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A Secure and Intelligent Drug Supply Chain System using IoT, Blockchain and Digital Twin-Based Quality Assessment

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Abstract - The pharmaceutical supply chain faces major challenges in ensuring the safety, authenticity, and proper storage of medicines during transportation and distribution. Traditional drug monitoring systems mainly rely on manual records and basic tracking methods, which lack real-time monitoring, transparency, and secure data management. Improper environmental conditions such as temperature and humidity variations can damage medicines and vaccines, leading to serious risks to patient safety. In addition, the absence of secure tracking mechanisms increases the possibility of counterfeit drugs and data manipulation in the supply chain.

To address these challenges, this project proposes a secure and intelligent drug supply chain monitoring system using IoT, Blockchain, and Digital Twin technologies. The system uses IoT sensors such as DHT11, and GPS to continuously monitor temperature, humidity, and location of pharmaceutical products during transportation and storage. The collected sensor data is processed using NodeMCU and transmitted through Wi-Fi to Firebase cloud storage for real-time monitoring and visualization through a web dashboard.

Blockchain technology based on Ethereum and smart contracts is integrated to provide secure, transparent, and tamper-proof storage of drug transaction and monitoring data. In addition, a Digital Twin model is implemented to create a virtual representation of the real-time condition of medicines, enabling better visualization and monitoring of the pharmaceutical environment. The system also generates instant alerts whenever environmental conditions exceed safe limits, helping maintain drug quality and safety.

Overall, the proposed system improves transparency, enhances patient safety, reduces the risk of counterfeit medicines, and provides a scalable and efficient solution for modern pharmaceutical supply chain management.

Index Terms - IoT, Blockchain, Digital Twin, Drug Tracking, Pharmaceutical Supply Chain, Firebase, Real-Time Monitoring, Smart Contracts, Cloud Storage, DHT11 Sensor

1. INTRODUCTION

In recent years, ensuring the safety, authenticity, and proper transportation of pharmaceutical products has become a major challenge in the healthcare industry. Medicines and vaccines are highly sensitive to environmental conditions such as temperature and humidity, and improper storage

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during transportation can reduce their effectiveness and quality. In addition, traditional pharmaceutical supply chain systems mainly depend on manual records, barcode tracking, and centralized databases, which lack real-time monitoring, transparency, and secure data management. These limitations increase the risk of counterfeit medicines, data manipulation, and delayed detection of unsafe conditions.

With the rapid growth of Internet of Things (IoT) technology, real-time monitoring systems have become more efficient in collecting environmental data using smart sensors. IoT devices such as temperature, humidity, GPS, and RFID sensors can continuously monitor pharmaceutical products during transportation and storage. However, storing sensitive supply chain data in centralized systems still creates security and trust issues.

Blockchain technology provides a secure and tamper-proof solution for managing pharmaceutical supply chain data. By using decentralized storage and smart contracts, blockchain improves transparency, traceability, and security of drug information while preventing unauthorized modifications. In addition, Digital Twin technology enables the creation of a virtual representation of the real-time condition of pharmaceutical products, helping stakeholders monitor and analyze the transportation environment more effectively..

Gamification elements such as point accumulation, skill-based badges, and streaks are incorporated to sustain long-term user engagement. An integrated leaderboard encourages healthy competition, while AI-powered assistance helps learners progress without revealing complete solutions, promoting true problem-solving skills.

This project proposes a secure and intelligent drug supply chain monitoring system using IoT, Blockchain, and Digital Twin technologies. The system continuously monitors temperature, humidity, and location data using IoT sensors and stores the information securely through blockchain integration. A real-time dashboard and Digital Twin model are used for visualization and monitoring, while alert mechanisms notify users whenever environmental conditions exceed safe limits. The proposed system aims to improve drug safety, enhance transparency, reduce counterfeit risks, and provide a scalable and efficient solution for modern pharmaceutical supply chain management.

Several research works have been carried out in the field of pharmaceutical supply chain monitoring using IoT and blockchain technologies. However, many existing systems still face challenges related to real-time monitoring, data security, and transparency. Therefore, studying previous research papers is important to understand existing methods, technologies, advantages, and limitations. The literature review helps in identifying research gaps and supports the development of an improved and secure drug tracking system using IoT, Blockchain, and Digital Twin technologies.

2. LITERATURE REVIEW

Several research works have been carried out in the field of pharmaceutical supply chain monitoring using IoT and blockchain technologies. However, many existing systems still face challenges related to real-time monitoring, data security, and transparency. Therefore, studying previous research papers is important to understand existing methods, technologies, advantages, and limitations. The literature review helps in identifying research gaps and supports the development of an improved and secure drug tracking system using IoT, Blockchain, and Digital Twin technologies.

A. Blockchain Integrated Drug Tracking System with IoT-Enabled Containers[1]

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TheBoopathi Raja G et al. (2025) proposed a blockchain-integrated drug tracking system using IoT-enabled smart containers for pharmaceutical supply chain monitoring. The system uses IoT sensors to monitor temperature, humidity, vibration, and GPS location during transportation. Blockchain technology is used to provide secure, transparent, and tamper-proof storage of drug information. The system also generates alerts whenever environmental conditions exceed safe limits. Although the proposed system

improves transparency and drug safety, it suffers from high implementation complexity and increased operational cost.

B. Ensuring Drug Safety and Exposing Counterfeit Drugs Using Blockchain and Edge Computing[2]

Neshika R et al. (2025) proposed a system that combines blockchain, IoT, and edge computing technologies to ensure drug safety and detect counterfeit medicines. The system uses RFID tracking and sensor monitoring to provide real-time data collection and secure storage through blockchain integration. Edge computing helps in reducing processing delay and improving response time. However, the system faces challenges related to scalability and high infrastructure cost.

C. Blockchain-based Trust and Privacy-Preserving Authentication using Federated Learning in Pharmaceutical Supply Chains[3]

Mala B A et al. (2025) introduced a blockchain-based authentication system integrated with federated learning for secure pharmaceutical supply chains. The proposed system focuses on privacy-preserving data sharing and trust-based authentication among stakeholders. Blockchain technology ensures secure transaction validation while federated learning improves privacy protection. However, the system involves high computational complexity and increased processing overhead.

D. Blockchain-Enabled Drug Traceability: Evaluating Smart Contract Performance[4]

Rahul Konapure et al. (2025) proposed a blockchain-enabled drug traceability system using IoT and smart contracts. The system tracks pharmaceutical products using IoT sensor data and stores the information securely through blockchain technology. Smart contracts automate verification and traceability processes in the supply chain. Although the system improves transparency and security, it experiences high gas fees and performance issues in large-scale environments.

E. Challenges and Solutions for Supply Chain Management using Blockchain and IoT [5]

M. Surya et al. (2023) discussed the challenges and solutions for supply chain management using blockchain and IoT technologies. The system improves supply chain transparency, monitoring, and secure data storage using IoT sensors and blockchain integration. However, the proposed approach faces issues related to resource limitations, integration complexity, and scalability challenges.

3. PROJECT IMPLEMENTATION AND FEATURES

The proposed system is designed and developed using IoT, Blockchain, Cloud, and Digital Twin technologies to provide a secure and intelligent pharmaceutical supply chain monitoring system. The system continuously monitors environmental conditions of medicines during transportation and storage while ensuring secure and transparent data management. This section describes the limitations of existing systems, the important features of the proposed system, and the technologies used for implementation.

A. Addressed Limitations in Existing Systems

Traditional pharmaceutical supply chain systems

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mainly depend on manual monitoring and centralized databases, which create several challenges in maintaining medicine safety and transparency. The major limitations identified in existing systems include:

1. Lack of real-time monitoring of environmental conditions.
2. Risk of medicine damage due to temperature and humidity variations.
3. No automatic alert mechanism for unsafe conditions.
4. RepetiPossibility of counterfeit medicines and data manipulation.
5. No Limited transparency and traceability in the supply chain.
6. Lack of virtual visualization and monitoring support.

B. Key Features and Architectural Components

1. IoT-Based Real-Time Monitoring

The proposed system uses IoT sensors such as DHT11, and GPS to continuously monitor temperature, humidity, and location of pharmaceutical products during transportation and storage. The sensors collect real-time environmental data and help in maintaining safe storage conditions for medicines.

2. Cloud-Based Data Storage

The collected sensor data is transmitted through NodeMCU using Wi-Fi communication and stored in Firebase Real-Time Database. Cloud integration enables real-time monitoring, remote access, and secure storage of pharmaceutical data.

3. Blockchain-Based Secure Storage

Blockchain technology based on Ethereum is integrated into the system to provide secure, transparent, and tamper-proof storage of supply chain data. Smart contracts are used to securely manage transactions and monitoring records, reducing the risk of unauthorized modifications and counterfeit medicines.

4. Digital Twin-Based Visualization

Users A Digital Twin model is implemented to create a virtual representation of the pharmaceutical transportation environment. The Digital Twin provides real-time visualization and monitoring of environmental conditions through a web dashboard, helping stakeholders analyze and monitor the system more effectively.

5. Alert and Notification System

The system generates instant alerts whenever environmental conditions exceed safe limits. This helps in preventing medicine damage and maintaining drug quality during transportation and storage.

6. Web-Based Monitoring Dashboard

A real-time dashboard is developed using HTML, CSS, and JavaScript for monitoring sensor values, alerts, and drug transportation conditions. The dashboard provides better visualization and easy access to system information.

C. Workflow Model

The overall workflow of the proposed system includes the following steps:

- IoT sensors collect environmental data such as temperature, humidity, and location.
- NodeMCU processes the collected data and transmits it through Wi-Fi.
- SoFirebase cloud database stores the real-time sensor data.
- Blockchain securely stores transaction and monitoring records.
- The Digital Twin dashboard visualizes the real-time condition of pharmaceutical products.
- Alert notifications are generated whenever unsafe conditions are detected.

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D. Technical Stack Overview

The proposed system uses the following technologies and tools:

- *Frontend:* ReacHTML, CSS, JavaScript
- *Backend:* Firebase
- *Hardware:* NodeMCU (ESP8266), DHT11 Sensor, GPS.
- *Blockchain:* Ethereum, Solidity, Web3.js, Ganache
- *Digital Twin:* Monaco Editor for syntax-highlighting and real-time editing.
- *Cloud Storage:* JuFirebase Real-Time Database
- *Communication Protocol:* 4HTTP/HTTPS and Wi-Fi Communication

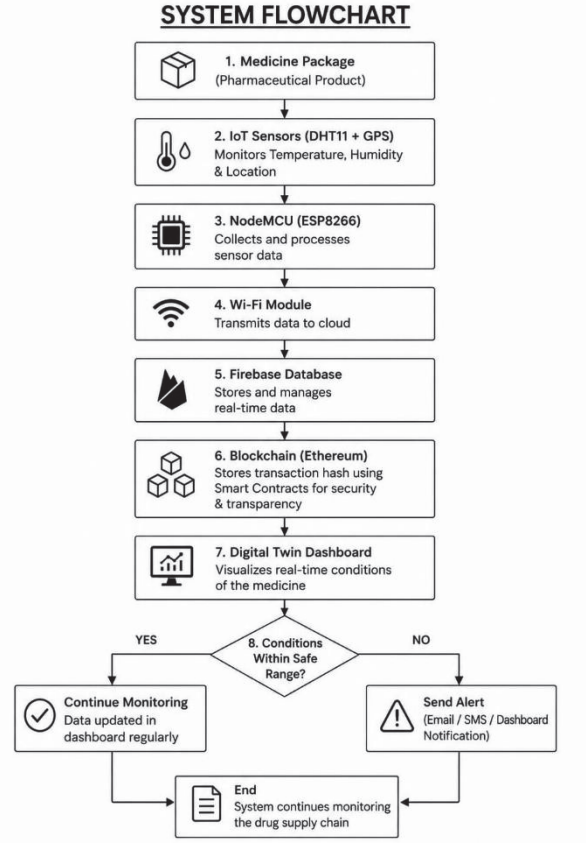

Figure: System Flowchart

4. CONCLUSION

The proposed secure and intelligent drug supply chain monitoring system using IoT, Blockchain, and Digital Twin technologies provides an efficient and reliable solution for improving pharmaceutical transportation and storage safety. The system helps in continuously monitoring important environmental conditions such as temperature and humidity during drug transportation and storage. By integrating IoT sensors, cloud computing, blockchain technology, and Digital Twin concepts, the proposed system improves transparency, security, and real-time monitoring in the pharmaceutical supply chain.

Traditional pharmaceutical monitoring systems mainly depend on manual records and centralized databases, which often lack transparency, secure data storage, and real-time monitoring capabilities. These limitations increase the possibility of counterfeit medicines, data manipulation, delayed detection of unsafe conditions, and medicine quality degradation. To overcome these challenges, the proposed system introduces a smart and automated monitoring framework capable of securely tracking pharmaceutical products throughout the supply chain process.

The integration of blockchain technology ensures secure, transparent, and tamper-proof storage of pharmaceutical data and transaction records. Smart contracts help maintain immutable records and reduce the possibility of unauthorized modifications. The Digital Twin model provides a virtual representation of real-time pharmaceutical conditions, allowing better visualization and

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monitoring through a web-based dashboard. In addition, the alert mechanism helps stakeholders take immediate action whenever unsafe environmental conditions are detected.

The major outcomes and advantages of the proposed system include:

- Real-time monitoring of pharmaceutical environmental conditions.
- Improved medicine safety and quality maintenance.
- Secure and tamper-proof storage using blockchain technology.
- Better transparency and traceability in the supply chain.
- Reduction in counterfeit medicine risks.
- Instant alert generation for unsafe conditions.
- Real-time visualization using Digital Twin technology.
- Scalable and efficient pharmaceutical monitoring system.

Overall, the proposed system improves pharmaceutical supply chain safety, transparency, and real-time monitoring using IoT, Blockchain,

and Digital Twin technologies. It enhances patient safety, reduces counterfeit risks, and provides secure data management. In future, the system can be improved using artificial intelligence, machine learning, additional sensors, and mobile-based monitoring for better efficiency and decision-making.

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