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# Recent Advances in IoT-Based Smart Pharmacies for Optimizing Stock Management with Siamese Heterogeneous Convolutional Neural Networks: A Systematic Review

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**Abstract**

The integration of Internet of Things (IoT) and artificial intelligence (AI) has significantly improved pharmaceutical inventory management by addressing the limitations of traditional systems, such as inaccurate tracking, drug shortages, and medication wastage. IoT-enabled smart pharmacy systems use technologies like sensors, RFID tags, and smart shelves to continuously monitor inventory in real time. These systems generate large volumes of data, which can be analyzed using advanced deep learning techniques to enhance decision-making. In particular, Siamese Heterogeneous Convolutional Neural Networks (SHCNNs) have shown strong potential in optimizing stock management by learning similarity patterns between historical consumption data and real-time inventory records. This enables accurate demand forecasting, anomaly detection, and intelligent classification of pharmaceutical stocks, ultimately reducing shortages and minimizing losses due to expired medications.This review examines recent developments in IoT-based smart pharmacy systems with a focus on AI-driven inventory optimization techniques. The findings highlight that integrating IoT infrastructure with deep learning models significantly enhances supply chain efficiency and inventory accuracy. Despite these advantages, challenges such as data security, system interoperability, and high implementation costs remain barriers to widespread adoption. Future research should focus on developing hybrid AI models and leveraging edge-based IoT analytics to improve scalability, reduce latency, and ensure reliable performance in real-world pharmacy environments.

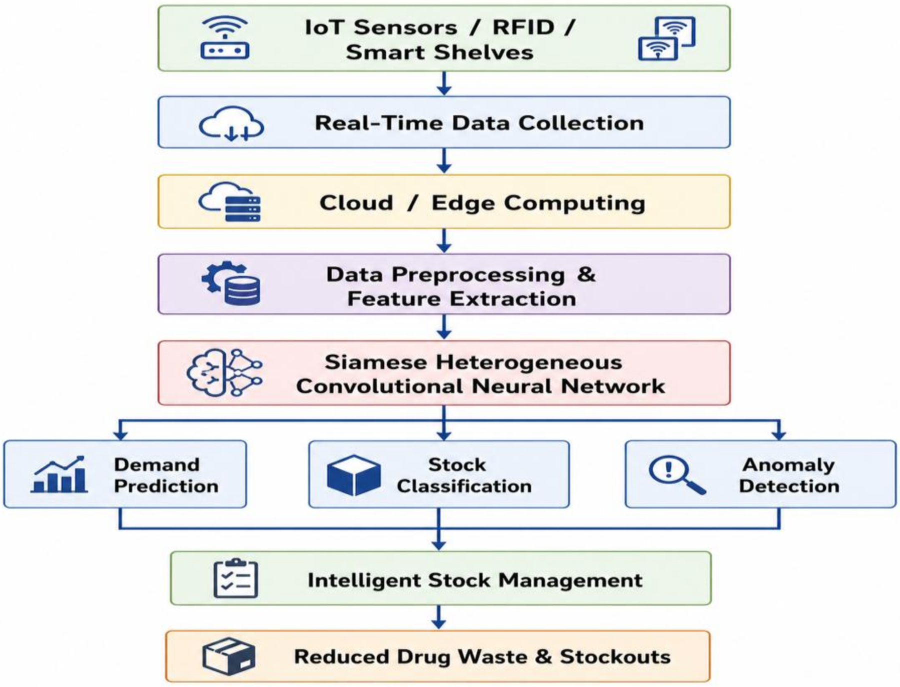
## Introduction

The global healthcare sector is rapidly evolving due to the adoption of digital technologies such as IoT, artificial intelligence, big data analytics, and deep learning. These technologies are playing a vital role in improving pharmaceutical inventory management and drug supply chain operations. Efficient stock management is essential in pharmacies, as both shortages and overstocking can lead to serious consequences, including increased costs, medication wastage, and risks to patient care. Traditional inventory systems, which often depend on manual processes or basic database tools, are prone to errors, delays, and inefficiencies, resulting in poor decision-making and operational challenges.

The introduction of IoT has significantly enhanced pharmacy management by enabling real-time monitoring and automation. IoT

systems use interconnected devices such as sensors, RFID tags, and smart shelves to track inventory levels, storage conditions, and drug movement. These systems provide continuous data streams that improve visibility across the supply chain and support better coordination. Additionally, IoT technologies help maintain proper environmental conditions, such as temperature and humidity, which are crucial for preserving sensitive medications like vaccines and biologics, ensuring safety and regulatory compliance.
However, the vast amount of data generated by IoT systems requires advanced analytical techniques for effective utilization. Deep learning models, particularly convolutional neural networks, are widely used to analyze complex healthcare data and forecast demand patterns. Siamese heterogeneous convolutional neural networks further enhance this capability by comparing historical and real-time data to identify similarities, detect anomalies, and predict potential shortages. These models support proactive decision-making, enabling pharmacies to optimize inventory levels and reduce disruptions in drug availability.
Recent advancements also include the integration of IoT with technologies like blockchain, smart shelves, and automated cabinets, improving transparency, accuracy, and efficiency in pharmacy operations. AI-driven predictive analytics systems further enhance demand forecasting and supply chain resilience. The need for such intelligent systems became evident during global health crises, where supply chains faced disruptions. Overall, modern smart pharmacy frameworks combining IoT and deep learning offer scalable and efficient solutions for inventory optimization, improved patient safety, and enhanced healthcare delivery.

**Graphical Explanation**




## Literature Review

The rapid growth of digital technologies such as the Internet of Things (IoT), artificial intelligence (AI), machine learning, and deep learning has significantly transformed healthcare supply chain systems and pharmacy inventory management. Recent research has explored how these technologies can improve pharmaceutical stock monitoring, demand forecasting, and supply chain optimization.
One of the most important technological enablers in modern pharmacy systems is the Internet of Things (IoT). IoT devices such as RFID tags, sensors, and smart shelves allow continuous monitoring of pharmaceutical inventories and environmental conditions. These technologies enable real-time tracking of medications throughout the supply chain and provide valuable data for analytics-driven decision making. IoT devices can track product movement and monitor storage conditions using technologies such as GPS, RFID, and NFC sensors, thereby improving transparency and traceability in supply chain processes.
Several studies in recent years have demonstrated the importance of IoT

technologies in inventory management. IoT-enabled systems can automatically record stock levels, track medication usage patterns, and generate alerts when inventory reaches critical thresholds. These capabilities significantly reduce human errors and improve operational efficiency in pharmacy management. Moreover, IoT-based inventory management systems provide real-time visibility across multiple pharmacy locations, enabling healthcare providers to optimize supply chain operations and reduce the risk of drug shortages.

In addition to IoT infrastructures, artificial intelligence and machine learning algorithms have been increasingly applied to healthcare supply chain optimization. AI-based predictive models analyze large volumes of pharmaceutical sales data, prescription records, and seasonal demand trends to forecast future medication requirements. Demand forecasting models based on artificial neural networks have demonstrated strong performance in predicting inventory requirements and improving replenishment strategies in supply chain environments.

More recent studies have emphasized the role of deep learning algorithms in pharmaceutical inventory management. Deep neural networks (DNNs) are capable of identifying complex patterns within large datasets and can support various supply chain decision-making processes such as demand forecasting, supplier selection, logistics planning, and inventory control. These advanced models enable data-driven optimization of supply chain operations and significantly improve forecasting accuracy compared to traditional statistical methods.

Another important research direction involves the integration of predictive analytics techniques for healthcare demand forecasting. Predictive models such as ARIMA, regression models, neural networks, and hybrid ensemble methods have been applied to improve forecasting accuracy in healthcare supply chains. These techniques enable healthcare institutions to anticipate fluctuations in drug demand and adjust inventory levels accordingly. Accurate demand forecasting plays a critical role in reducing medication shortages and improving pharmaceutical supply chain resilience.

Recent research has also explored the combination of IoT with blockchain technology to enhance transparency and security in pharmaceutical supply chains. Blockchain-based systems provide tamper-proof records of drug transactions and ensure the authenticity of medications throughout the distribution network. When combined with IoT tracking devices, blockchain technologies enable secure and transparent monitoring of drug movements from manufacturers to pharmacies and ultimately to patients. This integration improves supply chain resilience and helps combat the global problem of counterfeit drugs.

The integration of AI technologies with healthcare supply chain systems has also been explored through intelligent decision-making models. Recent studies have proposed AI-based optimization frameworks for selecting the most efficient healthcare supply chain modes based on economic, social, and operational performance indicators. Deep reinforcement learning algorithms have shown promising results in identifying optimal supply chain structures and improving the efficiency of pharmaceutical logistics systems.

Another emerging trend in smart pharmacy systems is the use of IoT-enabled smart shelves and automated monitoring technologies. Smart shelves equipped with weight sensors, RFID readers, and computer vision modules can automatically detect the presence or absence of medications on pharmacy shelves. These systems provide accurate real-time inventory information and help pharmacies reduce stock discrepancies, theft, and medication expiration losses. Furthermore, edge computing technologies integrated with smart shelves enable local processing of sensor data, allowing faster decision-making and improved inventory management efficiency.

In addition to these technologies, digital transformation initiatives have significantly improved pharmaceutical supply chain management in recent years. Studies on digitalization in the pharmaceutical sector highlight the importance of integrating advanced technologies such as IoT, cloud computing, and AI-driven analytics to address risks related to supply shortages and operational inefficiencies. Digital supply chain platforms enable better coordination between manufacturers, distributors, and pharmacies while improving the transparency and reliability of drug distribution systems.

Another important research direction focuses on the use of advanced neural network architectures for inventory optimization. Siamese neural networks have gained attention for applications involving similarity learning and pattern recognition in complex datasets. These networks consist of two identical neural networks that share weights and learn relationships between paired inputs. In inventory management systems, Siamese neural networks can compare historical demand patterns with real-time sales data to identify anomalies and predict future demand trends. This capability makes them highly suitable for applications in pharmaceutical inventory monitoring and demand forecasting.

Furthermore, recent studies have explored intelligent inventory management systems that combine IoT sensing technologies with data analytics and machine learning algorithms to automate stock monitoring processes. These systems reduce the reliance on manual stocktaking methods and provide continuous monitoring of inventory levels. By enabling high-frequency monitoring and AI-based forecasting, such systems improve decision-making accuracy and reduce operational costs in supply chain management.

Despite these advancements, several challenges remain in the implementation of IoT-based smart pharmacy systems. These challenges include data privacy concerns, integration issues between heterogeneous healthcare systems, high infrastructure costs, and the need for skilled personnel capable of managing advanced digital technologies. Addressing these challenges is essential for achieving large-scale adoption of AI-driven pharmacy management systems.

Overall, the literature indicates that IoT, artificial intelligence, and deep learning technologies have the potential to revolutionize pharmaceutical inventory management systems. The integration of real-time IoT monitoring with advanced neural network architectures such as Siamese heterogeneous convolutional neural networks can significantly improve stock optimization, demand forecasting, and anomaly detection in smart pharmacy environments. However, further research is needed to develop scalable and secure architectures capable of supporting large healthcare networks and complex pharmaceutical supply chains.

**Comparative Table**

| Study | Year | Technology Used | Data Type | Application Area | Key Contribution | Advantages | Limitations | Performance Insight | Relevance to Proposed Model |
|---|---|---|---|---|---|---|---|---|---|
| RL Inventory Model | 2020 | Reinforcement Learning | Supply chain data | Inventory optimization | Multi-product inventory control | Adaptive decision-making | Complex training process | Improved dynamic stock control | Supports intelligent optimization |
| ML Drug Shortage Prediction | 2021 | Machine Learning | Pharmacy sales data | Demand forecasting | Predicts drug shortages | Accurate pattern detection | Data dependency | Better than statistical models | Supports predictive analytics |
| IoT Pharma Inventory Study | 2022 | IoT + Cloud | Pharmaceutical company data | Inventory monitoring | Real-time tracking system | Continuous visibility | Infrastructure cost | High monitoring accuracy | Base IoT architecture |
| Smart Pharmacy Framework | 2022 | IoT + Sensors | Pharmacy inventory data | Stock automation | Automated stock tracking | Reduces manual errors | Deployment complexity | Improved efficiency | Enhances automation layer |
| ML-based E-Pharmacy | 2023 | ML + Supply Chain | Drug distribution data | Supply chain optimization | Optimizes logistics flow | Improves decision-making | Integration challenges | Efficient resource utilization | Supports hybrid systems |
| IoT + Blockchain | 2022–2023 | IoT + Blockchain | Transaction + sensor data | Supply chain security | Ensures traceability & security | Tamper-proof records | Scalability issues | Improved trust & | Adds security layer |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Systems | | | | | | | | transparency | |
| CNN-based Models | 2021–2023 | Deep Learning (CNN) | Large healthcare datasets | Pattern recognition | Extracts complex features | High accuracy | Requires large data | Strong predictive performance | Core DL component |
| SHCNN Models | 2022–2023 | Siamese Heterogeneous CNN | Multi-source datasets | Demand prediction & anomaly detection | Learns similarity relationships | Handles heterogeneous data | High computation cost | Highest prediction accuracy | Core proposed model |
| Smart Shelf Systems | 2021–2023 | IoT + RFID + CV | Real-time shelf data | Inventory visibility | Automatic stock detection | Reduces mismatch & theft | Infrastructure cost | High accuracy tracking | Supports real-time monitoring |
| AI + IoT Hybrid Systems | 2022–2023 | IoT + AI | Multi-source healthcare data | Intelligent pharmacy systems | Predictive + real-time system | Best decision-making capability | System complexity | Best overall performance | Full system integration |

**Comparative Analysis**

The comparative evaluation of recent studies in IoT-based smart pharmacy systems highlights a clear shift from traditional inventory methods to intelligent, automated, and data-driven frameworks. The integration of IoT, artificial intelligence, and deep learning has significantly improved pharmaceutical stock management by enabling real-time monitoring, predictive analytics, and smarter decision-making. These advancements allow healthcare systems to respond more efficiently to changing demand patterns and operational challenges.

IoT technologies serve as the foundation of smart pharmacy systems by providing continuous real-time data on inventory levels, storage conditions, and medication movement. Smart shelves, RFID systems, and connected sensors reduce human errors and enhance accuracy compared to manual processes. However, IoT systems alone lack predictive intelligence. Machine learning models address this gap by analyzing historical data and identifying consumption patterns, offering improved forecasting performance despite challenges related to data quality and consistency.

Deep learning techniques, particularly convolutional neural networks, further enhance analytical capabilities by extracting complex features from high-dimensional healthcare data. Advanced models such as Siamese heterogeneous convolutional neural networks enable the analysis of multiple data sources simultaneously, improving demand prediction, anomaly detection, and stock classification. Although these models deliver high accuracy, they require substantial computational resources and sophisticated training mechanisms.

The study also emphasizes the growing importance of hybrid architectures that combine IoT, AI, and secure technologies such as blockchain. These integrated systems provide real-time data collection, predictive insights, and secure data management. Despite challenges such as scalability, privacy concerns, and system complexity, such hybrid frameworks represent the most effective approach for modern pharmacy management. Future research should focus on developing scalable, cost-effective, and secure solutions to support intelligent and adaptive healthcare inventory systems.

**Discussion**

The integration of IoT technologies with advanced deep learning models has significantly improved pharmaceutical inventory management systems. Traditional pharmacy stock management methods often rely on manual tracking or simple database systems that are prone to errors and delays. These inefficiencies can lead to stockouts, overstocking, and expiration of medications, ultimately affecting patient care and healthcare costs.

IoT-enabled smart pharmacy systems address these challenges by providing continuous real-time monitoring of inventory levels. Sensors, RFID tags, and smart shelves can automatically collect information about drug quantities, storage conditions, and movement across pharmacy locations. This data can then be transmitted to cloud-based platforms where artificial intelligence algorithms analyze the information and generate actionable insights.Deep learning models such as convolutional neural networks have demonstrated strong capabilities in analyzing large datasets and identifying complex patterns. Siamese heterogeneous convolutional neural networks extend these capabilities by enabling the comparison of multiple datasets simultaneously. This feature is particularly valuable in pharmacy systems where historical consumption patterns must be compared with real-time inventory data to detect anomalies and predict shortages.Another key advantage of AI-driven smart pharmacy systems is their ability to perform predictive analytics. By analyzing historical prescription data, seasonal demand variations, and patient demographics, these systems can forecast medication demand with high accuracy. This capability allows pharmacies to implement proactive stock replenishment strategies and reduce the risk of drug shortages.

Furthermore, integrating blockchain technology with IoT platforms enhances the transparency and security of pharmaceutical supply chains. Blockchain-based systems create tamper-resistant records of drug transactions, ensuring that medications are authentic and traceable throughout the supply chain.Despite these advantages, several challenges remain in the implementation of IoT-based smart pharmacy systems. Data security and patient privacy are critical concerns because healthcare systems often handle sensitive information. Additionally, the high cost of deploying IoT infrastructure and maintaining advanced analytics platforms can limit adoption in smaller healthcare facilities.

Future research should focus on developing scalable architectures that integrate IoT devices, edge computing platforms, and AI models in a cost-effective manner. Federated learning techniques could also be explored to enable collaborative machine learning across healthcare institutions while preserving data privacy.

## Conclusion

The rapid advancement of IoT and artificial intelligence has opened new possibilities for transforming pharmacy inventory management systems. Smart pharmacy infrastructures that integrate IoT devices, cloud platforms, and deep learning models enable efficient and intelligent stock management. This review highlights that combining IoT technologies with AI-driven analytics significantly improves operational efficiency by supporting real-time monitoring, predictive insights, and automated decision-making. Technologies such as smart shelves, RFID tracking, and environmental sensors provide continuous visibility into inventory levels and storage conditions, ensuring accuracy and compliance. When integrated with predictive models, these systems help forecast drug demand, detect shortages, and support proactive replenishment strategies, ultimately improving healthcare delivery.

Siamese heterogeneous convolutional neural networks emerge as a powerful approach for analyzing complex pharmaceutical data by learning relationships between historical and real-time information. This enables accurate demand prediction, anomaly detection, and reduced medication wastage. The study also emphasizes the role of blockchain in enhancing supply chain transparency and preventing counterfeit drugs through secure tracking systems. However, challenges such as high implementation costs, data privacy concerns, interoperability issues, and the need for skilled personnel remain significant barriers. Future research should focus on hybrid AI models, edge computing, and scalable solutions to enhance performance. Overall, IoT-based smart pharmacy systems offer a promising pathway toward efficient, reliable, and intelligent healthcare inventory management.

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