

IoT and Machine Learning Based Smart Pharmacy Inventory Management For Drug Demand Prediction

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Abstract

The management of inventory in a pharmacy is critical in ensuring that medicines are available on a continuous basis while minimizing overstocking, waste and supply chain inefficiencies. The conventional method of managing inventory in a pharmacy includes manual monitoring and use of historical data to guide ordering of medicines. This method is inadequate as it does not account for the dynamic nature of consumption of medicines by patients. The incorporation of Internet of Things (IoT) technology and machine learning (ML) into the management of inventory in a pharmacy can result into an intelligent system for real time monitoring and accurate prediction of demand for drugs. This study proposes an IoT and ML-based framework for management of inventory in a smart pharmacy. The framework comprises of two layers, namely, the IoT layer which comprises of sensing devices that are connected and which are used to automatically capture data that are related to quantity of medicines, storage conditions of medicines, expiry dates of medicines and patterns of consumption of medicines. The data that are automatically captured are processed and analyzed by using ML algorithms in order to determine trends in demand and to predict future requirements of medicines. Several predictive models can be evaluated on the basis of their performance in forecasting by means of statistical measures that evaluate performance such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). The intelligent framework proposed in this study automatically makes decisions regarding management of inventory in a pharmacy by means of stock replenishment recommendations that are timely and which can result into prevention of several occurrences such as shortages of medicines and losses due to expiration of medicines. The real time sensing capability in conjunction with predictive analytics leads to efficient management of resources in a pharmacy and also aids in establishment of a smart and sustainable health care supply chain management system.

Keywords: Internet of Things, Machine Learning, Smart Pharmacy, Inventory Management, Drug Demand Forecasting, Predictive Analytics, Healthcare Supply Chain.

1. Introduction

The pharmaceutical sector plays a significant role in any health care system by providing patients with necessary medicines. Efficient inventory management in pharmacies is required to maintain adequate stock of medicines and to control costs[1]. Manual record keeping, periodic physical verification and ordering based on experience are common practices adopted by most pharmacies for inventory management. These practices have several limitations including inaccuracy in demand forecasting, non-real time inventory information, stock outs and excess stocks resulting in obsolescence and resulting losses[2]. The health care demand is increasing and health care patterns are changing very fast. Thus there is a need for an intelligent inventory management system which can monitor and respond in real time.

The monitoring of the healthcare domain has greatly benefited from the advent of IoT technology. The large array of sensors (such as smart sensors and RFID tags and readers) and IoT-connected devices can gather vast amounts of data from physical health-related entities and from their environments and store them in databases[3]. The information gathered by IoT sensors installed in a pharmacy can include data related to the quantity of stock, the environment in which it is stored and the movement of all items in and out of stock. This vast array of information can greatly enhance the monitoring of the data from physical health-related entities and from their environments and store them in databases[4]. The information gathered by IoT sensors installed in a pharmacy can include data related to the quantity of stock, the environment in which it is stored and the movement of all items in and out of stock. This vast array of information can greatly enhance the monitoring of the inventory in a pharmacy significantly and greatly reduce the human intervention required to do so manually[5].

Further, managing a pharmacy involves predicting future drug demand, which can be influenced by various factors, including seasonal variations, prevalence of diseases, demographical changes, and the number of prescriptions written by doctors over time[6]. Variations can occur due to unforeseen health emergencies. As

Inventory management in health care settings can benefit greatly from having ability to handle time-series data, numerous Machine learning algorithms have been designed for predicting future based on past data including time-series data[7]. These include algorithms for regression such as Random Forest Regression, Support Vector Regression, XGBoost, and even Neural Networks including those with memory such as LSTM. An integrated approach of IoT for real-time sensing and ML for data analytics can enable smart and automated inventory management in a pharmacy to minimize stock related losses and to have drugs in supply at all times[8].

Pharmacy management systems have traditionally focused on enabling inventory tracking and supporting transactions related to such stock. However, to provide the most added value and to enable intelligent drug demand forecasting using real-time sensing and associated storage parameters and other operational aspects, there is a need for a framework that combines real-time sensing IoT technologies with predictive analytics[9]. Such a framework would benefit from incorporating information related to past sales; however, most current approaches for forecasting rely on historical sales data and do not make use of the array of information available from inventory, that is in real time and also with respect to other factors of interest[10].

In this paper, an IoT and machine learning-based framework for the smart inventory management of a pharmacy has been proposed. Real-time data acquisition from IoT sensors has been used in conjunction with demand forecasting from machine learning models to facilitate the pharmacy to maintain sufficient supplies of drugs, minimize losses resulting from excess inventory, and ensure optimal inventory levels. The framework enables rational decisions regarding drug requirements through real-time inventory monitoring and automatic stock replenishment. In summary, this paper describes the implementation of modern technologies for the efficient management of a pharmacy's inventory.

2. Literature Review

Healthcare management systems are rapidly evolving with the advent of new technologies. Management of pharmaceuticals within health care systems is a challenging task especially with regards to inventory management. Most of the current methods of inventory management in pharmacies are based on manual recording and rely on periodic physical verification of stock and use of fixed ordering policies[11]. These methods suffer from several problems including inaccuracy in demand forecasting, delay in decision making, stock outs and losses due to perishability of products. To address these problems, there is a growing interest in the use of intelligent technologies, including the Internet of Things (IoT), machine learning (ML) and predictive analytics for managing inventory of pharmaceuticals in health care systems[12].

The adoption of IoT technologies for healthcare applications has received significant attention over recent years[13]. These systems, which comprise of sensors, RFID readers, tags, and also cloud-based platforms, are interconnected and able to collect and transmit data in real time[14]. For inventory management of a pharmacy, monitoring of storage conditions, the management of expiration dates, as well as the automatic update of stock are some examples of how IoT technologies can be used[15]. Additionally, there are smart shelves equipped with sensors of weight and RFID readers that are able to monitor the availability of products and thus to avoid human error during the physical count of the stock[16]. There are also temperature and humidity monitoring systems that are able to control the appropriate storage conditions of temperature sensitive products.

The use of Machine Learning (ML) techniques in healthcare supply chains for demand forecasting and decision support has been increasing, with many techniques being compared for their ability to forecast demand based on historical data as well as influencing factors[17]. Many of these approaches are supervised learning approaches, such as regression, decision trees, Random Forest, Support Vector Machines, and Gradient Boosting. More recently, there has been growing interest in using deep learning approaches, including artificial neural networks, and long short-term memory (LSTM) networks for time-series forecasting tasks[18].

Machine learning has been the focus of several studies on the prediction of pharmaceuticals' demand, for improving stock control in health-care facilities by making better estimates of the needed supplies based on historical sales data. However, most of these studies have relied on historical data, typically collected from databases and used for training and testing the performance of the proposed models, whereas, in reality, these models need to be fed by a continuous stream of real-time, operational data, which might be hard to collect, especially in settings that are not yet equipped with IoT devices and related technologies.

The last decade has witnessed immense growth in the adoption of IoT in healthcare. Much of the existing work has concentrated on developing integrated frameworks incorporating IoT with ML to support various healthcare applications. For instance, for managing pharmacy inventory, such a framework could enable real-time tracking of stock and apply ML algorithms for demand forecasting and automatic reordering. While significant progress has been achieved in these areas, challenges related to scalability, security, and interoperability, among others,

must still be addressed. Also, there is a need to develop and validate the models to support diverse health care systems with high variability in pharmaceutical demand.

The integration of IoT data with prediction models and in particular machine learning, and the resulting implementation of automated decision making systems within smart inventory systems for pharmacies has considerable potential to improve the efficiency of current pharmaceutical inventory systems and as a result the availability of medicines to patients. However, work is required to develop a framework that can incorporate the various different elements that are required for the implementation of such a system.

3. Proposed System Architecture

Smart Pharmacy Inventory Management Using IoT and Machine Learning for Real Time Monitoring of Drugs. In this paper, an attempt has been made to integrate latest technologies like IoT and Machine Learning in the Inventory Management of a Pharmacy. The system proposed in this paper consists of various layers namely IoT sensing layer, communication layer, data storage and processing layer, machine learning prediction layer and decision-support layer. Each of the layer has been made to perform their respective tasks in Inventory Management for a Pharmacy to monitor the physical stock of medicines and their requirements for supply.

In the proposed architecture, the IoT sensing layer consists of physical devices in a smart environment. The inventory-related information of a smart pharmacy is collected in real time. For example, an RFID tag, a barcode reader, a smart shelf, a weight sensor, and environment sensors are used to measure the quantity of a medicine, the movement of a medicine, the storage temperature, the humidity, and the approaching expiry date of a medicine, respectively. Information related to the medicine inventory is collected and viewed in real time in order to reduce human check ups and to take action in advance in case of low stock, wrong storage and an approaching expiry date.

The communication layer consists of communication methods that can send data in real-time from sensors and other edge devices to nodes in the data storage and processing layer. In the context of a smart pharmacy inventory management, it can include Wi-Fi, Bluetooth Low Energy (BLE), Zigbee or even LoRa-based wireless sensor networks. It allows seamless communication between the sensors, edge computing and cloud computing. The communication layer therefore plays a critical role in managing the data flow to enable timely and accurate decision-making in the management of a pharmacy's medicine stock.

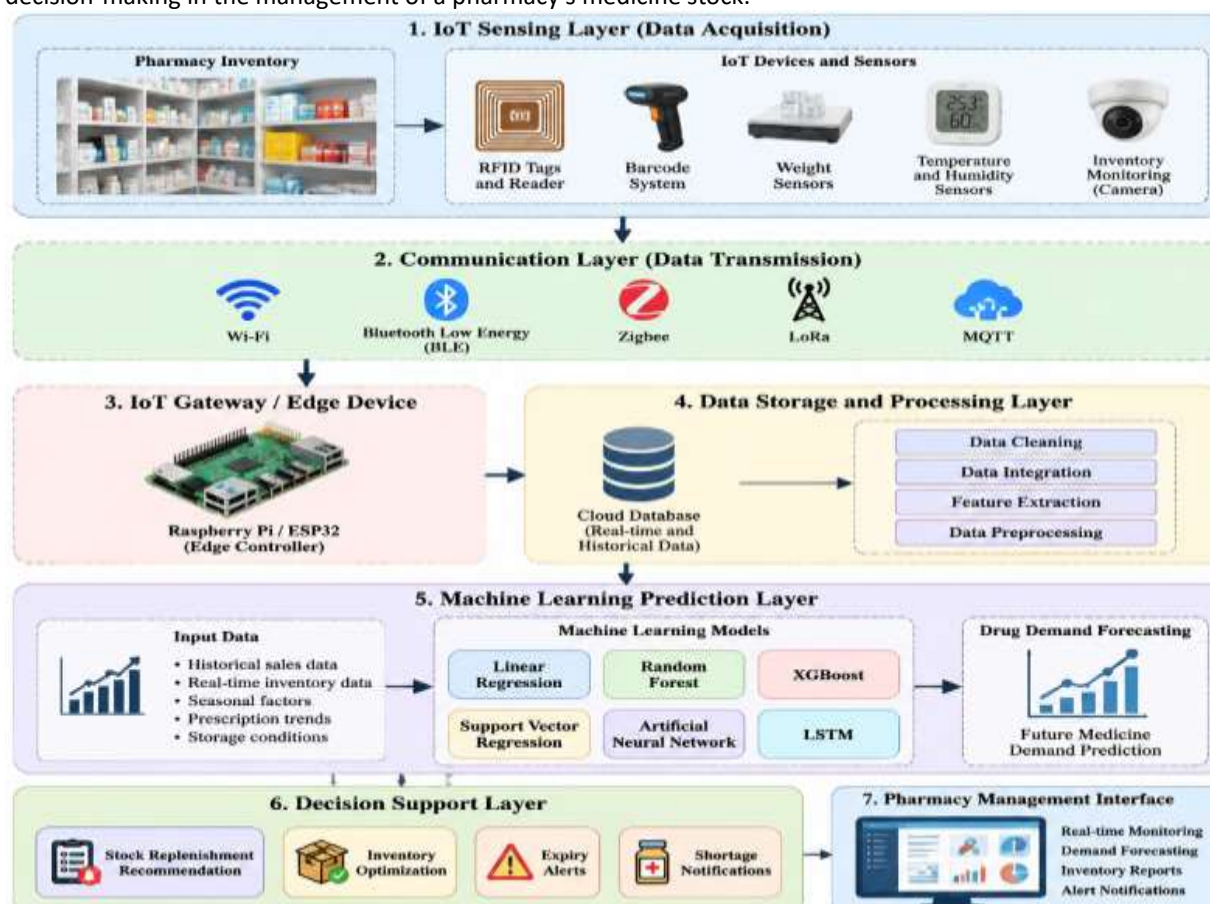


Figure 1. Proposed IoT and Machine Learning-Based Smart Pharmacy Inventory Management Architecture

Figure 1. Proposed IoT and Machine Learning-Based Smart Pharmacy Inventory Management Architecture. The framework integrates real-time inventory monitoring through IoT-enabled sensing devices with machine learning-based demand forecasting to support intelligent inventory optimization and automated decision-making. In the data storage and processing layer data collected from the IoT-sensing layer is stored within a data base or within a cloud-based storage system in a structured manner. The stored data (IoT data as well as historical/philosophical data) goes through several pre-processing steps, i.e. handling of missing values, normalization of attributes, feature generation, data integration etc. This layer makes use of the real-time data generated by the inventory in the pharmacy as well as the historical consumption information of the medicines, along with several other parameters such as seasonal variations, patient's prescription history etc.

In the proposed architecture the machine learning prediction layer predicts future medicine demand. This layer uses various machine learning models to monitor and to predict future usage of various medicines. The various models which can be used in this layer include regression models, decision trees, Random Forest models, XGBoost models, Support Vector Regression models, Artificial Neural Networks and long short-term memory (LSTM) models. The models are evaluated using various evaluation parameters such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE).

The decision-support layer supports the pharmacy management team by converting the demand-forecasting output into appropriate actions to run the medicines inventory on an optimal basis. Stocks that need to be replenished, overstock and near to expire medicines can be automatically notified to the team for necessary actions using alerts.

The proposed IoT and ML framework is envisioned to enable smart pharmacy inventory management that could be transformative for health care pharmacies. It supports real-time monitoring and inventory management and incorporates predictive functions to ensure optimal levels of necessary medicines in a timely manner and to manage corresponding health care supply chains efficiently.

4. Methodology

This paper presents a novel IoT and machine learning-based framework for smart pharmacy inventory management. A complete methodology for the implementation of such system is presented and includes data collection, data pre-processing, feature extraction, demand prediction using machine learning, performance evaluation, and finally, inventory management. The system will monitor the various pharmacy stocks and based on the past consumption of the medicine, predict future requirements of the drugs.

To set up a framework to monitor the stocks of a pharmacy, we need to first collect the data of the inventory of the pharmacy. For the purpose of our project, we can use various types of IoT enabled sensors such as RFID readers, barcode readers, smart shelves, weight sensors, temperature sensors, and humidity sensors to fetch the information of the medicine that is available in the pharmacy in real time. These real time fetched information can include the information of the medicine, the current stock of the medicine, the frequency of sales of the medicine, the storage conditions such as temperature and humidity, and the remaining time for which the medicine is valid to be used. We also need to fetch the historical data of the medicines that are sold in the pharmacy. The historical data can include the information of the medicines that are sold in the pharmacy in the past, the frequency of sales of the medicines, the information of the prescriptions that are made by the doctors of the pharmacy, etc. This historical data will help us to predict the demand of the medicine in future by analyzing the long term trends, seasonal trends, and various other trends.



Figure 2. Workflow of the Proposed IoT and Machine Learning-Based Drug Demand Prediction Methodology

Figure 2. Workflow of the Proposed IoT and Machine Learning-Based Drug Demand Prediction Methodology. The methodology includes IoT-enabled data acquisition, historical data integration, preprocessing, machine learning model development, performance evaluation, drug demand forecasting, and intelligent inventory management decisions. The pre-processing step is required to improve the quality of the data and make it suitable for a learning algorithm. In this step the data is cleaned, missing values are handled, inconsistent data points are removed, and the data is normalized. The main goal of this step is to select the most relevant features that can be used to predict the medicine demand. Previous sales values, daily and monthly consumption values, seasonal indicator, current inventory levels, disease related demand variations and storage conditions are some of the relevant features that can be extracted from the collected data. The dataset is then split into a training set and a testing set.

In the prediction stage, models are developed to forecast future drug demand using features extracted in the feature extraction stage. Various supervised learning models such as Linear Regression, Random Forest, Support Vector Regression (SVR), Extreme Gradient Boosting (XGBoost), and even feed forward Artificial Neural Networks (ANN) are compared to each other and used for the inventory management. While traditional models can handle various inventory-related variables, and predict their behavior using the relationships found between these variables, deep learning models like Long Short-Term Memory (LSTM) networks are especially efficient in time-series prediction problems, where drugs' consumption over time forms a time-series. Therefore, the best model to predict the future demand of drugs is chosen based on its performance in forecasting as well as in handling various dynamics in the medicine demand over time.

The prediction models are evaluated using the standard metrics used to measure the performance of regression models. These are the Mean Absolute Error (MAE), Root Mean Square Error (RMSE) and Mean Absolute Percentage Error (MAPE). The best model is then used to make predictions about future demand and to support the inventory management decisions of the smart pharmacy.

This integrated framework will be coupled with a decision-support system which utilizes the predicted demand along with current stock levels and expiry dates to provide pharmacy management with automated stock-replenishment recommendations, helps manage the current inventory levels, and alerts for potential stock-shortages prior to occurrence. Overall, the proposed framework aims to transform traditional inventory management within the smart pharmacy from a human-intensive task to an automated-intelligent task utilizing data acquired via IoT sensors and sophisticated predictive analytics provided via Machine Learning algorithms.

5. Machine Learning Model Development

The machine learning model development goal in this stage is to identify the appropriate models for predicting future drug demand in pharmacies, to be integrated into an intelligent inventory management system. Model development involves data preparation, feature selection, model building, hyperparameter optimization and evaluation using appropriate metrics. Several different machine learning approaches will be considered for the prediction of medicine requirements.

The input variables used for establishing the model comprise various historical data such as past sales of medicines, category of the medicines, past values of demand, current stock, seasonal, past prescription, diseases, storage and expiration information of stock. The time dependent features that have been extracted to capture patterns in the consumption of stock over time are the daily, weekly and monthly trends. This data is then integrated with the current real time stock information generated by the IoT sensors of the pharmacy to develop a robust model that is capable of understanding the current stock situation and adapting to changing consumption patterns.

In this work several supervised machine learning models are analyzed for the prediction of drug demand, including Linear Regression as the simplest predictor to model relations between inputs and the demand and more complex models such as Random Forest, Support Vector Regression (SVR) and Extreme Gradient Boosting (XGBoost). The previous model of Linear Regression can model only linear relationships between inputs and the demand of medicines, whereas the demand of medicines depends on several factors including seasonal variations, stockouts caused by natural or man-made disasters, and variations in healthcare needs of patients. Thus, the models other than Linear Regression can model nonlinear relationships and can also capture interactions between input variables. The Random Forest model consists of a large number of decision trees, which are combined to improve the robustness of the model. On the other hand, XGBoost is based on an optimized gradient boosting framework that is able to handle large and complex datasets.

Deep learning methods can also be explored since they are suitable for processing sequential and time-series data. For this purpose, an Artificial Neural Network (ANN) is first designed to find the relationship between several variables affecting the inventory of a pharmacy, and then the performance of this model is evaluated. In addition, a Long Short-Term Memory (LSTM) network is designed to the end of predicting future values based on past values for pharmaceutical sales.

The data set is divided into two parts, one for training the model and another for testing the model's generalization. In the training data set, model learns to recognize patterns and to fine-tune parameters of the model. On the other hand, the testing data set is used to calculate error of the model for unseen data. For this purpose, model optimization methods, i.e., parameter tuning and cross-validation, are used. These are compared to each other to select the most appropriate model for the problem at hand.

The performance of proposed models in terms of forecasting accuracy has been assessed using standard regression evaluation metrics such as Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Mean Absolute Percentage Error (MAPE). The best-performing model has the capability to predict the future drug demand values that can be easily integrated with the proposed inventory management system for enabling automated re-ordering, preventing stock shortages and reducing medicines' obsolescence.

The resulting framework supports predictive and adaptive inventory management of pharmacies using IoT and historical data. It enables the identification of the best approach for the specific application to predict the dynamic pharmaceutical demand and supports the development of an intelligent healthcare supply chain management system.

6. Results and Discussion

To assess the performance of proposed IoT and machine learning-based framework of smart pharmacy inventory management, we have employed simulated inventory and drug demands data to demonstrate the effectiveness of proposed framework to improve the forecasting of demands of medicines for optimizing the inventory of smart pharmacy using predictive analytics. We have presented a comprehensive evaluation of proposed framework, focusing on key performance measures that include demand forecasts accuracy, comparisons of performances of different machine learning models, inventory management, and prediction reliability. The results of our evaluations clearly indicate that proposed framework of smart pharmacy uses real-time data generated by IoT-enabled inventory of smart pharmacy, and historical demand data to make intelligent decisions for effective management of pharmacy.

The demand values predicted by the proposed MLF methodology are compared to the real demand values experienced in the smart pharmacy over a period of 36 months in Figure. 3. This plot clearly demonstrates that there exists a strong relationship between the real and predicted demand values of drugs that are monitored in the smart pharmacy. This is due to the fact that the MLF methodology utilizes the real time IoT generated inventory data in conjunction with the historical values of the various input parameters that are used to forecast the demand values of different types of medicines. The predicted values follow the real demand values consistently. The methodology captures the non-linear relationship between the various input parameters and the demand values of the drugs. The methodology is also capable of capturing the temporal variations in the demand values of the various drugs monitored in the smart pharmacy. The methodology performs well in forecasting the demand values of the various types of medicines that are required by the patients on a future time-stamp. There are minor discrepancies in the predicted values and the real values experienced by the pharmacy on occasional instances when there are sudden spikes in the demand values of the various types of medicines monitored in the smart pharmacy. The spikes in the demand values occur due to sudden disease outbreaks, patients requiring immediate medicines, sudden change in the behavior of patients in obtaining prescriptions from doctors etc.

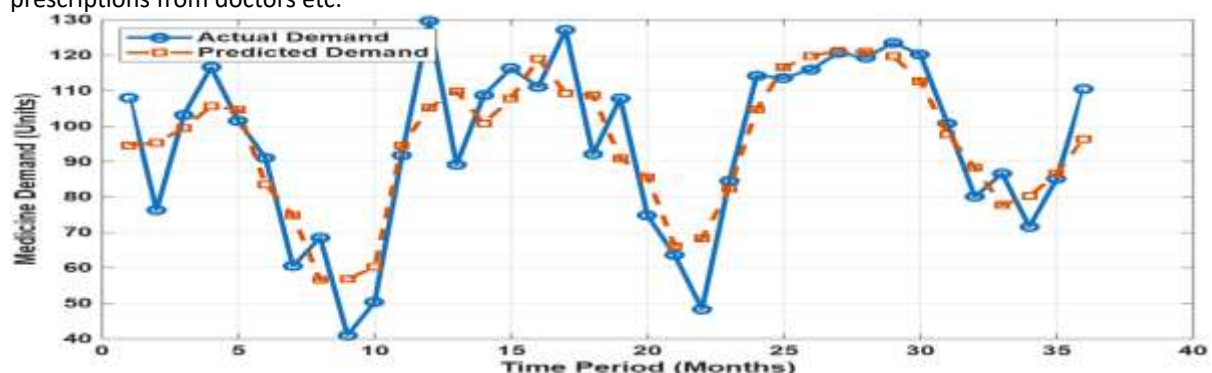


Figure 3. Actual and Predicted Drug Demand Using the Proposed ML Model

The performances of several Machine Learning (ML) models have been compared in terms of Root Mean Square Error (RMSE) and Mean Absolute Error (MAE) in Figure. 4. Traditionally, ML models such as Linear Regression have been widely used for forecasting applications. However, the forecasting errors obtained by using Linear Regression have been found to be high. This is because the nonlinear patterns in the drug demand data cannot be modeled using a simple Linear Regression model. On the other hand, ensemble-based models such as Random Forest and XGBoost have been found to obtain better results by learning correlations among the various inventory-related input features. In particular, the LSTM model, which is particularly designed for time-series forecasting applications, has been found to obtain the lowest RMSE and MAE values among all the models considered in this study. This is because the LSTM model is capable of retaining memory of past demand values, and learning long-term patterns in the consumption of drugs over time.

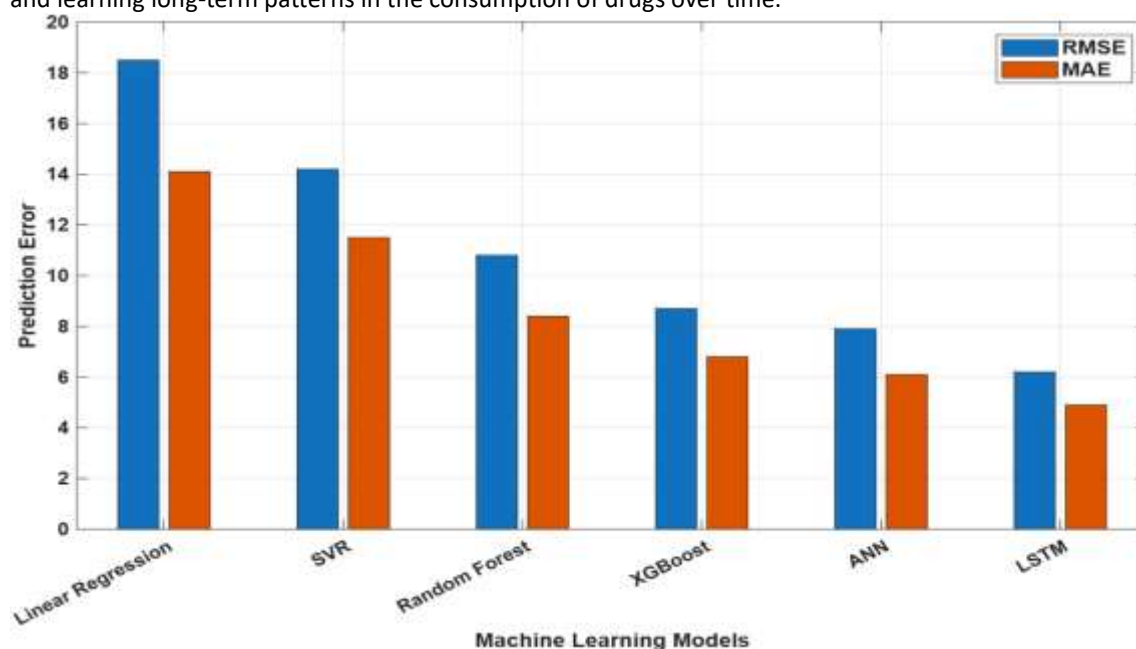


Figure 4. Performance Comparison of Machine Learning Models

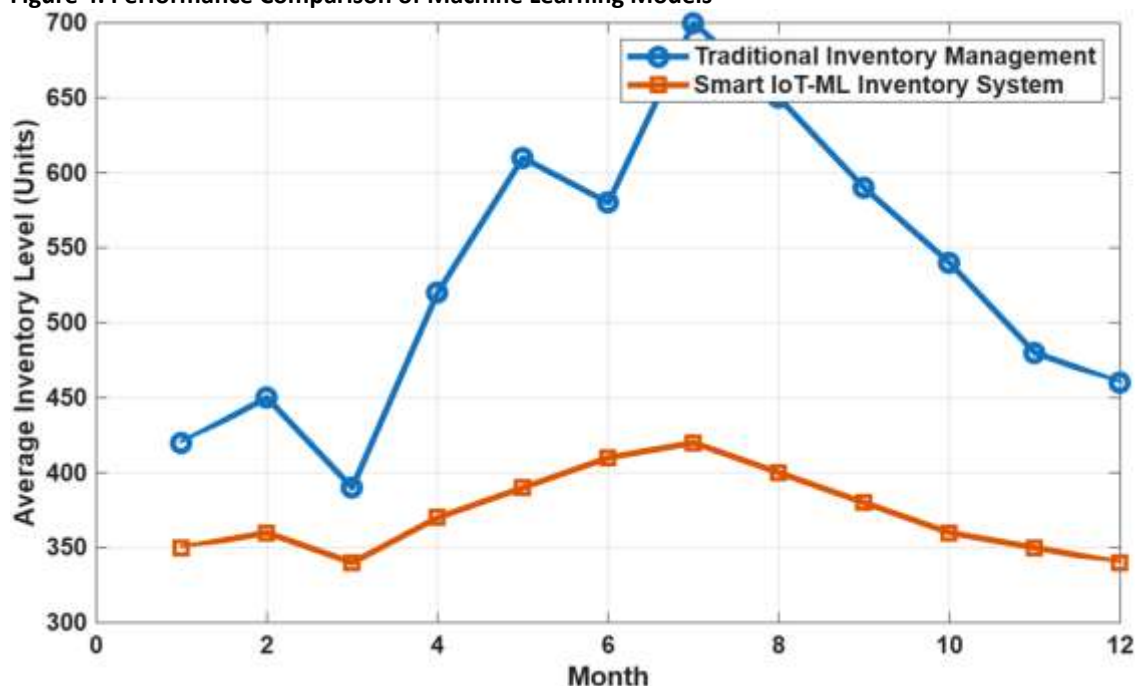


Figure 5. Inventory Optimization Before and After ML-Based Prediction

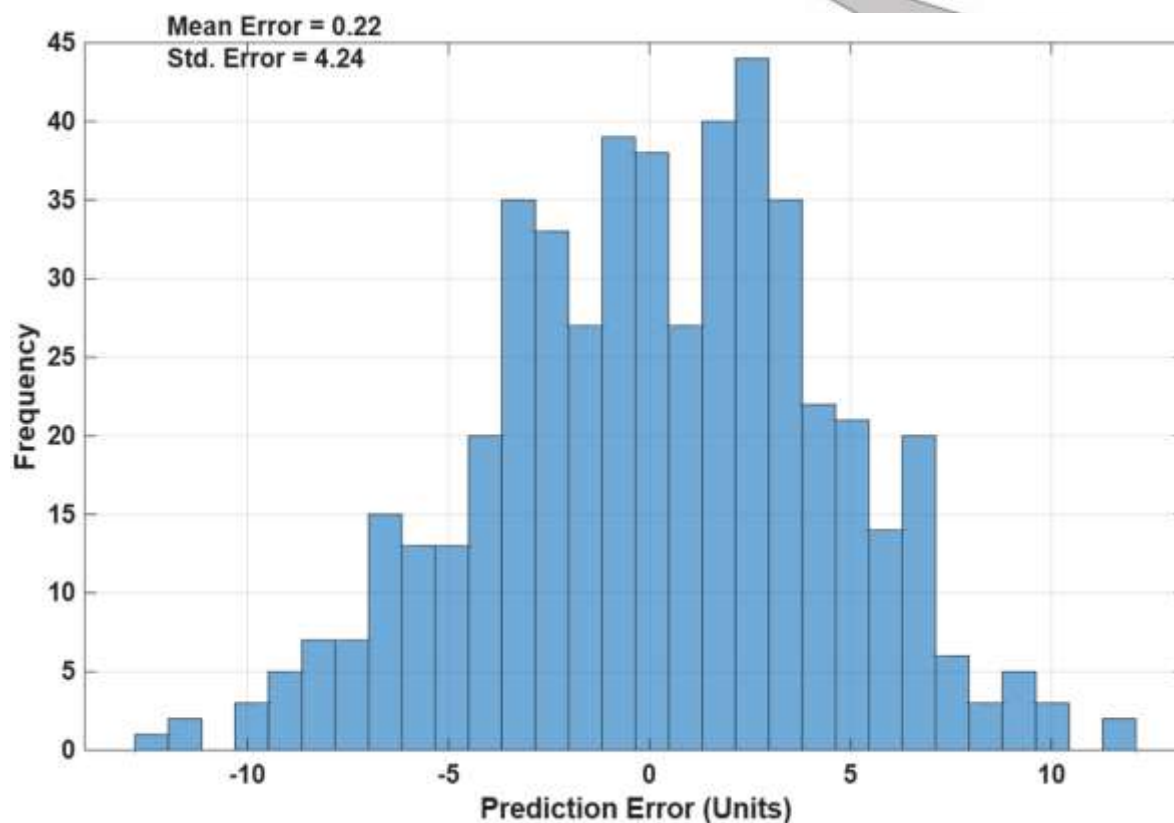


Figure 6. Prediction Error Distribution and Reliability Analysis

The figure.5. also demonstrates that the inventory levels under the conventional system fluctuate at higher levels and follow fixed ordering strategy which does not utilize the demand information. On the other hand, the intelligent inventory management approach utilizes the real time information and the predicted demand values to maintain the inventory at optimal levels and ensures the medicine availability at all times while avoiding the medicine stock out situations. The system thus avoids unnecessary accumulation of medicines and also prevents the medicines from expiration. The system thus optimizes the resources and leads to efficient management of pharmacy inventory.

Error distribution for the proposed model is depicted in Figure 6. The errors are most concentrated at zero error region with few errors distributed on either side of the zero error line. Error distribution appears to be approximately symmetrical indicating that there is no serious bias to over-estimation or under-estimation. In addition, the model has very low mean error as well as low standard deviation values, thus ensuring that the model can be confidently used for decision-making for automation of inventory of pharmacy.

The results of the evaluation using IoT generated inventory data within a simulated pharmacy setting have confirmed the potential of the framework in managing intelligent pharmacy inventory using real time data generated within the health care environment. The framework is also capable of improving the demand forecasting of the pharmacy using the inventory generated data and thus enables the pro-active management of inventory within the pharmacy thus reducing inefficiencies associated with stock management. Additionally, it supports intelligent health care decision making within the pharmaceutical supply chain.

7. Conclusion

A novel framework of IoT and machine learning-based smart pharmacy for managing drug inventory has been proposed for improved drug demand forecasting. The framework utilized real-time monitoring of inventory for making intelligent decisions through implementation of predictive models. The models were able to capture complex pharmaceutical demand pattern for improved forecasting. The performances of various models were compared including conventional machine learning models. Among the models, LSTM-based approach showed highest prediction accuracy by achieving lowest RMSE of 6.2 and MAE of 4.9. Moreover, the proposed framework of intelligent inventory strategy was able to utilize stock effectively by maintaining optimum inventory level as compared to other conventional inventory management approaches. The error prediction graphs showed stability of model with errors scattered around zero deviation line thereby signifying robust demand forecasting

capability of the model. Future work will focus on more realistic tests using current real-world pharmacy datasets, large-scale multi-pharmacy studies and real-time cloud-based implementation. In addition to improved prediction accuracy, future work can also focus on improving the intelligent inventory strategy by incorporating a reinforcement learning-based automated ordering system, secure pharmaceutical traceability using a blockchain-based system, and a federated learning approach for privacy-preserving health care data analysis. Such a framework can support the implementation of an autonomous, adaptive and sustainable supply chain for pharmacy management systems.

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