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Drug Inventory Supply Chain Tracking System Using Blockchain

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Abstract

This study focuses on the growing need within the pharmaceutical industry to preserve the integrity of temperature-sensitive drugs like vaccines and biologics throughout their storage and transport. Existing systems, often relying on manual or semi-automated processes, frequently lead to drug spoilage, inefficiencies, and poor traceability. This paper introduces the design and implementation of a platform that utilizes the Internet of Things (IoT) for drug inventory management and monitoring the cold supply chain. The system incorporates real-time environmental sensors, user-friendly web interfaces for both administrators and consumers, automated alerts, and a secure database to ensure efficient operation. The goal is to improve transparency, maintain regulatory compliance, and safeguard the effectiveness of drugs during distribution. Through simulated trials, the platform demonstrates promising results in terms of inventory precision, responsiveness to alerts, and overall accessibility for users. This scalable and secure solution is ideal for pharmaceutical and healthcare logistics sectors.

I. INTRODCUTION

The proper storage and transportation of pharmaceutical products are essential to maintaining their potency and ensuring public health safety. A significant number of medications are susceptible to fluctuations in environmental conditions such as temperature and humidity. If these parameters are not properly regulated, it may result in decreased drug effectiveness or pose potential health risks. Consequently, there is a growing demand for dependable systems capable of continuously monitoring and managing the pharmaceutical supply chain.

To address these challenges, this study introduces a web-based platform that integrates inventory control with real-time environmental tracking using Internet of Things (IoT) sensors. These sensors monitor critical factors such as temperature and humidity throughout storage and transportation, facilitating rapid detection of deviations and enabling swift corrective action to maintain regulatory compliance.

The system is designed with role-specific access, distinguishing administrative users who oversee inventory and logistics from general users who can explore available medicines and place orders. This structured approach enhances both operational efficiency and user engagement.

By combining IoT-based environmental monitoring with intelligent inventory tools, the platform seeks to minimize drug spoilage, ensure supply chain transparency, and enhance patient safety. This paper outlines the design, functionality, and anticipated benefits of the proposed system in improving pharmaceutical logistics practices.

II. LITERATURE REVIEW

Existing Approaches in Pharmaceutical Logistics

Recent advancements in technology have contributed to numerous innovations in the field of pharmaceutical logistics. Various research efforts have focused on integrating IoT and blockchain

technologies to improve supply chain transparency and drug safety.

1.**Pharma Chain 2.0**
This study introduces a blockchain-enabled framework tailored for monitoring the environmental conditions of pharmaceuticals remotely. By combining IoT sensors with cloud computing and a lightweight blockchain consensus protocol, Pharma Chain 2.0 ensures secure and consistent recording of temperature and humidity data. The system enhances transparency by enabling real-time traceability and protecting data integrity through tamper-proof logs.

2.**IoT Middleware Integrated with Blockchain (Osama Ishmilh et al., 2024):**
This research proposes a middleware architecture using the Hyperledger Fabric blockchain to secure pharmaceutical storage data. Sensor data is transmitted via the MQTT protocol and stored immutably on the blockchain. Performance assessments showed the middleware could scale effectively under high loads while maintaining real-time monitoring capabilities, thereby strengthening data security and traceability in logistics operations.

3.**IoT-Based Cold Chain Monitoring System (Sutapa Sarkar et al., 2022):**
A cost-efficient IoT solution was developed to oversee cold storage conditions during the shipment of sensitive medical and food products. The system employs a combination of sensors—temperature, humidity, gas, and light—to monitor storage environments. Data is uploaded to cloud services like ThingSpeak, and real-time alerts are triggered when any parameter falls outside the permissible range. The inclusion of gas sensors for detecting hazards like methane and smoke further enhances safety, making the solution viable for low-resource settings.

Identified Research Gaps

Despite these advancements, current pharmaceutical logistics systems still suffer from significant shortcomings:

- Limited Technological Integration: Many existing platforms rely on basic data loggers that only record environmental conditions intermittently, lacking the ability to issue timely alerts.
- Delayed Response: Without real-time monitoring, any deviation in storage conditions might only be discovered after the drugs have been delivered, compromising their safety and efficacy.
- Manual Management: Inventory and order tracking are still largely dependent on manual processes, increasing the risk of errors, delays, and inefficiencies.
- Lack of Transparency: End-to-end traceability remains inadequate, reducing trust among consumers, manufacturers, and regulators.
- Restricted User Access: Stakeholders, especially consumers, often do not have access to environmental data or interactive order management features.

2.2 Limitations of Current Systems

1.No Real-Time Monitoring: Environmental data is collected at fixed intervals, causing delays in addressing storage issues.

2.Absence of Automated Alerts: Systems do not notify stakeholders when environmental thresholds are breached.

3.Manual Operations: Dependence on human input for tracking inventory and orders leads to potential errors and inefficiencies.

4.Weak Traceability: Inadequate tracking capabilities hinder identification of when and where issues occur.

5.Low User Engagement: Existing platforms lack interactive, user-friendly interfaces for monitoring and managing medicine orders.

III. PROPOSED METHODOLOGY

To address the gaps in current pharmaceutical logistics, this project introduces a

modern, secure, and IoT-driven platform for drug monitoring and inventory management. The system will utilize real-time environmental sensors to monitor critical metrics like temperature and humidity across the entire supply chain. The platform will feature two user roles: administrators and consumers. Consumers can register, explore available medicines, place orders, and track their deliveries via an intuitive interface. Administrators will have access to tools for updating inventory, managing orders, and reviewing sensor data. The system will trigger automatic alerts if any environmental parameters fall outside acceptable ranges, enabling prompt corrective actions. The dashboard will provide real-time sensor data, and secure data logs will support regulatory compliance.

3.2 Benefits of the Proposed System

- Instant alerts: Automated notifications enable quick intervention when environmental conditions are violated.
- Streamlined inventory management: Admins can monitor and control stock efficiently with real-time updates.
- Intuitive Interface: Designed to provide easy navigation and accessibility for both administrators and end users.
- Enhanced transparency: Stakeholders gain access to detailed tracking and condition reports.
- Regulatory compliance: Ensures pharmaceutical handling aligns with safety standards through continuous monitoring and secure record-keeping.

IV. OBJECTIVES

Develop an online platform connecting rural artisans with urban consumers to showcase and sell handicraft products. The platform addresses challenges like limited market access and business tools, promoting economic growth, cultural preservation, and community engagement.

1. Enable Real-Time Inventory Monitoring:

Provide continuous visibility of stock levels across all storage and distribution points to support efficient replenishment and reduce mismatches.

2. Reduce Medication Waste:

Implement automated expiry monitoring, apply First-In-First-Out (FIFO) inventory practices, and trigger timely notifications to minimize waste from outdated or unused medications.

3.Optimize Distribution Processes:

Improve supply chain logistics through predictive dispatching, route optimization, and real-time vehicle tracking, ensuring timely delivery to remote locations.

4. Increase Supply Chain Transparency:

Offer traceability of product movements and environmental conditions, building trust with regulators, manufacturers, and end users.

5. Ensure Compliance with Regulatory Standards:

Automate documentation, create audit trails, and generate environmental logs to align with guidelines set by regulatory authorities such as the FDA and WHO.

6.Combat Counterfeit Drugs

Integrate authentication technologies like RFID, barcodes, and blockchain serialization to ensure only approved drugs enter the supply chain.

V. SYSTEM DESIGN AND IMPLEMENTATION

Introduction of Input Design:

Input design focuses on ensuring the secure, accurate, and efficient entry of data into the Healthcare Management System. The system uses structured forms and user-friendly interfaces to allow seamless interaction between administrators, physicians, and users. Data inputs are validated to minimize errors and ensure consistency. Patients

can register by entering personal information, while physicians and administrators have distinct login areas to access specific functionalities. The system supports tasks like appointment scheduling, medical reminders, and uploading records for Optical Character Recognition (OCR) processing. Physicians can update patient diagnoses and prescriptions, while administrators manage hospital and ambulance details via organized dashboards

Objectives for Input Design:

Purpose:

The main goal of the Healthcare Management System is to provide a secure, user-friendly platform that enhances healthcare service delivery for patients, physicians, and administrators. The platform simplifies tasks like appointment scheduling, medical reminders, ambulance access, and hospital management. By integrating advanced technologies like OCR and GeminiAPI, the system helps patients manage medical data and assists clinicians with daily workflows. Administrators benefit from centralized control over hospital and ambulance resources, improving coordination. Ultimately, the system fosters better communication between healthcare providers and patients, ensuring timely care and supporting the digital transformation of healthcare.

Output Design:

Output design ensures that the processed data is presented clearly and accurately. The system's output is tailored to meet the needs of administrators, physicians, and users. For users, outputs include appointment confirmations, prescription reminders, and doctor and ambulance availability. Physicians receive real-time patient updates and appointment schedules, while administrators view dashboard data such as ambulance status and hospital statistics. Outputs can be downloaded as PDFs or images and are displayed responsively on the web interface. The design prioritizes clarity, accuracy, and relevance to enhance user interaction and decision-making.

UML diagrams

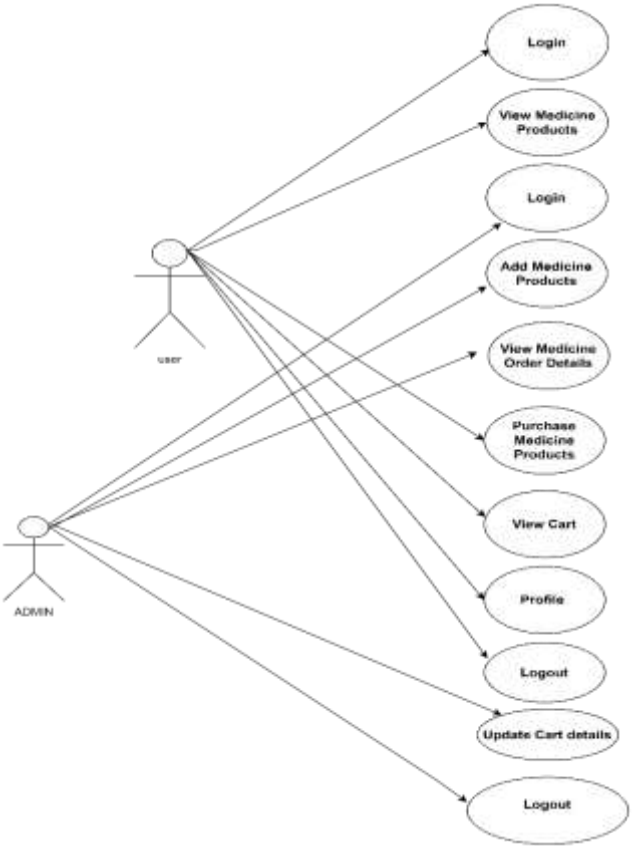
The Unified Modeling Language (UML) is a universally recognized modeling language utilized in object-oriented software development. It facilitates the design, visualization, construction, and documentation of software systems through standardized diagrams. UML offers a consistent way to represent system components and their relationships. Additionally, it is applicable to business processes and non-software systems. By incorporating established industry practices, UML serves as a reliable tool for modeling and understanding complex system architectures.

Goals of UML Design:

- Provide users with an expressive and accessible visual language to create and share meaningful models.
- Expand core concepts to allow for specialization and flexibility.
- Remain adaptable by not relying on any particular programming language or development methodology.
- Offer a structured approach to understanding and using the modeling language.
- Incorporate industry best practices for system design.

USE CASE DIAGRAM:

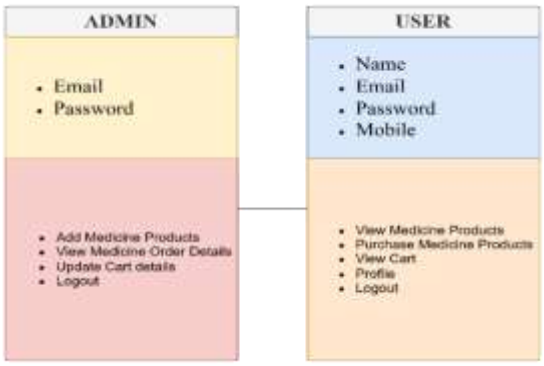
A use case diagram's primary objective is to demonstrate which actors use the system's functionalities.



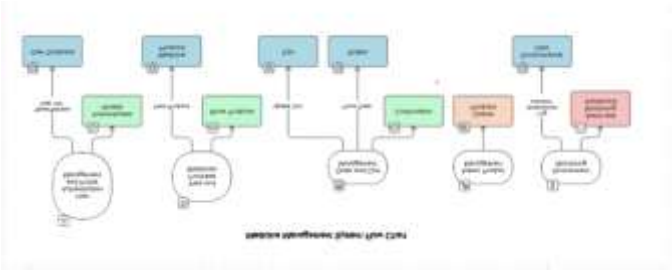
According to the Unified Modeling Language (UML), a use case diagram is a particular kind of behavioral diagram that is produced from and defined by a use-case study. In terms of actors, their objectives (shown as use cases), and any dependencies among those use cases, it serves to graphically summarize the functionality offered by a system.

2. CLASS DIAGRAM

A class diagram, as defined by the Unified Modelling Language (UML), is a kind of static structural diagram used in software engineering that illustrates a system's classes, attributes, actions (or methods), and relationships between the classes. It indicates which class has information in it.



3. DATA FLOW PLATES



The conventional system of imaging the information flows inside a system is to use a Data Flow Diagram (DFD). A substantial portion of the system conditions can be graphically represented by a clean and unequivocal DFD. It may be automatic, homemade, or a blend of the two. It displays where information is stored, how it enters and exits the system, and what modifies it. A DFD is used to illustrate the limits and extent of a system overall. As the first step in redesigning a system, it can serve as a communication tool between a systems critic and any individual involved in the system.

VI. OUTCOMES

1. Improved Inventory Accuracy

Real-time inventory tracking reduces discrepancies between recorded and actual stock levels, with each transaction logged for increased accountability.

2. Reduced Drug Expiry and Waste

Proactive tracking of expiry dates and FIFO systems help minimize the distribution of expired drugs, contributing to sustainability.

3. Faster Distribution

Route optimization and order tracking enhance delivery speeds, particularly for essential medicines in critical areas.

4. Full Supply Chain Visibility

Stakeholders gain comprehensive access to shipment statuses and condition logs, improving transparency and reducing fraud or mishandling.

5. Regulatory Compliance Support

Automated data logs and reports assist in meeting compliance standards set by global and local health authorities.

6. Enhanced Drug Safety

Barcode scanning and real-time environmental monitoring ensure drug authenticity and proper handling conditions.

7. Strategic Insights

Dashboards and visualizations provide insights into procurement trends, medicine demand, and operational performance.

VII. RESULTS AND DISCUSSIONS

Feasibility study

The feasibility study evaluates the project's viability by considering social, technical, and economic factors to ensure the solution is feasible and won't burden the business. The study provides a basic understanding of the system's requirements, with a focus on:

- **Social Feasibility**

Assessing the acceptance and benefit to all stakeholders.

- **Technical Feasibility**

Ensuring the technology required can be effectively implemented.

- **Economic Feasibility**

Analyzing financial aspects, including cost estimates and expected returns.

VIII. Types of Test & Test Cases

Unit Testing:

Unit testing verifies that individual components of the system work correctly and that inputs produce the expected outputs. It ensures that each component functions according to specifications before integration.

Integration Testing

Integration testing ensures that combined software components work as a unified system, highlighting any issues that may arise from their interaction after unit testing has confirmed their individual functionality.

VII. CONCLUSION

This project offers a robust, IoT-enabled platform for drug inventory and supply chain management. It addresses key logistical challenges in pharmaceuticals by integrating real-time monitoring, secure data handling, and automated workflows. The platform enhances patient safety, improves operational efficiency, and ensures compliance with global health standards, representing a significant advancement in the safe distribution of temperature-sensitive medications.

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