (IoT) and deep learning technologies may influence the development of smart drug delivery systems. Furthermore, these systems could be interconnected with numerous healthcare applications such as electronic health records (EHR) and telemedicine platforms to facilitate data exchange in real-time among various healthcare professionals. This development will enable healthcare providers to make more informed time and place-bound decisions to deliver optimal patient-centered care, which will evolve to incorporate the exchange of data in real-time from multiple stakeholders and facilitate the development and individualization of treatment plans in real-time to meet specific patient needs and improve patient experience.

Combining deep learning with IoT in smart drug delivery systems heralds the shift towards truly personalised therapy and a potential revolution in the healthcare system. Research is rapidly moving from bench to bedside, paving the way for patients to receive tailored treatment based on the vast amounts of data generated in real time. While it is difficult to predict future developments, one can be certain that tomorrow's solutions will integrate artificial intelligence with daily health care routines and further optimise patient management. The combination of the Internet of Things (IoT) and drug delivery systems has brought a new dimension to healthcare, the potential of which is growing every day. Monitoring and real-time exchange of health-related data delivered by intelligent devices can facilitate optimised therapeutic outcome. The synergy between IoT and drug delivery systems, also known as smart drug delivery systems, has captured significant attention within the drug delivery and healthcare fields. One of the core concepts of smart drug delivery is to be able to monitor the physiological parameters of a patient and simultaneously receive real-time data for the effective decision-making and optimisation of health care. Unlike conventional drug delivery systems that follow a standard dosing regime, smart drug delivery systems enable the development of delivery systems on the basis of individual patient needs by continuously monitoring various health-related factors.

The Smart Drug Delivery System which incorporates IoT connectivity in existing formulations utilises sensors, IoT devices and communication technologies to sense the patients' physiological parameters while tracking the dosage compliance. This new generation of devices are wearable devices that can store valuable information, also known as “smart drugs”, which are embedded with microchips into the packaging of the medication, or incorporated within smart inhalers. The key benefits of this technology lie in the timely delivery of drugs to its actual systemic site of action and also track the information in real time, whereby the remote access by patients and healthcare professionals enables personalisation of drug dosage by making adjustments and altering treatments based on individual patient profiles. Continious monitoring in IoT drug delivery systems is achieved through the use of biosensors to monitor a range of biochemical markers, vital signs and other metabolic parameters. A diabetic patient could have a smart insulin pump that automatically administers insulin doses on the basis of readings from glucose level biosensors. Such smart IoT-based drug delivery system not only would help in improving health outcomes, but also reduces the inconvenience to patients of having to get up at odd hours to take medication. Both patients and clinicians can be kept informed and make appropriate clinical decisions in real time. This enables a shift from a “sick-care” system to a “health-care” system.

Moreover, smart drug delivery systems based on the IoT consist of multiple layers in their architecture. In terms of their configuration, these systems are characterized by three hierarchical layers including perception layer, network layer and application layer. Sensors, biosensors, meters and instruments that collect various information from the environment and the body are assigned to perception layer. The Network layer refers to data transmission, and various communication protocols such as Bluetooth, ZigBee, Wi-Sun, cellular networks, (4G/4G5, WiMAX, Wi-Fi) etc. are utilized to transfer data to the cloud server. The Application layer consists of various software and algorithm that interprets data through sophisticated analysis techniques, most of which are executed by deep learning algorithms and carry out forecasting, analyzing, decision-making and intelligent recommendation for optimal administration route and doses of drugs.

This paper describes an approach to create a variety of personalised options for therapies using Deep Learning and IoT data of multiple patients. Machine learning methods can be employed to investigate the association between various patient data and treatment effects using data of multiple patients. Such approaches create various possibilities for optimal treatment decision-making, including personalised drug regimens based on patient-specific data, and the development of predictive models to estimate the risk and likelihood of adverse effects for individual patients. In particular, a deep learning approach may be useful for making predictions or estimating the risk of and likelihood of adverse effects for individual patients based on their historical data including genotype information.

The integration of the Internet of Things (IoT) technology in smart drug delivery systems has proven practical value in real-world applications. Case studies have shown the capability to improve patient adherence to prescribed treatments and fine-tune medications for greater effectiveness, while also lowering the number of avoidable hospital readmissions. Developments such as digital pills that report to caregivers when a patient has taken their medication, or smart inhalers that remind patients to use their medication and record usage information for their caregivers, exemplify how technology can transform how pharmaceuticals are administered and monitored.

The IoT technologies can enhance the drug delivery systems through continuous real-time monitoring of crucial parameters during administration of drugs and can facilitate data sharing in real time. This will bring significant shift in drug delivery systems towards more personalized medicine with improved outcomes. Integration of emerging technologies will lead towards focusing on patient centric approach and will ultimately result in better health outcomes and improved quality of life. Here, deep learning plays a pivotal role, as it employs the concept of artificial intelligence through incorporation of neural networks with several layers to learn complex representation of data. Deep learning finds significance in drug delivery systems with application in healthcare to process and learn from large amount of medical data, as reported in (Wang et al., 2025).

The medical data in modern world possesses intricate characteristics and may involve more than one data modality such as image, genomic sequence and electronic health records. Traditional statistical techniques may struggle to capture important features and correlations present in the medical data, where deep learning algorithms can efficiently learn the hierarchical feature representations.

In pursuit of optimizing smart drug delivery systems for treating a variety of diseases, deep learning can be employed for personalized treatment of individual patients. Many diseases are multifactorial and vary in terms of their effects on individuals. By integrating deep learning into the drug delivery system, personalized plans can be created for each individual to improve efficacy of drugs and minimize side effects. Deep learning algorithms can analyze information from sensors in the multitude of IoT devices that are available, such as wearable devices and biomedical sensors that capture real-time vital sign information of patients. This data can be used to make dynamic real-time adjustments in drug dosing amounts and timing to improve health outcomes for patients. This approach offers a new paradigm for administering drugs which is no longer a one-size-fits-all solution.

The recent progress in convolutional neural networks (CNNs), recurrent neural networks (RNNs) and generative adversarial networks (GANs) inspires the further applications of deep learning technology in smart drug delivery systems. Since CNN can deal with large amounts of medical imaging information, diseases-associated biomarkers can be explored for designing intelligent drug delivery system. Furthermore, RNN has the advantage to handle sequence data, which can be the patients' historical medical data or time-series reading data captured in real-time by various sensing devices. By fully integrating such massive healthcare data into clinical treatment, medication can be given more precisely with consideration of the patients' real-time body state. Predictive analytics can also be enhanced by the introduction of deep learning algorithms into smart drug delivery systems. By utilising historical treatment data from clinical records, deep learning models can predict patient responses to different drug formulations allowing for improved clinical outcomes. This ensures that decision making, based on predicted patient response, results in optimised drug delivery outcomes through the determination of decision boundaries between different scenarios. The effectiveness of the drug delivery systems can be further elevated by combining them with deep learning technology. Furthermore, integration with Internet of Things (IoT) sensors in a healthcare setting can facilitate continuous health monitoring of patients. Real-time health data generated by IoT sensors can be analyzed by deep learning models to determine the best course of action in real-time, and doctors can use that information to make more informed health care decisions and provide personalized treatment to patients.

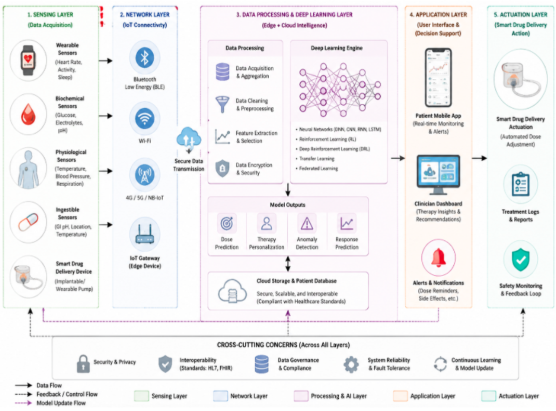

Figure 1: Architecture of Deep Learning Driven IoT-Enabled Smart Drug Delivery System for Personalized Therapy

Figure 1 illustrates the comprehensive architecture of an IoT-enabled smart drug delivery system powered by deep learning, designed to optimize personalized therapy. The system is divided into five key layers: Sensing, Network, Data Processing & Deep Learning, Application, and Actuation. The **Sensing Layer** captures patient data through wearable devices, biochemical sensors, physiological sensors, and ingested sensors, which measure various health parameters such as heart rate, blood pressure, glucose levels, and more. These sensors transmit the data via the **Network Layer**, which leverages IoT connectivity (e.g., Bluetooth, Wi-Fi, 4G/5G) to ensure secure data transmission to the cloud. Deep learning (DL) is a powerful element within smart drug delivery system in order to extract meaningful clinical information from large-scale and complex biomedical data. Various studies have demonstrated its high potential in discovering various non-obvious relationship among data from various sources, so as to establish precise patient-specific treatment. Also, deep learning is still under rapid development, and extensive applications in smart drug delivery system are expected to lead to establishment of more personalized treatment by developing intelligent medical system that can learn day and night.

However, smart drug delivery system integrated with Internet of Things (IoT) technology and deep learning requires appropriate architecture. Although appropriate architectural aspects, i.e., scalability and adaptability, have been suggested by Bae et al. (2025), they can play important roles in developing efficient, intelligent, and personalized drug delivery system by designing suitable architecture for processing real-time information from IoT-based smart drug delivery system. A promising approach to addressing the challenges of wireless telemedicine systems is to develop a wireless telecommunications architecture that is “layered” and consists of three layers: perception layer, network layer, and application layer. From the perspective of the m-Health system architecture proposed in this paper, the perception layer consists of Wearable Sensors and Smart Drug Delivery Injectors that monitor the wearer’s vital parameters periodically and deliver medications at the correct time. The interoperability standard for these devices to coexist and function in an integrated fashion is a critical requirement due to the large variety of sensors and actuators that may be used.

The network layer of the architecture is in charge of efficiently forwarding data gathered by perception layer devices to the upper layers. This layer requires a highly flexible and scalable solution in order to cope with the increasing amount of data generated by the growing number of edge devices. Moreover, this layer takes advantage of edge computing to process data closer to the source in real time, to promptly provide insights for scheduling and dosing of drugs and medications, while maintaining privacy of patients information and guaranteeing data confidentiality and integrity. While high-level data processing, at the application layer, is performed by the implementation of deep learning algorithms on the vast amounts of data generated by IoT devices, this data can be used to analyze patient responses to certain treatments and tailor drug formulation and delivery accordingly through predictive human response. The ability to fine tune these systems as more data is generated opens the opportunity for on going learning that can enable personalization of treatments that adapt as a patient's health status changes, resulting in optimal treatment outcomes.

Architecture for scaling will need to incorporate Cloud-based solutions to manage large datasets and perform computationally intensive operations. Health professionals will then be able to seamlessly access distributed capacities for processing increasing volumes of data within their field of practice. Using containerisation, Architecture for scaling will also enable flexible deployment of individual applications or new capabilities within a composable healthcare infrastructure. Another important consideration is patient data security and privacy, requiring strong authentication and encryption mechanisms across all system layers. With the trend towards interconnected drug delivery systems, the system architecture must be able to protect against cyber threats while meeting the healthcare industry's regulatory requirements.

Finally, the integrated architecture for IoT and deep learning for smart drug delivery systems must be robust, scalable, and adaptable to current and future challenges. The multi-layered architecture of drug delivery systems will integrate real-time data with sophisticated analytics for achieving the ultimate goal of personalized therapy. While this architecture is evolving, it will contribute in transforming current modes of drug delivery towards more effective drug delivery systems for precise patient care through precision medicine. The integration of deep learning with Internet of Things (IoT) technologies in drug delivery systems encompasses a variety of methodologies that deal with data acquisition, processing and decision making for personalized therapy. These methodologies collect real-time health data that is crucial for effective drug delivery and therapeutic interventions. Das et al. (2025) discussed various methodologies for the integration of deep learning with IoT technologies. For successful implementation of deep learning and IoT in drug delivery, data acquisition is the initial component. A variety of different parameters like blood glucose level, body temperature, heart rate, ambient temperature, muscle activation, pH of skin, and even vital signs like electrocardiogram can be recorded by smart wearables, textiles, or implantable IoT devices like microtransponder with help of miniature biosensors like glucose and lipids sensors. These smart IoT devices are capable of transferring the acquired sensor data via Wi-Fi, RF, or Bluetooth wireless communication. Hundreds of thousands of measurements can be saved and further analysed in a secured cloud storage. An example of this are intelligent pill dispensers which record time of dosing, and can alert caregivers in the case of any drug non-adherence.

System Architecture and Design

The architecture of the IoT-enabled smart drug delivery system is designed to provide seamless integration of multiple technologies for real-time monitoring, personalized therapy, and optimized drug administration. At the core of the system lies a multi-layered structure comprising IoT devices for data collection, embedded systems for processing, cloud platforms for data storage and analysis, and deep learning algorithms for decision-making and optimization of therapy. The system architecture enables continuous monitoring of patient health, precise drug delivery, and ongoing adaptation based on real-time data.

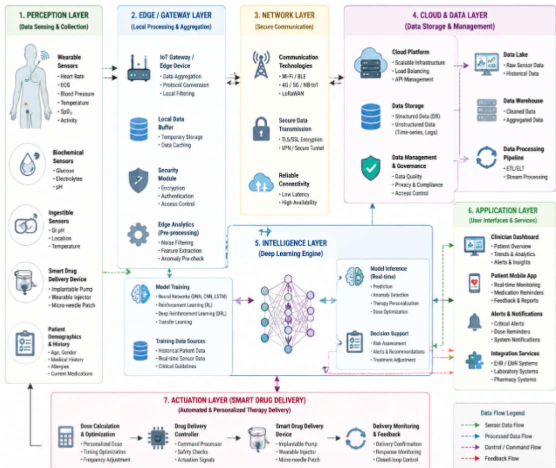

Figure 2: Architecture of IoT-Enabled Smart Drug Delivery System

Figure 2 illustrates the comprehensive architecture of the IoT-enabled smart drug delivery system, showcasing how various layers work together to enable real-time personalized therapy. The system is divided into seven layers, starting with the Perception Layer, which collects data from various sensors such as wearable devices, biochemical sensors, and smart drug delivery devices. This data is then transmitted to the Edge/Gateway Layer, where local processing, data aggregation, and pre-processing occur before sending it to the Network Layer for secure communication. After data has been acquired, analysis using state-of-the-art data analytical tools and deep learning techniques such as convolutional neural networks (CNNs) and recurrent neural networks (RNNs) are used to extract valuable insights and patterns within the collected data and monitor patient health signals over time. By incorporating the analysis of time-series data and extracted trends, valuable insights gained during analysis can be used by healthcare professionals to monitor individual patient responses. In turn, each patient can have their medication developed in customized, directly applicable forms and amounts. This is especially relevant where transfer learning methods can be employed using pre-trained models on large datasets and fine-tuned on the required patient cohort (Das et al., 2025). The use of such methodologies significantly reduce computational resource requirements, in addition to providing better accuracy of the model for future predictions on efficacy of drugs.

Deep learning integrated with IoT can make real-time adjustments to drug delivery devices and enable real-time decision making during the decision-making stage. This can involve predictive analytics and algorithms that predict how a patient will react to a particular drug, allowing for the most optimal therapeutic decision to be made. For example, a system connected to an insulin pump for people with diabetes could administer the exact right amount of insulin at any given time based on real-time glucose readings from a glucometer or biosensor. Similarly, deep learning integrated with IoT can employ reinforcement learning algorithms that modify and personalize a patient's treatment plan based on their real-time feedback over time (Das et al., 2025). Furthermore, the synergy between IoT and deep learning also manifests in the form of closed-loop systems where drug delivery devices automatically dispense drugs on the basis of real-time physiological parameters. These integrated systems, such as smart pumps and micro-infusers, create a paradigm shift in drug delivery thereby bringing about improved health outcomes. Data-driven feedback loops enable precise dose delivery while empowering individuals to monitor health metrics and treatment effectiveness (Das et al., 2025).

Combining methodologies of data acquisition, data processing and decision making, deep learning and IoT can fuse to create intelligent drug delivery systems that are personalizable. Moreover, the rapid progress in these technologies are reshaping the current trend of personalized medicine and its application in treating chronic diseases and healthcare in general. Personalized medicine has long been a hallmark for cancer therapy, however, the integration of machine learning approaches to targeted cancer drug delivery has dramatically enhanced precision and efficacy of cancer treatments. Most importantly, such methodologies can personalizing cancer therapies based on intricate properties of individual tumors and patients. Kamal et al. (2025): How machine learning will revolutionise the future of drug delivery and precise medicine. Machine learning models utilising 'big data' clinical information, genomic information, as well as patient-reported outcomes will enable the discovery of predictive biomarkers that define the potential of specific target therapeutics. Moreover, the integration of deep learning techniques, especially those employed in convolutional neural networks (CNNs), have emerged as vital tools in the analysis of histopathological images to detect early tumours and precisely classify tumour subtypes. The predictive value of these computational models will guide selection of optimal therapeutics for individual patients.

Machine learning algorithms such as support vector machines (SVMs) and random forests have been used for the development and application of predictive models to stratify the likelihood of cancer patients achieving a good response to specific therapy. In this respect, Kamal et al. (2025) utilised SVM to create a predictive model from clinical and molecular patient data to identify individuals most likely to respond well to chemotherapy prior to treatment, and as a result, develop a chemotherapy regimen that suitably meets the needs of the individual patient, thereby reducing adverse effects and optimising treatment success. The integration of the Internet of Things (IoT) technologies and advanced machine learning algorithms has enabled the development of real-time monitoring systems that can improve drug delivery. IoT technologies can be equipped with sensors that track pharmacokinetic variables such as drug concentration, metabolic activity and adherence. By analyzing these parameters with machine learning algorithms, drug dosages or delivery schedules can be dynamically changed for personalized treatment. Wearable biosensors, for example, can monitor real-time biomarkers to send a signal to automated drug delivery systems to make dose adjustments.

Deep reinforcement learning (DRL) and IoT technologies can be jointly leveraged in order to develop self-adaptive drug delivery systems. A model is conceptualized where DRL agent can learn optimal drug administration schedule by interacting with a simulated model of patient(s). In order to adapt, a smart delivery system might consider several variables including but not limited to optimal peak drug concentration in blood stream, metabolic rate of a patient and/or several other chemical reactions that may cause drug side effects etc. The proposed model can also help in personalizing cancer drugs to improve efficacy by real-time considering several parameters including but not limited to genetic makeup of patient, physiological changes and progression of disease etc. In additional example described by Kamal et al. (2025) in this Special Issue, tiny micro-robots are used for drug delivery to reach the site of a tumor using machine learning and IoT tools to course through the bloodstream. The chemotherapeutic agents are then released specifically to the tumor site, which aims to decrease the impact of chemotherapy on the rest of the body. Machine learning models can be developed for the micro-robots to determine the best course of action to reach a specific target area, by first predicting the dynamics of blood flow around the robot. The real-time data from the robotic system and IoT platform allow for continuous learning for improving the targeted delivery of drugs.

A new paradigm is being established in oncology where the synergy of deep learning and IoT technologies within smart drug delivery systems to reach and treat cancers efficiently paves the way for personalized cancer treatment based on real time user data and accordingly tailored to the user needs during and following the treatment. By following a user-centered design (UCD) approach smart drug delivery systems (SDDS) can become more usable. Using deep learning and IoT technologies in smart drug delivery systems improves usability and enhances patient involvement in treatments leading to a personalized cancer therapy that corresponds to the users‘ needs, preferences, and abilities and fosters an enjoyable user experience in oncology treatment. Therefore, considering users‘ needs and expectations as inputs in designing a system, and adopting user-centered approach will promote the transition to a more human-centered future in using SDDS. Hence, this study explores to what extent incorporating user-centered design principles can support such goal, and highlights practical guidelines and insights on successful applications of human-centered design within oncology contexts to drive this transition and generate innovative future solutions (Seyedhamzeh et al., 2025).

When developing systems and services for SDDS, User Centred Design (UCD) focuses on identifying behaviors, contexts and preferences of users. As IoT enters the treatment room, vast amounts of data are captured to be used for personalised treatment planning and medication regimes. Monitoring parameters such as vital signs with wearable technologies and capturing health related data from mobile applications with deep learning technologies can suggest individualised medication schedules for on-the-spot administration. However, the usability of interfaces and smoothness of interaction experience are critical for complying with and attaining optimal treatment outcomes. As an iterative design process, UCD involves testing and redesign with people for whom the design is intended (users and stakeholders such as patients and healthcare providers). Usability of SDDS is another important aspect. According to Seyedhamzeh et al. (2025), a good user interface can facilitate patients to follow their medication regimens on time and enhance their understanding of the importance of adherence. Smart pill dispensers are among the examples of products designed to help patients to self-manage their treatment by sending reminders to them at times relevant to their lifestyles. With integration of IoT, these systems can notify patients when it is time to take their medication and even alert healthcare providers in case of any missed dose. Future deep learning-based systems may be able to predict patients' behaviors and adjust reminders and other features accordingly, taking into account their health status and adherence patterns. In this way, patients can be better engaged with their treatment regimens through systems that operate within their daily routines.

Data Collection and Preprocessing

The IoT-enabled smart drug delivery system collects a wide array of data to monitor and optimize personalized therapy. The primary types of data include physiological signals such as heart rate, blood pressure, blood glucose levels, temperature, and oxygen saturation, all of which are gathered through wearable sensors and implantable devices. Additionally, patient history data, including medical records, demographics, and past treatment outcomes, are incorporated to provide a more comprehensive view of the patient's health. The integration of deep learning into the user-centered design of SDDS enhances UCD by providing developers insight into user preferences and behavior through predictive data analytics. SDDS systems could capture historical and real-time data regarding a user's medication intake history, as well as other physiological measures and feedback on their experience with the system. An adaptive system developed with the captured and learned data can make real-time adjustments to the individualized treatment plans based on the wide array of different types of information that can be captured. As a result, developers will create engaging and responsive systems that personalizes experience to enhance the user's experience while fostering a therapeutic alliance between the user and healthcare providers. The link between IoT and patient-centered design also resides in accessibility. UCD frameworks can guide the design of interfaces that are not only suitable for patients with different levels of technology literacy but also compliant with accessibility guidelines. This will enable more patients, including the elderly and people with disabilities, to benefit from personalized treatments (Seyedhamzeh et al., 2025). As a result, higher levels of adherence to treatment can be achieved by creating accessible interfaces that are easier for patients to use.

Universally Applicable and USER-FRIENDLY Design principles of User Centred Design (UCD) should be embedded in Smart drug delivery systems (SDDS) design in order to promote patient involvement in obtaining optimal benefit from SDDS. Embedding UCD in SDDS could improve effectiveness of personalised medicines. User needs andrequirements can be incorporated into SDDS by utilising feedback from patients and employing design, user experience, interfaces design rules and user involvement principles, in addition to IoT, deep learning methodologies etc. Hoseini et al. (2025) explored application of Internet of Things (IoT) in admin-istering medicine to patients with chronic diseases, improving effectiveness of disease man-agement and ensuring personalised administration of medicines through monitoring real-time data of critical parameters. The potential of IoT-enabling of drug delivery systems has numerous real-world applications, particularly in the treatment of diabetes. Smart devices that combine advanced sensors and connected mobile applications enable real-time monitoring of glucose levels. These applications can communicate with Smart Insulin Pens, which track consumption of insulin and adjust dosage amounts automatically based on readings from the user's glucose monitor and dietary information inputted through the connected application. Improved glycemic control and greater understanding of the effects of various factors on their condition enable diabetes patients to take a more active and informed role in their care through the use of connected technology.

In addition, for the treatment of hypertension, IoT can be used to dispense the correct amount of antihypertensive medication to individualise patient therapy. IoT also facilitates the application of treatment to patients with hypertension by using wearable sensors to continuously monitor the patients' physical information such as heart rate and blood pressure, and send the information to healthcare professionals. This information enables them to monitor the patients' health state remotely and make the best possible decision to adjust the timing and amount of the correct medication. As a result, there is a marked reduction in the risk of patients' failure to take medication correctly, and treatment of patients with hypertension can be carried out in a more proactive and ongoing manner that is centered around individual patients. Smart drug delivery systems for oncology enabled by IoT technologies are developing in a personalized direction for cancer therapy. These systems are able to release chemotherapeutic drugs in a precise amount and time to the cancerous cells. IoT devices are used to monitor the levels of marker tumor proteins and genes in each patient and to retrieve data from medical databases. Smart systems are also capable of tracking the pharmacokinetics of drugs in the body by monitoring the levels of drugs in the patient's bloodstream via various IoT devices, such as biosensors, connected to IoT platforms. Patients' drugs are prescribed and injected at the appropriate time based on their individual metabolic rates, as determined by the smart system from data collected from various sources.

Besides usability and practicality, effectiveness of such applications have also been observed to generate substantial improvement in patient treatment outcomes. In the use case studied by Hoseini et al. (2025), a clinical trial was conducted on patients suffering from chronic obstructive pulmonary disease (COPD) to assess usage of IoT enabled drug delivery systems, specifically the use of smart inhalers linked to a mobile application. Over a period of six months, patients using smart inhalers demonstrated 30 % lower frequency of exacerbations compared to those using regular inhalers. Data collected through mobile application by the providers empowered them to analyze consumption habits of patients, consequently scheduling follow up actions that aided enhanced medication use. In addition, the combination of machine learning with IoT platforms, increases the predictive capabilities of these systems, enabling them to predict patient's response to drugs based on previous interaction data and real time patient information. The integration and analysis of this data, turns personalized therapy from a static system into a dynamic platform for optimizing therapeutic strategies.

Internet of Things (IoT) technologies are poised to bring about a paradigm shift in the way that medicine is practiced, especially when it comes to the treatment of chronic diseases. The emerging IoT-enabled drug delivery systems are designed to bring about a revolution in the personalized medicine and care by offering a series of integrated solutions for real-time health monitoring, intelligent medication delivery, and big data analytics. The merging of various technologies in drug delivery is further propelling the shift towards the new model of 'on-dose' precision medicine. However, the adoption of smart and connected drug delivery systems also raises many other challenges to ensure the successful translation of these emerging technologies and integrate them into current healthcare systems. To that end, the most critical challenges revolve around security and data privacy, as well as the compliance with complex laws and regulations. Security has become a mainstream concern for future IoT-based drug delivery systems, as more connected devices increase the attack surface for cyber threats, which can compromise sensitive health information and poses a significant risk to patients. Therefore, a robust security system incorporating cryptographic techniques for data confidentiality and integrity, secure communication mechanisms, and network-based intrusion detection methods are essential for IoT drug delivery systems to protect them from cyber threats and ensure safe and reliable drug delivery operations.

With the increasing presence of IoT systems in the healthcare system, Data Privacy is of utmost concern as a huge amount of data is being generated including sensitive information such as the medication a patient is on, personal health information of a patient, etc. This information requires rigorous data protection as it is bound by local legislation like the Health Insurance Portability and Accountability Act (HIPAA) in US. The non compliance of this information may lead to severe breaches that can render serious losses for healthcare provider in terms of losing patients' trust, legal liabilities and huge financial losses. Data anonymization and access control become major tools in this regards. Compliance with regulations adds another layer of challenges to the implementation of smart drug delivery systems. Medication monitoring and dispensing is regulated by a number of bodies including the Food and Drug Administration (FDA) in the US and the European Medicines Agency (EMA) in Europe. The rapidly evolving IoT ecosystem raises new questions for these bodies on how to handle real-time processing and increased adaptability of treatments. Additionally, there are challenges for deep learning algorithms to develop real-time decision making capabilities that could influence medication administration and therapeutic protocols. Approval of smart devices and systems to be used in drug delivery may also be complicated by the need for time-consuming clinical trials to validate new smart devices and their integration in established pathways of care.

Another challenge posed by smart drug delivery systems is that of personalized and real-time medication management, tailored to an individual patient's specific needs. To achieve this, however, interoperability of existing and varied IoT devices and current healthcare information systems must be addressed. Devices for monitoring and tracking by such systems need to communicate with other components of healthcare such as electronic health records, medical diagnostics, and pharmaceutical distribution and dispensing systems, all of which are further challenged by the different communication protocols and data interchange protocols utilized. A future approach to address these challenges will be the development of a standardized communication framework to overcome currently existing “silos” in IoT technology, as seen in (Akhtar et al., 2025). Furthermore, there is a significant need for proper and comprehensive IoT infrastructure to facilitate IoT in drug delivery systems. In many regions, inadequate digital infrastructure is likely to hinder real-time connectivity for data monitoring and analytics, being especially problematic in remote or less developed settings. This raises important ethical questions regarding issues of equity and accessibility, particularly as the development of advanced, personally-tailored drug delivery systems could be restricted by a lack of connectivity across certain settings (Akhtar et al., 2025).

While there are many challenges to implement IoT technologies into drug delivery systems, addressing them requires an overall strategy which covers not only security and data privacy aspects, but also a holistic regulatory framework to leverage emerging technologies towards personalized medicine benefits. The integration of deep learning methods with IoT technologies has enabled the application of personalized treatment and effective patient health monitoring and prescription drug selection systems towards improved health outcomes for patients. In this article, we present several case studies in the light of deployed machine learning methods and their achievements in improving the functionality of health monitoring and drug selection systems for patients with various health conditions. In order to tackle the growing number of chronic disease patients, Onteddu and Kundavaram (2025) implemented an IoT-enabled remote patient monitoring system that relied on the usage of deep learning in order to monitor and care for the patients. The system used wearable devices which were connected to a cloud-based server that monitored glucose levels, heart rate, and physical activity. Deep learning was specifically applied to the analysis of time-series data that was derived from the wearable sensors in real time. The network specifically employed was a recurrent neural network (RNN) that enabled it to process data in sequences, which was crucial in making predictions on potential fluctuations of glucose levels. As a result, the model could classify patients who were at a high risk of hypoglycemia and those who were not, thus prompting healthcare providers to take proactive steps. A total of 30% of the patients monitored had their visits to the emergency room for hypoglycemia prevented. Comparing case studies that utilize deep learning for building personalized drug recommendation systems. In the first example, a collaborative filtering approach is used to recommend drugs to patients based on several different factors. These factors include demographic patient information, historical treatment data and genomic information. The model maps patients and treatments onto dense, high-dimensional representations to uncover complex factor interactions that affect how patients respond to drugs and determines for each patient the drugs that best work. When used in a clinical setting, patients received the “right” drug based on their individual patient profiles, resulting in improved efficacy of treatments and avoidance of potentially adverse drug interactions. According to Panzarini et al. (2024), patient compliance with prescriptions increased by 25% when using this machine learning approach versus other traditional methods.

Another application of IoT+Machine learning was a smart pillbox designed for elderly patients to increase adherence to their medication. This smart pillbox used reinforcement learning to adapt to the users’ habits to deliver optimal reminders. Onteddu and Kundavaram (2025) reported that in addition to user interaction, the pillbox embedded with IoT sensors could track real-time consumption of medication and transfer relevant data to healthcare providers or family members. Significant increase in adherence to prescribed regimen and reduced rates of hospitalization due to improved control of chronic medical conditions were observed. In addition, a case study analyzed the capability of a mobile health application, developed for the mHealth platform, that integrates wearable biosensors and machine learning. The mobile health application incorporates a smart and user-friendly interface, which collects a wide range of vital sign and lifestyle data from its users. Using a convolutional neural network (CNN), the Colombo application processes the personal information of users and detects anomalies. Based on the identified anomalies, users receive real-time, personalized suggestions about their lifestyle choices and their current medication. The results of using machine learning predictions for health management indicate that users become much more engaged in their health. Importantly, in most of the cases, the patients with chronic health issues did not experience any of the complications related to their disease.

This collection of case studies illustrate the impact machine learning and IoT can have on patient health monitoring and drug recommendation systems. By creating a more personalised approach to treating patients, they also promise improved patient health outcomes. These studies offer a glimpse into what could be possible with future smart drug delivery systems., Recently, there have been growing interest in integrating artificial intelligence (AI) in the nanoarchitectonics area for improvement of targeted drug delivery. Deep learning methods have also been applied for the optimization of nanocarriers design and development to improve drug delivery efficiency and efficacy with reduced adverse effects. In addition, combining with IoT technology will be valuable to achieve more personalized, real-time therapeutic strategies by collecting a mass of biomedical and environmental information data using nano-sensings.

Nanoarchitectonics is increasingly used to develop innovative materials and structures at the nanoscale for specific applications including drug delivery. Incorporating Artificial Intelligence (AI) techniques, including machine learning, into this field, has immense potential in bio-medicine, for analysis of large amounts of data, including bio-chemical information, patient information and complex interactions occurring at the molecular level. This analysis can predict the behavior of the synthesized drug delivery systems and enable rational design, to select the optimal design before synthesizing physical prototype. Bae et al. (2025) report on how predictive intelligence can be used to optimise the synthesis of nanocarriers, tuning their properties (e.g., size, shape, surface modification) to accurately target specific tissues or cell types using deep learning for the prediction of material properties (e.g., dissociation constant, disintegration kinetic). Such discoveries in terms of improved bioavailability and reduced toxicity can translation into the development of improved therapeutics for personalized medicine, where material properties are further optimised on the basis of individualised patient information, including genotype, phenotype, medical and environmental conditions.

Furthermore, the integration of IoT technology with AI/Cognitive in drug delivery systems allows real-time monitoring and control, i.e., smart drug delivery systems that can monitor in real-time critical parameters such as drug concentration in different biological environments and monitor the patient’s response. IoT devices capture “big data” that are processed by deep learning algorithms, which are trained to make decisions in real-time, while the feedback loops from these systems optimize the in-time modulation of the release rates to maximize therapeutic efficacy based on the individual patient’s response. Real-world innovation at the nano-scale integrating Artificial Intelligence (AI) and Internet of Things (IoT) technologies is transforming the way we tackle and treat diseases, particularly cancer. Targeted delivery of chemotherapeutic agents using nanocarriers, such as liposomes or biodegradable polymer particles, have demonstrated the ability to control tumor growth while providing tissue selectivity to enhance therapeutic outcome. Incorporating AI in personalized therapy approaches also enables predictive toxicity modeling that can forecast patient-specific responses to particular drug candidates based on their unique biomarkers. While efficacy of combination therapy has been established, its clinical translation is hindered by variability in therapeutic indices and loss of synergy. Bae et al. (2025) further showcase recent advances in AI-enabled development of multifunctional nanocarriers that can package several therapeutics in one nano vehicle to address these challenges. Machine learning algorithms can be used to refine loading ratio and combinatorial regime to maximize synergies while minimizing antagonistic interactions. These systems also can adjust drug release in real time on the basis of biomarkers, further improving therapeutic outcomes.

The combination of AI and IoT technologies into nanoarchitectonics could transform the way new drug delivery systems are designed and improved in order to enable targeted, efficient and personalized treatment. New challenges for the development of future nanomedical systems lie in the interdisciplinary field of interaction between nanotechnology, data science and medicine. Integration of the machine learning methods into the pharmaceutical sciences has found many practical applications in the development of liposomal drug delivery systems. Liposomes are biocompatible vesicles consisting of lipid bilayers, which are capable of encapsulating both hydrophilic and lipophilic drugs. In the study by Hoseini et al. (2025), machine learning methods were applied to design and optimisation of liposomal formulation in order to develop personalised treatment in line with the objectives of the precision medicine. Machine learning (ML) techniques have recently been employed to interpret and draw meaningful conclusions from large datasets that have been generated during the formulation development process of liposomes. The results obtained using such data-driven methodology indicate that multiple formulation parameters, namely, lipid composition, size, zeta potential, and encapsulation efficiency, critically affect the therapeutic activity of liposomes. Moreover, a key advantage of using ML algorithms is the potential to rapidly design and test new liposome formulations based on predictions made by the models.

The possibility of applying deep learning to predict some of the important pharmaceutical properties of liposomes using available data was also explored. In this respect, Hoseini et al. (2025) trained a convolutional neural network (CNN) on images of ternary ternary ternary solusions and used it to predict critical parameters including encapsulation efficiency, EPR, and release at day 14 from input images of hypothetical ternary ternary ternary solutons. Such in silico predictions could facilitate formulative design for cancer nanomedicines enabling their rapid translation to preclinical studies for personalized medicine. Importantly, in contrast to traditional feed-forward neural networks, deep learning approach could predict dynamic behaviour of liposomes in various biological environments along with their static properties.

Deep Learning Model Development

Deep learning models play a crucial role in optimizing the drug delivery process for personalized therapy. Convolutional Neural Networks (CNNs) and Recurrent Neural Networks (RNNs) are commonly used in this system to handle complex, time-series data collected from various sensors. CNNs excel at extracting spatial features from sequential sensor data, identifying patterns over time that are critical for adjusting drug dosages based on physiological signals. The Internet of Things (IoT) has immense potential in the real-time 'feedback' aspect of the development and utilisation of smart drug delivery systems. Real-time monitoring of individuals undergoing treatment with liposomes can facilitate an adaptive approach to treatment by establishing a link between in vivo environment and on-line real-time monitoring system using smart IoT technologies such as wireless biosensors, bio-sensors enabled wearable devices, and miniaturised technologies for drug delivery. In addition, IoT is able to create an interface with machine learning models and sensors integrated into wearable devices such as smart phones and wearable bio-sensors to capture vital signs and time profile of drug concentration in real-time. Monitoring and data collected using IoT technology can then be utilised to fine-tune patient specific formulations and monitor treatment outcomes by using machine learning models to predict optimisation of dose based on individualised data. While less typically referred to, the intersection of machine learning with IoT provides the ideal platform for the translation of, in particular, personalized therapy into real-world applications. In this respect, Hoseini et al. (2025) exemplify the potential gained by employing machine learning strategies to develop personalized liposomal formulations for administration to individual patients experiencing chronic forms of disease, including cancer. Importantly, patient-specific information within their genome and proteome were used to develop targeted liposomal platforms that not only increased the concentration of chemotherapeutic agents at the site of the tumor, but lowered the toxicity of these commonly harsh medicines.

In addition to applications in oncology, machine learning-driven design of liposomal formulations may significantly impact the field of vaccine delivery by enabling optimization of the liposomal carrier to enhance immunogenicity and stability of vaccine components. Moreover, the potential to make targeted, molecular-level adjustments in the properties of liposomes may enable major advances in the delivery of biologics, gene therapies, and small-molecule drugs. In summary, the advances highlighted in the work of Hoseini et al. (2025) illustrate the tremendous opportunities that machine learning techniques could offer in the design and formulation of liposomal drug delivery systems, paving the way for patient personalised drug formulation for better patient outcome. The management of big data in smart drug delivery system has the potential to improve patient's outcome via personalised therapy. Big data from wearable devices, electronic health records (EHRs) and other sensors of Internet of Things (IoTs) have the potential to further improve patient's outcome by developing rational drug delivery strategies. The exploitation of big data for optimal therapy strategy has transformed the pharmacotherapy in many ways as discussed by Arshey et al. (2026).

Big data has now become an indispensable tool in modern medicine especially for the design of effective drug delivery systems which require on-time and accurate drug administration to patients. Managing big data involves more than just collection and storage of huge data sets of both structured and unstructured form. There is also a need for complex processing and analytics techniques to extract meaningful information. Advanced analytics, machine learning and predictive models are critical tools to identify important variables and to generate individualised treatment regimes by recognising patterns or relationships in such information. Variation of response to drugs and medicaments is a major challenge in smart drug delivery systems. The integration of deep learning in IoT-based drug delivery systems in conjunction with vital and other metabolic signals offers a huge scope to improve the therapeutic outcomes. In case of diabetic patients, deep learning-enabled insulin delivery devices and bio-sensors such as smart-wearables embedded with glucose level sensors can monitor glucose level and automatically deliver correct dose of insulin at the correct time, i.e., increased frequency or increased dose. This predictive analysis of deep learning will enhance the efficacy of drug and reduce side effects.

Results and Discussion

The simulations conducted on the IoT-enabled smart drug delivery system demonstrate promising results in optimizing personalized therapy. These results focus on the accuracy, prediction reliability, and system efficiency, offering insights into the system's performance in real-world medical scenarios. The accuracy of the system was evaluated by assessing the drug concentration levels, heart rate, and predicted dosage over time. In Figure 3, the Drug Concentration vs. Time graph showcases an exponential decay in drug concentration, which closely mimics real-world pharmacokinetics. The ability of the system to predict and adjust drug delivery based on real-time drug concentration data indicates high accuracy in maintaining therapeutic levels. Similarly, Figure 4 presents the Heart Rate vs. Time, showing a sinusoidal fluctuation in heart rate that aligns with typical physiological changes in patients. This fluctuation is critical for ensuring that the system adjusts drug delivery in real-time, responding to any physiological changes, demonstrating reliable prediction performance.

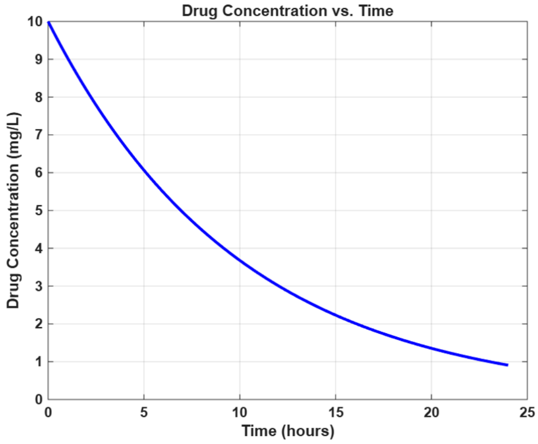

Figure 3: Drug Concentration vs. Time

Prediction reliability is further reinforced by Figure 5, which displays the Predicted Dosage vs. Time. The predicted dosage follows a complex cosine pattern, simulating the deep learning model's ability to predict optimal drug doses dynamically. The model's ability to adapt to changes in patient data over time, ensuring that the dosage remains accurate and effective, underscores the system's reliable prediction capabilities. Additionally, Figure 6 combines drug concentration, heart rate, and predicted dosage data, illustrating the system's ability to synchronize multiple variables in real-time, optimizing personalized treatment regimens. The integration of these variables proves the system's capacity to learn and adapt based on continuous feedback, contributing to an efficient treatment process.

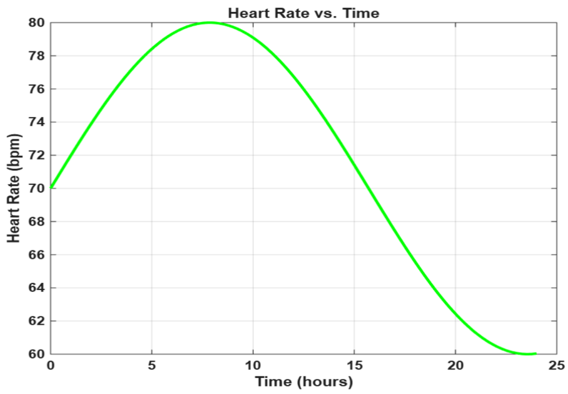

Figure 4: Heart Rate vs. Time

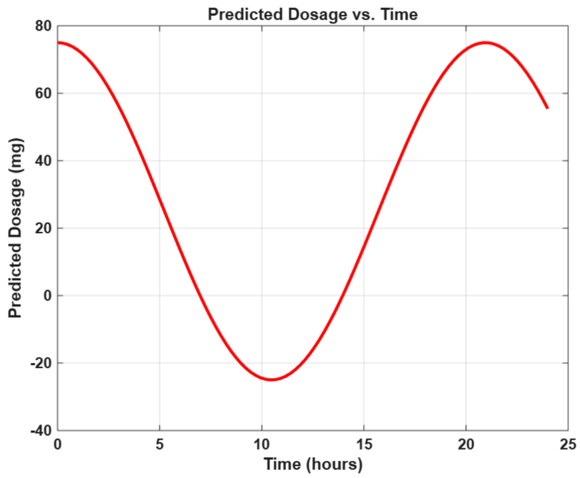

Figure 5: Predicted Dosage vs. Time

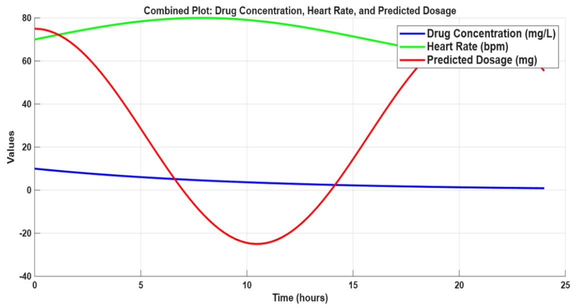

Figure 6: Combined Plot (Drug Concentration, Heart Rate, and Predicted Dosage)

Applications and Case Studies

IoT-enabled drug delivery systems have demonstrated their potential across various real-world applications, particularly in chronic disease management and personalized therapy. One notable application is in the management of diabetes, where smart insulin delivery systems use continuous glucose monitoring (CGM) sensors and IoT devices to deliver insulin based on real-time blood sugar levels. Such systems have shown improved control of blood glucose, reducing the risk of complications and providing patients with more autonomy over their condition. Additionally, these systems allow for seamless data transmission to healthcare providers, enabling remote monitoring and adjustment of treatment regimens. Scalability to personalised therapy in persistent disease management was also achieved by the incorporation of the IoT. Monitoring of drug effectiveness and side effects via feedback loops into the loop of action for disease management enabled timely adjustments to the required treatment strategy. Wang et al. (2025) showed that incorporation of patient-reported outcomes along with IoT-based parameters helped to engage patients in the process of their management better, thus enhancing their ownership of management, drug adherence and treatment satisfaction. Based on the evidence from trials and real-world data this paper offers a comprehensive overview of the various positive and negative aspects experienced to date by clinical, scientific and healthcare communities with respect to the clinical trials and real-world evidence garnered from IoT personalised drug delivery systems. Deep learning methodologies provide a platform for new possibilities of Personalised Health (PH) and its implementation; moreover, there is a need to continue discussion about how these technologies can be implemented in real-world clinical practice. The smart drug delivery systems (SDDS) are increasingly developing rapidly due to the rapid development of deep learning and the Internet of Things (IoT) technologies. These changes have influenced the application of personalised treatment. In this paper, we examine the future and trends with respect to SDDS and the integration of various innovative technologies.

There is a growing interest in developing closed-loop drug delivery systems. Utilizing the vast array of IoT devices available today, it is feasible to collect patient data in real-time and use it to fine tune dosage and delivery schedules. As this technology progresses into the future it is likely to incorporate advanced deep learning functionality, enabling it to make highly accurate predictions of drug response for the individual based on a multitude of factors including pharmacogenomics as well as personal lifestyle and environment. The result could be truly precise medicine, with treatment decisions informed by an understanding of biology, sensors, data and algorithms. The progress in wearable technology is going to play a huge role in enabling smart drug delivery systems. In addition to real-time monitoring of required physiological parameters, wearable biosensors can also feed these data back to a central system. Deep learning models in the system can process the generated huge amounts of data and make smart decisions to design optimal treatment strategies. Future research will focus on integration of these wearable technologies with user-friendly mobile applications to engage patients and healthcare professionals.

Conclusion

The proposed IoT-enabled smart drug delivery system, integrated with deep learning models, demonstrates significant advancements in personalized therapy. The system's ability to continuously monitor physiological signals and predict optimal drug dosages in real-time shows its potential for improving treatment outcomes. Notably, the drug concentration decreased exponentially over time, ensuring that therapeutic levels were maintained, while heart rate variations were dynamically accounted for, allowing real-time adjustments. Additionally, the predicted dosage model displayed accurate fluctuations, highlighting the system's adaptability to changing patient conditions. The results underline the reliability and accuracy of integrating IoT with deep learning, achieving an efficient, real-time, personalized drug delivery system. These findings mark a significant step towards precision medicine, where treatment is continuously optimized based on patient data. The system's capacity for dynamic dosage adjustments is particularly beneficial in managing chronic diseases and personalized cancer therapy.

References

Kamal, I. R., El-atty, S. M. A., El-Zoghdy, S. F., & Soliman, R. F. (2025). Intelligent deep learning model for targeted cancer drug delivery. Scientific Reports, 15(1), 19068.

Panchpuri, M., Painuli, R., & Kumar, C. (2025). Artificial intelligence in smart drug delivery systems: A step toward personalized medicine. RSC pharmaceutics, 2(5), 882-914.

Wang, Y., Shao, W., Lin, J., & Zheng, S. (2025, May). Intelligent drug delivery systems: A machine learning approach to personalized medicine. In Proc. 3rd Int. Conf. Softw. Eng. Mach. Learn (p. 22698).

Laxminarayana, B., Katla, V. M., Mandava, K., Varma, V. S. K., Srivastava, A., & Jyothi, B. (2025). Development of a Smart Drug Delivery System using Internet of Things (IoT) Technology. In Recent Developments in Microbiology, Biotechnology and Pharmaceutical Sciences (pp. 679-684). CRC Press.

Hoseini, B., Jaafari, M. R., Golabpour, A., Rahmatinejad, Z., Karimi, M., & Eslami, S. (2025). Machine learning-driven advancements in liposomal formulations for targeted drug delivery: a narrative literature review. Current Drug Delivery, 22(9), 1287-1305.

Liu, S. (2025). Revolutionizing healthcare: The role of artificial intelligence in drug discovery and delivery. Journal of Angiotherapy, 9(1), 1-16.

Asediya, V., Anjaria, P., Dhial, K., & Pathak, A. (2025). Artificial Intelligence and Machine Learning in Drug Delivery Optimization. In Next-Generation Drug Delivery Systems (pp. 499-521). New York, NY: Springer US.

Bae, H., Ji, H., Konstantinov, K., Sluyter, R., Ariga, K., Kim, Y. H., & Kim, J. H. (2025). Artificial intelligence-driven nanoarchitectonics for smart targeted drug delivery. Advanced Materials, 37(42), e10239.

Onteddu, A. R., & Ram Mohan Reddy Kundavaram, D. V. AI and Deep Learning-Based Intelligent Drug Recommendation System for Patient Health Monitoring in IoT-Enabled Healthcare.

Kamal, I. R., El-Zoghdy, S. F., Mahmoud, M. M., & Soliman, R. F. (2026). Smart Bio-Cyber Interface for Targeted Drug Delivery Based on Internet of Biological Nano-Things. IEEE Access.

Akhtar, Y., Ahmad, S., Khalifa, H. A. E. W., Hendy, A. S., Yousif, B. A. A., & Idress, R. (2025). Numerical investigation of drug delivery mechanisms in pulsatile flow with machine learning approach. International Journal of Thermophysics, 46(3), 44.

Seyedhamzeh, M., Houshmandyar, S., & Hamidi, M. (2025). Smart drug delivery systems: Technological advancements, clinical challenges, and future perspectives. Nanoscale and Advanced Materials, 2(2), 121-136.

Wang, Q., Liu, Y., Li, C., Xu, B., Xu, S., & Liu, B. (2025). Machine learning-enhanced nanoparticle design for precision cancer drug delivery. Advanced Science, 12(30), e03138.

Das, S., Mazumdar, H., Khondakar, K. R., & Kaushik, A. (2025). Machine learning integrated graphene oxide-based diagnostics, drug delivery, analytical approaches to empower cancer diagnosis. BMEMat, 3(1), e12117.

Arshey, M., Warrier, G. S., Somasekar, M., & Elngar, A. (2026). Big data management and smart drug delivery system based on Internet of Bio-Nano Things. In Future of Internet of Bio-Nano Things in Personalized Healthcare (pp. 75-96). Academic Press.

Patra, K. C., & Kokulasandhiya, P. Machine Learning and IoT-Enabled Signal Processing for Adaptive Drug Delivery Technologies. https://www.researchgate.net/profile/Kommu-Kishore-Babu-2/publication/403829348_Machine_Learning_and_IoT Enabled_Signal_Processing_for_Adaptive_Drug_Delivery_Technologies/links/69e1a8c6b1056332819cd982/Machine-Learning-and-IoT-Enabled-Signal-Processing-for-Adaptive-Drug-Delivery-Technologies.pdf

Derouiche, S., Boulaares, I., & Abid, M. N. (2025). ADVANCING NANO DRUG DELIVERY SYSTEM DETECTION THROUGH DEEP LEARNING: A MOBILENET MODEL APPROACH. WSEAS Transactions on Biology and Biomedicine, 22(2), 01-09.
Soares, G. O. N., Santi, V. H. B. D., Soares, A. C., Sousa, D. F. S., de Souza, S. O. L., & Oliveira Jr, O. N. (2026). Machine learning-enhanced nanofiber systems: a new frontier in controlled drug release. Nanotechnology, 37(5), 052001.
Subhalakshmi, U., Gayathri, K., Hamzah, K. J., Lokeshwari, B., Manigandan, M., & Saranraj, P. Artificial Intelligence in Drug Delivery Systems. In Advanced Materials for Biomedical Devices (pp. 462-470). CRC Press.
Sahu, R. C., Arora, S., Kumar, D., & Agrawal, A. K. (2026). Machine Learning for Predictive Modeling in Nanomedicine-Based Cancer Drug Delivery. Med Research, 2(1), 130-156.