

IoT Enabled Smart Pharmacy Management System For Real-Time Drug Inventory Monitoring

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Abstract

Healthcare services have experienced rapid growth in recent years, which has led to an increase in complexity for the pharmaceutical inventory management of healthcare services. There are many challenges in maintaining accurate stock of drugs, checking the expiry dates of drugs, and ensuring the availability of drugs on time. Most of the existing systems for managing pharmacies rely on manual data entry and on occasional verification of inventory. This results in many problems such as inaccuracy in inventory records, wastage of medicines, delayed replenishment, and ineffectiveness of resources. In order to address these challenges, an IoT-based smart system for the management of pharmacies is proposed in this paper for the real-time monitoring of the inventory of drugs and intelligent management of stock. This framework utilizes the sensors of IoT, RFID and barcode technologies, and the intelligent analytics in a cloud-based platform for the management of real-time information of drugs that are in the inventory of the pharmacy and for monitoring of storage conditions of drugs. Information can be acquired from the various units of the inventory of pharmacy on a real-time basis. This information is sent to the cloud platform through various communication protocols of IoT after processing. Various alerts and notifications are generated automatically through the automated processing and decision-making system in the cloud platform. This framework also utilizes machine learning technique for the demand forecasting of the medicines by analyzing the past consumption patterns of the medicines. The stock can be predicted on time by this technique, which can result in avoidance of overstocking and shortage of medicines. The framework can also monitor the inventory on time, and can minimize human intervention in the inventory of pharmacy, thus resulting in increased efficiency of the operations of pharmacy. Performance of the framework can be evaluated using various parameters such as accuracy of detection of inventory, response time, accuracy of prediction of stock, and reduction in wastage of medicines. This system provides a scalable and intelligent solution for the modern pharmacy management by enabling monitoring of inventory on automated basis, and predictive management of stock, and effective management of health care supply chain.

Keywords: IoT, Smart Pharmacy, Drug Inventory Management, RFID, Cloud Computing, Machine Learning, Healthcare Automation, Real-Time Monitoring.

1. Introduction

The healthcare services are rapidly expanding and there is a high demand for production of various drugs. There are thousands of different drugs with different characteristics and thus it becomes a complex task to manage the inventory of these medicines[1]. Accurate management of drugs is required by all the pharmacies, clinics, hospitals and other organizations to ensure that all the necessary medicines are available at all times, minimize the operational costs and reduce the wastage of medicines[2]. Conventional systems for the management of the pharmacies rely mainly on manual entry of data and from time to time the physical verification of stock. The information is stored in databases, but the systems fail to achieve the desired goals due to several errors in counting the stock, delayed updates and other human errors[3].

In the current pharmacy management practices, the real-time information for the availability of medicines and their storage location cannot be obtained. As a result, the inventories are counted manually from time to time and this can lead to many errors[4]. Also, there is a possibility of overstocking, stockout, and even expired medicines which can result in huge financial losses. Many of the medicines require to be stored in controlled environmental condition such as temperature and humidity[5]. Therefore, there is a need for an automated system that can continuously monitor the medicine inventories and make intelligent decisions to manage the inventories in a smart manner.

Healthcare services are rapidly evolving[6]. In order to manage the increase in healthcare services, a wide array of advanced management solutions have been proposed and implemented. Healthcare systems have increasingly adopted and integrated the Internet of Things (IoT) technology and its corresponding applications, which in turn has resulted in a number of intelligent healthcare solutions[7]. Such systems incorporate numerous sensors, enable communication through a network of data transferring nodes, use cloud computing systems for

data processing, and employ various data analysis techniques to generate and manage information[8]. The application of the above-mentioned technologies in managing the services of a pharmacy could facilitate the automatic identification of all types of medication as well as monitor their stock levels on a continuous basis. Additionally, such systems could also be used to detect any form of anomaly in the storage environment of a pharmacy and inform the corresponding personnel in due time[9].

However, most existing digital solutions for managing pharmacies' stock of medicines lack predictive functionality, i.e., they essentially record and monitor the stocks of medicines, without automating decisions concerning said stocks[10]. They often lack also real-time sensing, real-time decision-making and the functionality of demand-forecasting using machine learning. Thus, a comprehensive framework for IoT-based monitoring, for storing and processing of data in cloud and for predictive analytics is required.

In order to efficiently manage the complex tasks of a modern health care system, an IoT-enabled smart pharmacy management system can be designed to monitor the inventory of medicines, their expiry dates and the surrounding environment. By utilizing historical data from past consumption of medicines, an intelligent system can predict future requirements. In this way, timely reordering can be achieved to prevent situations of overstocking and stockout, thus ensuring operational efficiency of health care supply chains. The system can be used to design and evaluate an intelligent framework for the management of a pharmacy for real-time monitoring and predictive management of the inventory of medicines in health care.

2. Literature Review

The Internet of Things (IoT) is an emerging technology to improve healthcare services. Because of its automation, real-time information generation, and operational efficiency, many healthcare applications, including patient monitoring, health care equipment tracking, health care supply chain management, and pharmaceutical inventory management, have been studied in recent years[11]. Given the continuous monitoring and automation of IoT technology, intelligent healthcare services can be developed by collecting and transferring health care related information in real time by connecting and communicating sensing devices together through networks[12]. The pharmaceutical management using IoT technology can solve the limitations of the conventional inventory management systems[13].

Many existing systems in the pharmaceutical domain depend on manual update of stocks by pharmacy staff. These systems often lack real-time information, leading to numerous problems, and are highly dependent on human intervention and hence prone to errors[14]. Further, a system that uses a barcode for a particular task, for example, identifying a medicine for issuing, does not aid in monitoring of inventory in real time. With thousands of stock-keeping units in a large pharmacy, requiring frequent updates for ordering, an automated system of real-time monitoring using latest technologies for identification and tracking is the need of the hour for managing inventory of medicines accurately and efficiently in a pharmacy[15].

In recent years the use of Radio Frequency Identification (RFID) technology to automatically identify and collect data from medicine has received considerable attention[16]. The information provided by RFID systems can improve the management of inventory, enhance the tracking of products and reduce errors caused by human intervention[17]. However, most of the existing systems that are based on RFID technology focus on automatic identification of products and tracking of their location[18]. Little attention has been given to continuous monitoring of environment, prediction and intelligent control of inventory. There are also significant difficulties in terms of cost and infrastructure for the implementation of such systems in pharmacy environments[19].

For environmental monitoring, temperature, humidity and other sensors are widely implemented for monitoring of storage conditions of pharmaceuticals. In order to ensure the quality and safety of temperature-sensitive medicines, such monitoring allows for the prevention of degradation of the medicines due to improper storage conditions[20]. However, such solutions do not provide for comprehensive integration with systems for tracking and monitoring of inventory, for managing of expiry dates and for forecasting of demand.

Furthermore, cloud computing is highly integrated into existing solutions for health care by providing the required storage, accessibility and analysis of big amounts of data of the IoT applications. Thus, a cloud-based pharmacy management system enables real-time-synchronization of all data from all devices in the pharmacy to a management system that can be accessed by health care professionals anywhere, at any time. Nevertheless, most of the solutions lack an intelligent prediction model to predict the future demand based on historical consumption data.

Many existing systems use machine learning to predict and optimize the needs of a client in terms of inventory in health care supply chains. For example, regression analysis, decision trees, and deep learning have all been tested in a number of applications for predicting future requirements of products in health care. This can enable more accurate forecasting of stock requirements and optimal inventory levels in order to minimize stock outs

and overstocking of products in health care supply chains. However, currently most such forecasting applications use historical data for making predictions.

There are numerous approaches in pharmacy management systems that target the several issues like product identification, environmental monitoring, demand prediction, etc. A comprehensive framework which utilizes IoT sensing for inventory monitoring, RFID tagging for automated identification, cloud-based infrastructure for storing large amounts of data and a machine learning algorithm to forecast inventory needs would be highly beneficial for improving the overall efficiency of healthcare supply chains.

3. Proposed IoT-Based Smart Pharmacy Framework

The main objective of the proposed framework for an IoT-based smart pharmacy is to enable the pharmacy to manage its stock of medicines automatically on an ongoing basis using IoT technologies, identifiers, cloud computing, and learning from large amounts of data. The framework to be proposed aims to remove limitations of existing management information systems for pharmacies and to provide the pharmacy on an ongoing basis with complete information regarding stocks of drugs in the pharmacy. The framework proposed consists of several layers that enable a continuous flow of information regarding the inventory of a pharmacy and which manage this information in a suitable manner. The layers proposed are those of a sensing layer, a communication layer, a cloud processing layer and an application layer.

The sensing layer includes various hardware modules that continuously gather events occurring within the inventory of a smart pharmacy. For the purpose of automatically identifying and managing medicines, RFID tags and/or barcodes would be used to store information like name of the medicine, batch number, manufacturing date, and expiration date etc. IoT-sensors would continuously monitor various parameters of the environment of the inventory of the smart pharmacy like temperature and humidity, as these affect quality and efficacy of medicines. The weight-sensors would be used to estimate quantity left in stock and send information to the computer program of the smart pharmacy regarding consumption of the medicine etc.

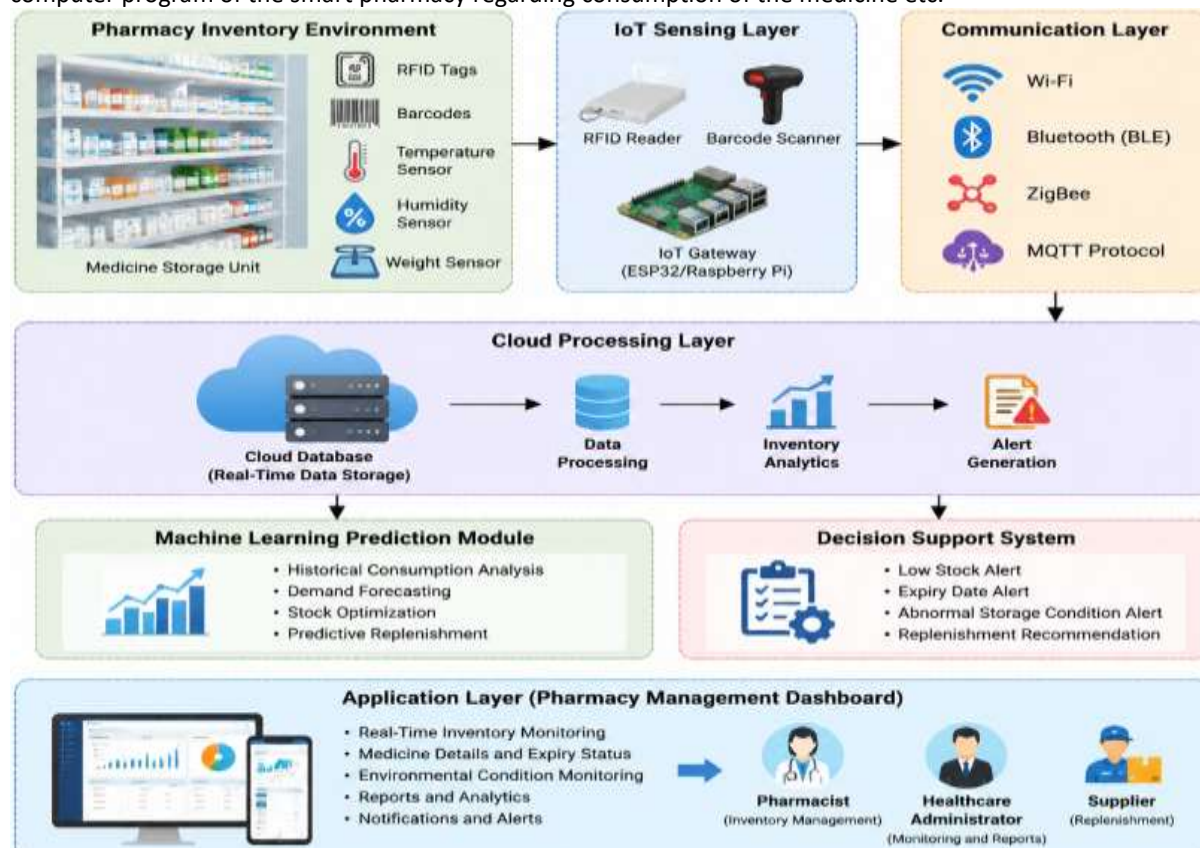


Figure 1. Overall architecture of the proposed IoT-based smart pharmacy management framework

Figure 1 illustrates the overall architecture of the proposed smart pharmacy framework. The system begins with the collection of real-time information from medicine storage units using RFID tags, barcode identification mechanisms, and environmental sensors. The acquired data are transmitted through IoT communication protocols to a cloud-based processing platform. The cloud layer performs data storage, analysis, and intelligent decision-making by evaluating inventory status, expiry conditions, and environmental parameters. A machine

learning module analyzes historical consumption patterns to forecast future medicine requirements. Based on analytical outcomes, automated alerts and notifications are generated and displayed through the pharmacy management dashboard, enabling efficient inventory control and proactive decision-making.

Communication layer: It facilitates communication between inventory's physical parts and digital parts. This layer uses various wireless communication protocols such as Wi-Fi, Bluetooth Low Energy (BLE), ZigBee and Message Queuing Telemetry Transport (MQTT) as required. IoT Gateway of communication layer performs preliminary processing and communicates with cloud platform for safe storage and processing of collected data from inventory's sensing parts.

The cloud processing layer processes and stores all the collected data from the different units in the pharmacy inventory. This layer makes use of large analytical algorithms which are able to identify the current status of all the items in stock, the approaching expiration date of the medicines, any anomalies with the stored products, and so on. All of these situations trigger corresponding alerts which are managed by automated decision-making processes. Users can access information on pharmacy inventory in real time from anywhere in the world using cloud computing.

The application layer comprises various layers and components in the smart pharmacy framework, namely interactive interfaces for the pharmacists, administrators and suppliers of health care in order to access and view the various information pertaining to the inventory in real time and various analytical information in the smart pharmacy. A user interface or the user-friendly interface, namely the dashboard will display the information of various types including the current stock of the various types of medicines, the information pertaining to the various types of medicines that are nearing their expiration dates, the information of various types of environmental parameters, alerts and other notifications.

The proposed system is a part of an intelligent healthcare inventory management system that makes use of automation, real-time monitoring, and predictive analysis. It also facilitates smart and efficient supply chain of health care drugs and enables operational efficiency of pharmacies and other health care facilities, thus minimizing manual intervention and reducing drug waste. The system can be implemented for small retail pharmacies, hospitals, and other large health care centers.

4. Methodology

This study adopts an integrated framework, comprising a real-time drug stock monitoring mechanism, an automated data collection system, an intelligent data analysis system, and a predictive inventory management system. A smart pharmacy stock management system, utilizing the IoT technologies and incorporating with RFID/barcode and cloud computing and machine learning, is designed to automate and enhance the pharmacy inventory management functions and improve the healthcare supply chain management.

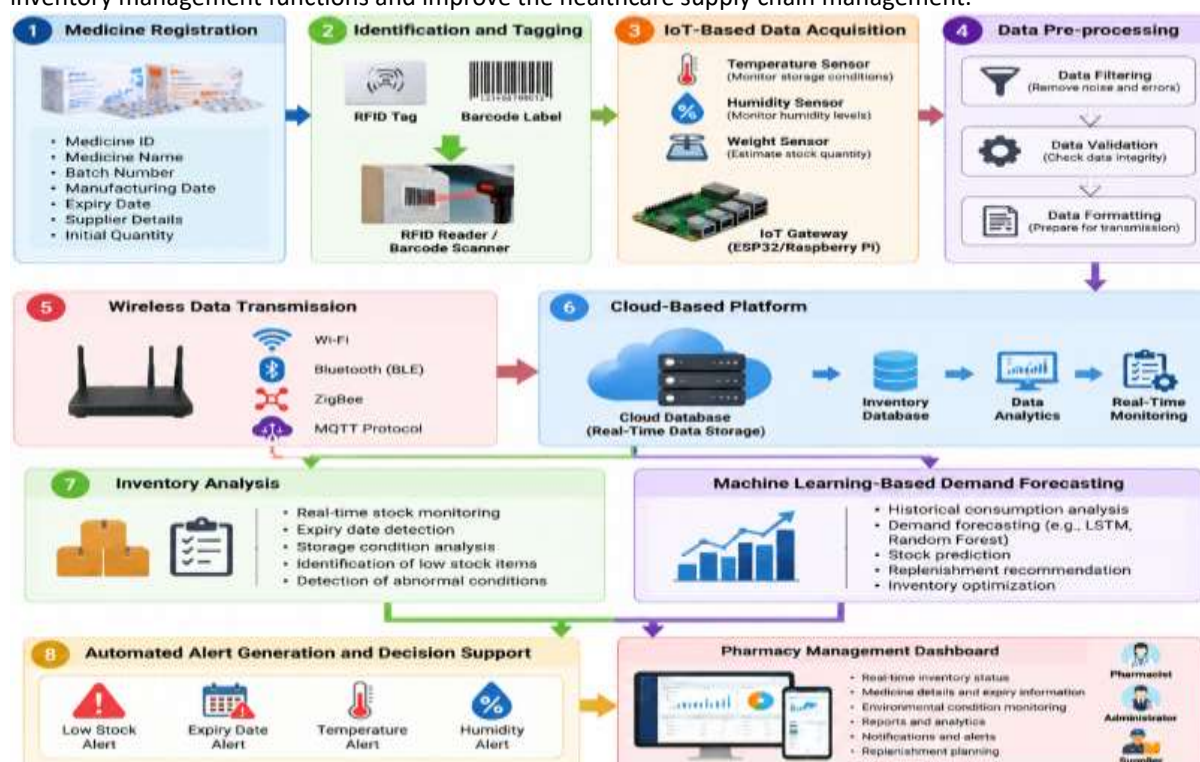


Figure 2. Methodology Workflow of the Proposed IoT-Based Smart Pharmacy Management System

Figure 2 presents the complete workflow of the proposed methodology. The process begins with the registration of medicine information and assignment of unique identification through RFID or barcode technologies. Real-time data related to medicine quantity and storage conditions are collected using IoT-enabled sensing devices. The acquired information is processed through an IoT gateway and transmitted to a cloud-based platform for storage and analysis. The cloud environment performs inventory evaluation, expiry monitoring, and environmental condition assessment. Furthermore, machine learning algorithms analyze historical consumption patterns to forecast future medicine demand. Based on analytical outcomes, automated alerts and replenishment recommendations are generated to support efficient pharmacy management and optimize healthcare inventory operations.

Data collection: All data related to medicines in a pharmacy is registered and entered in a medicine storage unit in a pharmacy. Each medicine is given a unique identification record, and in this record the following data are entered: name of the medicine, product identification number, batch number, date of manufacture, date of expiry, supplier, quantity in stock, etc. In order to automatically identify and track all the packages of a medicine, an RFID tag or a barcode label is attached to the package of each medicine. All RFID tags or barcode labels in a pharmacy are read by RFID readers or by a barcode scanner installed in a medicine storage unit. This identification information is then entered in the corresponding field of the inventory database.

The real-time monitoring of medicine's storage in the pharmacy environment is performed by the means of various sensors in order to control the appropriate environment of storage of each medicine. Environmental sensors (temperature, humidity) as well as weight sensors or even smart shelves are used in this system in order to determine the quantity of the medicines that are in stock and thus track the changes caused by consumption as well as by restocking of medicines. The data that are collected by the aforementioned sensors are analyzed and processed by the IoT gateway of the system under consideration and are then sent to the cloud server.

Communication: The collected data will be transferred to cloud servers via communication layer. As there are various wireless communication technologies like Wi-Fi, Bluetooth Low Energy, ZigBee and others, required communication technology can be integrated as per the needs of pharmacy. In the proposed IoT architecture for healthcare application, Most Popular TCP/IP protocol over the internet – MQTT protocol is used for communication between end devices and cloud servers. It is lightweight and efficient for real-time updates. The communication layer ensures the synchronization of physical and digital inventory of the pharmacy on real-time basis.

In the cloud processing stage, the collected data of the inventory of the pharmacy is stored, managed and analyzed. In the cloud-based database, in real-time, all the data of the inventory of the medicines, the information regarding the expiration of the medicines, and the environmental information are stored. By analyzing the data of the inventory of the medicines, the system determines whether there are any crises, such as low stock, near expiration, etc. And by the automated notification system, the pharmacist and the administrator of health care are notified in time.

Finally, machine learning-based demand forecasting will be employed to enable smart stock management. All historical consumption data, seasonal patterns, and past restocking actions will be analyzed and utilized to best predict future requirements. This would include the use of simple linear regression, random forest regression, and even long short-term memory (LSTM) neural networks to accurately attempt to forecast future demands and manage related inventory stocks accordingly.

These measures can be used to assess the methodology presented here, including the accuracy of inventory detection, the response time of the system, the accuracy of forecasts, the efficiency of alerts and the reduction of surplus medicines that could become obsolete. The proposed methodology offers a totally automated system based on the IoT for managing stock in pharmacies and for monitoring healthcare supplies in an efficient manner.

5. Results and Performance Evaluation

In order to evaluate the performance of the proposed system, we have performed a comprehensive evaluation and analyzed its performance in terms of various parameters. These parameters include accuracy of inventory detection, response time of the system, forecasting capability, and reduction in wastage of medicines. To evaluate the performance of proposed framework, we have used various realistic parameters to carry out simulation and to assess its effectiveness over conventional approaches of managing pharmacy. Results of our evaluation show that proposed framework of IoT-enabled smart pharmacy management is able to effectively manage the inventory of medicines using sensing, analytics of cloud and learning of machine. It helps in establishing intelligent supply chain of healthcare.

Figure 3 demonstrates the Inventory Detection Accuracy comparison between the Manual system, Barcode system and IoT-based framework for different inventory sizes of Medicine units (from 100 to 1000). In Manual system inventory accuracy decreased as the size of the inventory increases. This is because of human intervention and errors involved in recording. On the other hand, Barcode system has shown an increase in inventory detection accuracy as the inventory size increases. However, it has an intolerance to increase in complexity of inventory as it requires manual scanning of each and every item. The IoT-based framework achieved high inventory detection accuracy of around 99% for small size of inventory and has stable high accuracy for large inventory sizes (above 97%). This is due to the RFID tag identification and automated sensing of the framework and also the continuous data synchronization with the cloud platform. Thus, IoT framework is highly suitable for intelligent inventory monitoring of modern pharmacies.

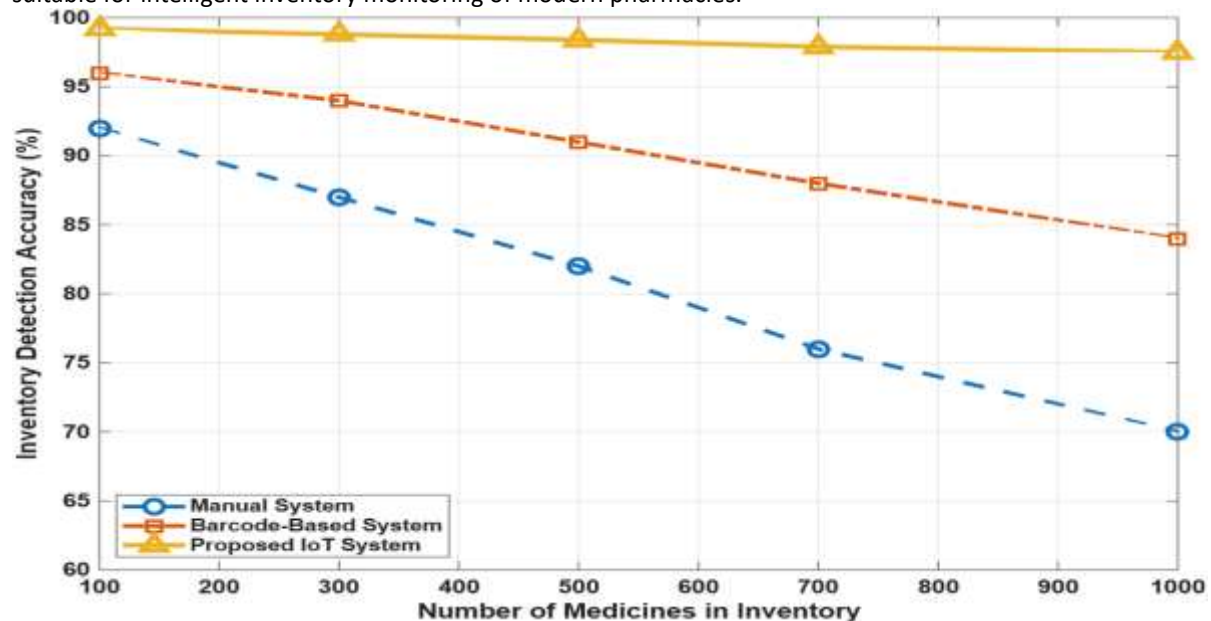


Figure.3: Real-Time Inventory Monitoring Accuracy Under Different Inventory Loads

Figure 4 illustrates the delay experienced by different approaches to inventory monitoring with the number of connected clients increased in steps to test the network load. The cloud-based approach demonstrated longer delays to process information and respond to inventory changes as it depends heavily on cloud-based computation. On the other hand, the edge-cloud-based approach demonstrated lower delay as initial processing took place closer to the sources of the data. Importantly, the proposed IoT framework presented lowest delay of all approaches included in the test and managed to respond within seconds even under highest loads. The analysis of delay to respond presented in Figure 5 further underlines the efficiency of the IoT-based processing at the gateway and communication approach adopted in the proposed smart pharmacy framework.

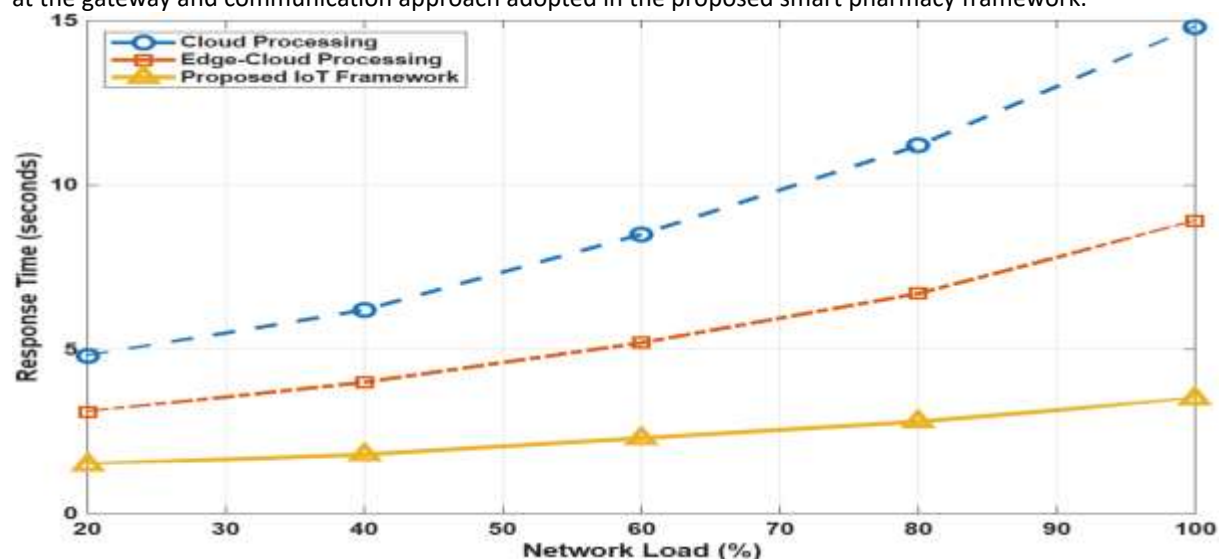


Figure.4: Response Time Analysis for Real-Time Inventory Updates

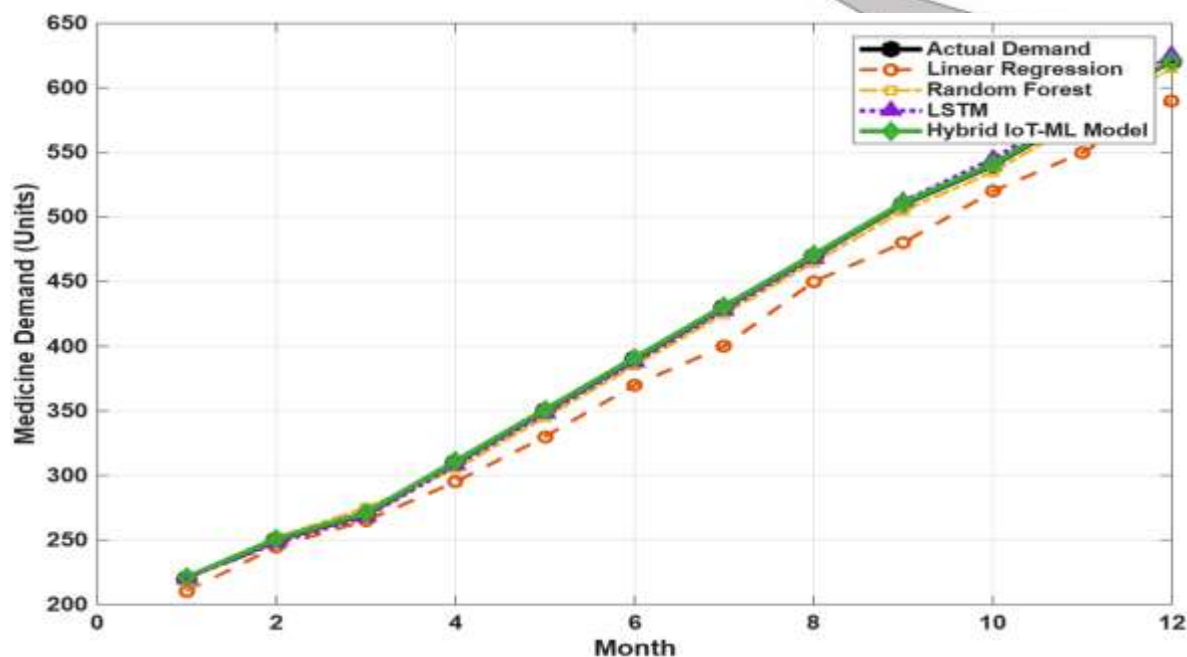


Figure.5: Machine Learning-Based Medicine Demand Forecasting Performance

Performance metrics were used in the evaluation of the proposed framework to assess various aspects of the proposed framework for IoT-enabled smart pharmacy. It was evaluated based on various performance metrics i.e. Inventory Detection Accuracy, System Response Time, Predicted Values Error and Waste Reduction. It was simulated using various pharmacy inventory profiles to evaluate its potential to handle challenges posed by various pharmacy inventory management approaches. Results from the simulation studies revealed high accuracy in inventory detection and promising results for stock management and thereby low medicine waste in a pharmacy.

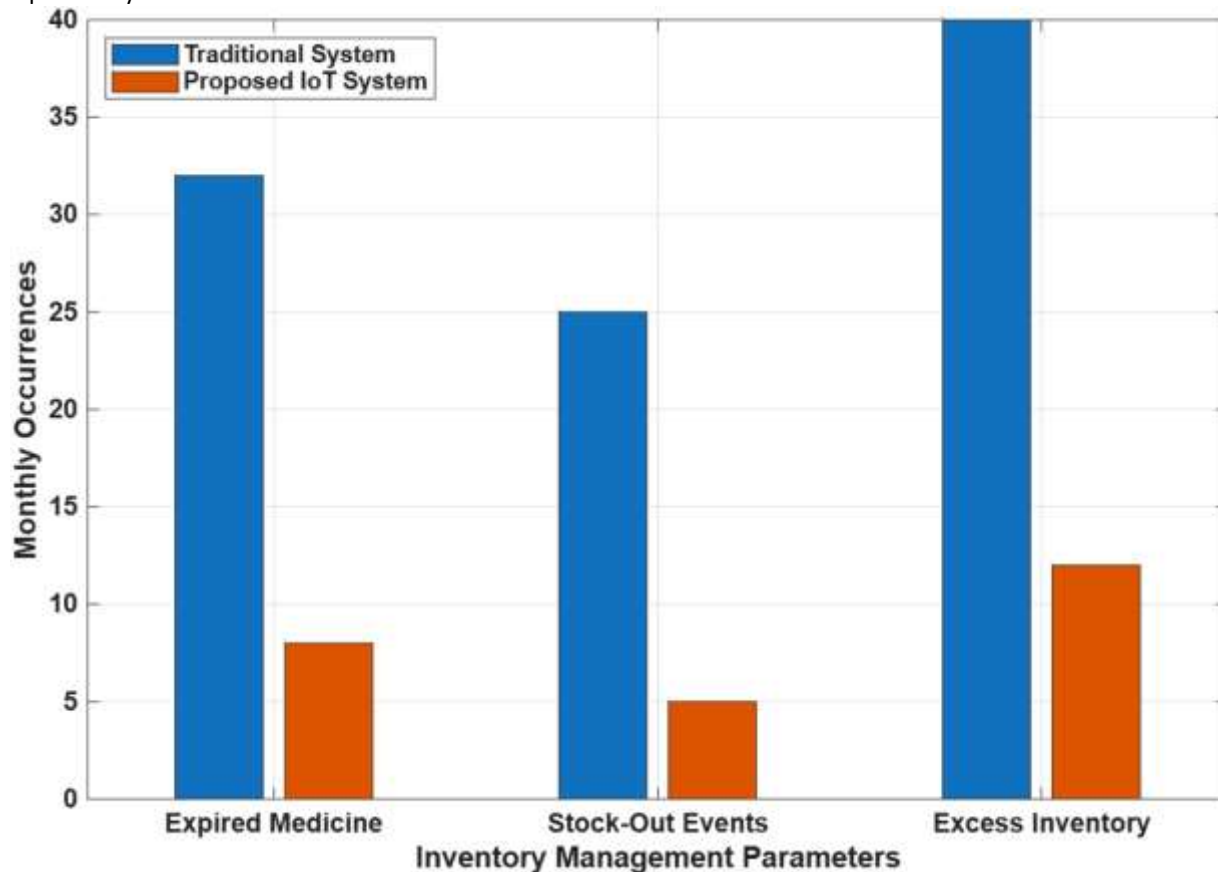


Figure.6: Reduction in Medicine Wastage and Stock-Out Events

The figure 6 demonstrates the decrease of waste of expired medicines, the number of stock-outs and of excess of stock as function of time by implementing the proposed framework for intelligent management of inventory of medicines in a smart pharmacy versus a conventional system for management of inventory of medicines. The expiry of medicines is monitored automatically, which allows in time to identify approaching expiry date of medicines and to manage stock smartly for prediction of demand of medicines.

The performance assessment of the proposed IoT-enabled smart pharmacy management system for the implementation of a smart pharmacy for effective management of the inventory was conducted to measure key performance indicators of the system including accuracy of detection of inventory, time taken by system for response to query, and capability of the system for forecasting demands of medicines for reduction in their wastage. The system thus is capable of bringing improvements in management of pharmacy's inventory significantly.

6. Conclusion

This paper presents an intelligent system for managing drug inventories of pharmacies by leveraging the vast potential of IoT, RFID/barcode technologies, cloud computing, and machine learning techniques to automate the monitoring of medicines in stock, their storage conditions, and their future requirements. The proposed system was evaluated via simulation, and obtained the inventory detection accuracy of more than 97% for various levels of complexity in simulating inventories, demonstrating its scalability and capability of being used in very large pharmacies. The system also provided real-time processing with low delays in updating inventory information, where the average delay was approximately 2–3.5 seconds under various network scenarios. Additionally, the proposed system incorporated an intelligent prediction model that used machine learning techniques to predict future demands by modeling historical consumption data of various medicines with high levels of accuracy. Furthermore, automated monitoring, and predictive analytics of the proposed system helped in drastically reducing the number of expired medicines, stockouts, and overstocking compared to conventional manual methods of managing inventory of medicines. Future work could include the implementation of deeper models (such as deep learning) to improve the demand forecasting in health care environments that are constantly changing, a blockchain-based framework for authentication of medicines and transparency in the supply chain, and a digital twin for the simulation of pharmacy operations in real time. Experiments can be repeated using existing real world datasets as well as larger scale experiments to study the proposed framework's potential implementation in hospitals and in health care networks in general.

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