# Design and Implementation of a Multi chain Block Chain-Based Security Solution for Pharmaceutical Supply Chain Transparency Using an IoT Devices

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**ABSTRACT**

*Counterfeit medicines, poor traceability, and data tampering remain major challenges in pharmaceutical supply chains. This paper presents a permissioned Multi Chain block chain-based security solution integrated with Internet of Things (IoT) technology to improve transparency, traceability, and data integrity. The system employs ESP32 microcontrollers representing the Manufacturer, Distributor, Pharmacy, and Retailer, each equipped with a DHT11 sensor for monitoring temperature and humidity. Pharmaceutical transaction data are transmitted through a Flask-based Restful middleware, validated, and securely published to a Multi Chain block chain. A web-based dashboard provides real-time visualization and verification of block chain records. Experimental evaluation demonstrates successful environmental monitoring, secure transaction recording, and immutable block chain storage throughout the pharmaceutical distribution process. The developed prototype enhances transparency, accountability, and product traceability while providing a practical and cost-effective approach for reducing counterfeit drug distribution.*

**KEYWORDS**

*Pharmaceutical Supply Chain, Multi Chain Block chain, Internet of Things (IoT), ESP32, Flask, Drug Traceability, Transparency*

## I. INTRODUCTION

The pharmaceutical supply chain plays a critical role in ensuring that medicines are safely manufactured, transported, stored, and delivered to patients. However, counterfeit medicines, inadequate traceability, unauthorized data modification, and poor monitoring of storage conditions continue to threaten public health, particularly in developing countries where supply chain management systems are often weak.

Traditional pharmaceutical information systems are centralized, making them vulnerable to data manipulation, limited interoperability, and single points of failure. In addition, these systems rarely provide continuous monitoring of environmental conditions during transportation and storage, making it difficult to verify product authenticity and quality.

Block chain technology has emerged as an effective solution because of its decentralization, immutability, transparency, and secure transaction management. Permissioned block chain platforms such as Multichip allow authorized stakeholders to securely record and verify pharmaceutical transactions while preventing unauthorized modifications. Nevertheless, block chain alone cannot capture environmental conditions that influence pharmaceutical quality.

The Internet of Things (IoT) complements block chain by enabling real-time monitoring through embedded sensing devices. Temperature and humidity sensors continuously monitor storage conditions, while block chain permanently stores the collected data, providing trusted and verifiable records throughout the supply chain.

This study presents the design and implementation of a permissioned Multi Chain block chain-based pharmaceutical monitoring system that integrates ESP32 microcontrollers, DHT11 sensors, Flask middleware, and a web-based dashboard. The system provides secure transaction recording, continuous environmental monitoring, and real-time visualization to improve pharmaceutical traceability and transparency.

The main contributions of this work are:

- Design of a permissioned Multi Chain block chain architecture for pharmaceutical supply chain monitoring.
- Integration of ESP32 microcontrollers and DHT11 sensors for real-time environmental monitoring.
- Development of a Flask-based Restful middleware for secure communication between IoT devices and the block chain.
- Implementation of a web-based dashboard for monitoring and verification of pharmaceutical transactions.
- Experimental validation of the system using a hardware prototype.

The remainder of this paper is organized as follows. Section II reviews related work, Section III presents the methodology and implementation, Section IV discusses the experimental results, and Section V concludes the paper.

## II. RELATED WORK

Block chain technology has been widely investigated as a secure solution for improving traceability, transparency, and data integrity in pharmaceutical supply chains. Its decentralized and immutable ledger enables secure recording of pharmaceutical transactions, reducing the risks associated with counterfeit medicines, unauthorized data modification, and poor product traceability.

Early studies mainly conceptual block chain frameworks for pharmaceutical traceability without implementing practical hardware prototypes. Although these studies demonstrated the potential of block chain to improve trust among supply chain stakeholders, most lacked real-world validation and environmental monitoring capabilities.

Recent research has integrated Internet of Things (IoT) technology with block chain to enable real-time monitoring of pharmaceutical products during transportation and storage. IoT sensors continuously measure environmental parameters such as temperature and humidity, while block chain ensures that the collected data remain secure, immutable, and verifiable. Permissioned block chain platforms, including Multi Chain and Hyper ledger Fabric, are particularly suitable for healthcare applications because they provide controlled access, improved transaction efficiency, and enhanced privacy.

Several studies have also incorporated web-based dashboards to visualize block chain transactions. However, many existing implementations rely on simulated datasets or fail to provide a complete end-to-end architecture that combines IoT sensing, middleware services, block chain storage, and real-time visualization using affordable hardware.

To address these limitations, this work presents a complete pharmaceutical monitoring system based on ESP32 microcontrollers, DHT11 environmental sensors, Flask middleware, a permissioned Multi Chain block chain, and a web-based dashboard. The system provides secure transaction recording, continuous environmental monitoring, and real-time visualization to enhance transparency, traceability, and data integrity across the pharmaceutical supply chain.

Table 1. Comparison of Related Studies with the Proposed Work

| Feature | Existing Studies | Proposed Work |
|---|---|---|
| Blockchain-based traceability | ✓ | ✓ |
| Permissioned MultiChain blockchain | Limited | ✓ |
| IoT integration | Partial | ✓ |
| ESP32 implementation | Limited | ✓ |
| Real-time temperature monitoring | Partial | ✓ |
| Real-time humidity monitoring | Partial | ✓ |
| Flask RESTful middleware | Rare | ✓ |
| Web-based monitoring dashboard | Partial | ✓ |
| Experimental hardware prototype | Limited | ✓ |
| End-to-end pharmaceutical tracking | Partial | ✓ |

## III. METHODOLOGY

*A. System Architecture*

The system integrates Internet of Things (IoT) devices with a permissioned Multi Chain block chain to provide secure, transparent, and real-time monitoring of pharmaceutical products. The architecture consists of four layers: the IoT sensing layer, middleware layer, block chain layer, and application layer. Four ESP32 microcontroller nodes represent the Manufacturer, Distributor, Pharmacy, and Retailer.

Each node acquires pharmaceutical information together with temperature and humidity readings from a DHT11 sensor. The transaction data are formatted as JSON objects and transmitted through Restful HTTP requests to a Flask middleware. After validation, the middleware converts the data into block chain-compatible format and publishes the transaction to the Multi Chain block chain. Authorized users can retrieve immutable records through a web-based dashboard. Figure 1 presents the overall architecture and operational workflow of the Multi Chain-based pharmaceutical monitoring system.

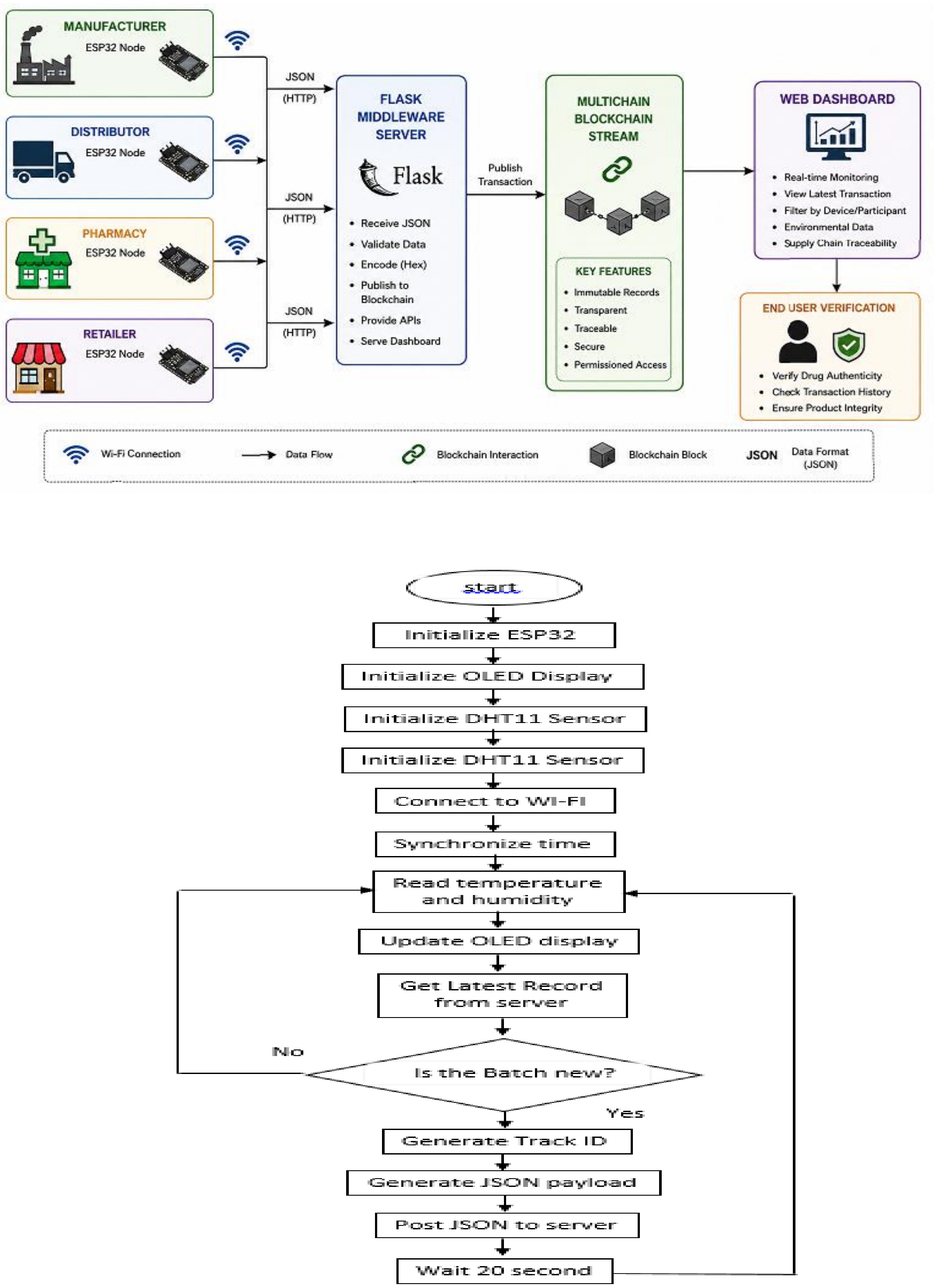



Figure. 1. Multi Chain-based pharmaceutical monitoring system: (a) Overall architecture; (b) System flowchart

### *B. IoT and Block Chain Integration*

The IoT layer consists of ESP32 Dev Kit V1 boards integrated with DHT11 temperature and humidity sensors and OLED displays. Each node performs environmental sensing, generates pharmaceutical transaction records, assigns timestamps, and transmits the collected information to the middleware through Wi-Fi.

The Flask middleware acts as an interface between the IoT devices and the block chain by validating incoming JSON transactions, converting them into hexadecimal format, and publishing them to a permissioned Multi Chain block chain. Every validated transaction contains the drug name, batch number, tracking identifier, manufacturer, temperature, and humidity, timestamp, and stakeholder identity. Once stored, block chain records become immutable and accessible only to authorized participants.

The application layer consists of a Flask-based dashboard that supports transaction visualization, environmental monitoring, stakeholder-based filtering, and product tracking through unique tracking identifiers.

### *C. System Implementation*

A hardware prototype consisting of four ESP32 nodes was developed to represent the Manufacturer, Distributor, Pharmacy, and Retailer. Each node was equipped with a DHT11 sensor and an OLED display for local visualization of environmental conditions.

The prototype communicated with the Flask middleware over a wireless local area network. Validated transactions were securely stored on the Multi Chain block chain and subsequently displayed through the monitoring dashboard. The implementation demonstrates the feasibility of combining low-cost IoT hardware with a permissioned block chain for secure pharmaceutical supply chain monitoring. Figure 2 shows the developed hardware prototype used to implement the system.

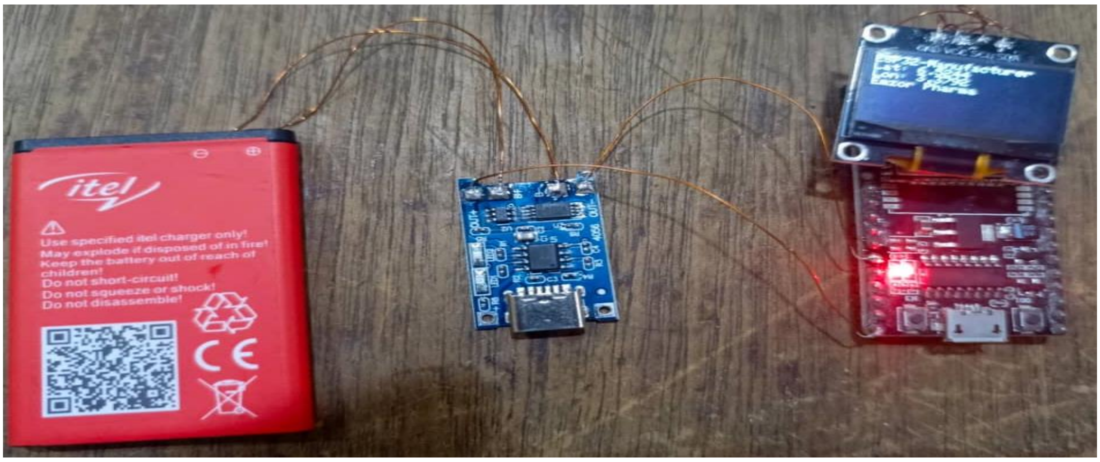



Figure. 2. Developed prototype: (a) Hardware implementation

### *D. System Algorithm*

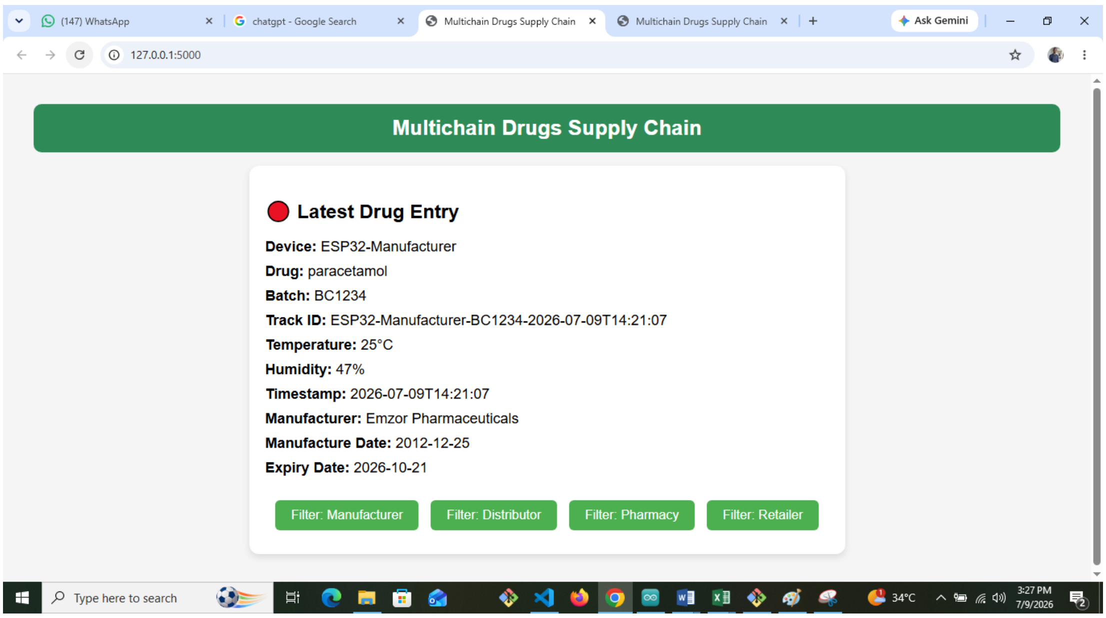
The operation of the system is summarized as follows:

Algorithm 1. Pharmaceutical Transaction Processing

- Initialize the ESP32 node and connect to the Wi-Fi network.
- Read temperature and humidity from the DHT11 sensor.
- Collect pharmaceutical transaction information.
- Generate a JSON transaction object.
- Transmit the transaction to the Flask middleware.
- Validate and convert the transaction into block chain-compatible format.
- Publish the transaction to the Multi Chain block chain.
- Display the transaction through the monitoring dashboard.
- Repeat the process for subsequent transactions.

## IV. EXPERIMENTAL RESULTS AND DISCUSSION

The developed prototype was evaluated using four ESP32 nodes representing the Manufacturer, Distributor, Pharmacy, and Retailer. Each node acquired temperature and humidity measurements using a DHT11 sensor and transmitted pharmaceutical transaction records to the Flask middleware through a wireless network. The middleware validated the received data and successfully published the transactions to the Multi Chain block chain, confirming reliable communication between the IoT devices and the block chain network. Figure 3 presents the system output, including the monitoring dashboard and block chain transaction verification.



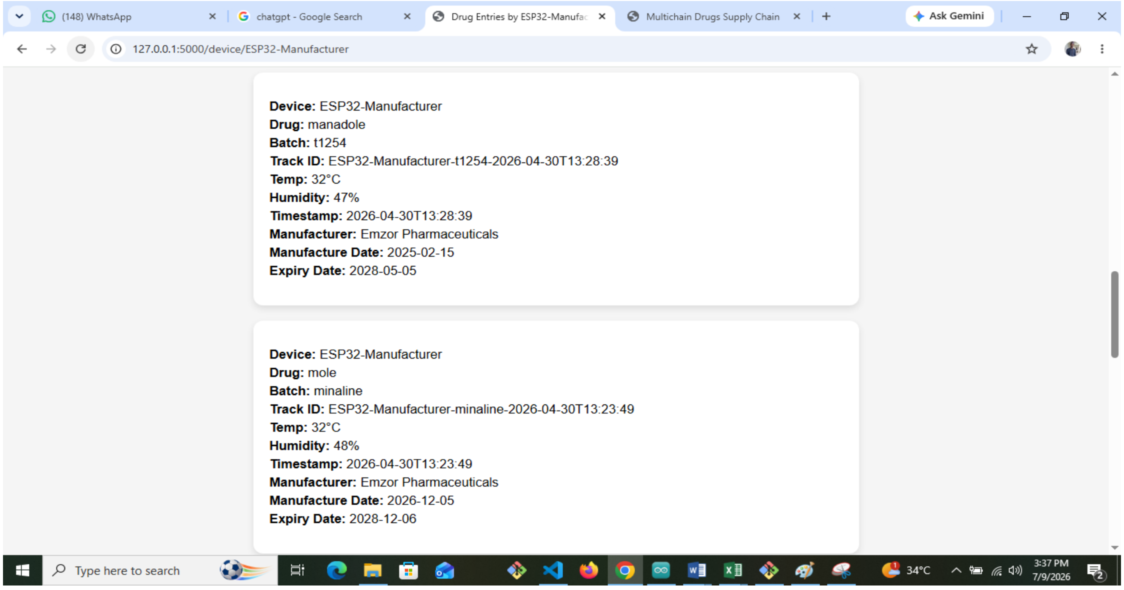


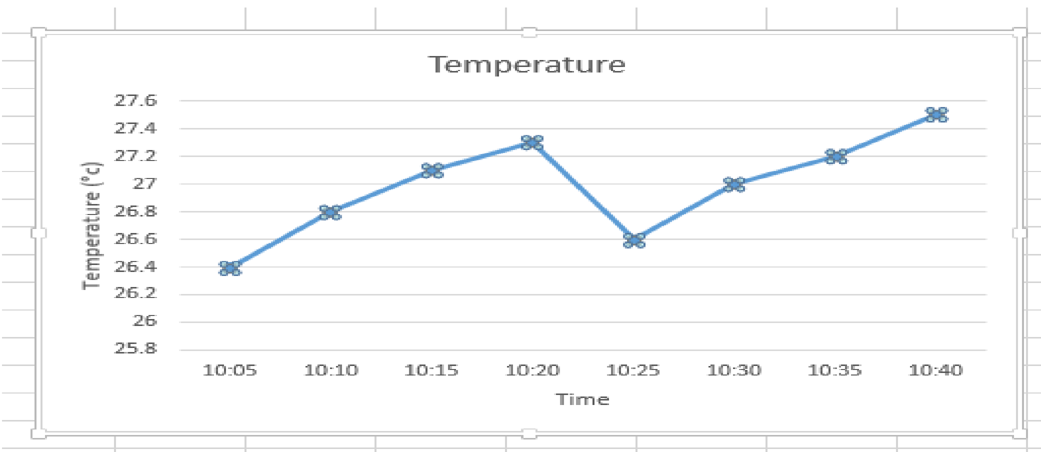

Figure. 3. System output: (a) Real-time monitoring dashboard; (b) Multi Chain block chain transaction verification

The web dashboard displayed pharmaceutical information, environmental measurements, timestamps, and stakeholder details in real time. Block chain records remained immutable after publication, ensuring secure storage and preventing unauthorized modification of pharmaceutical transaction data.

### *A. Environmental Monitoring*

The DHT11 sensor continuously monitored storage conditions throughout the experiment. These results demonstrate that the system is capable of continuously monitoring environmental conditions that may affect pharmaceutical quality during transportation and storage.

Figure 4 presents representative temperature and humidity measurements obtained during system operation.



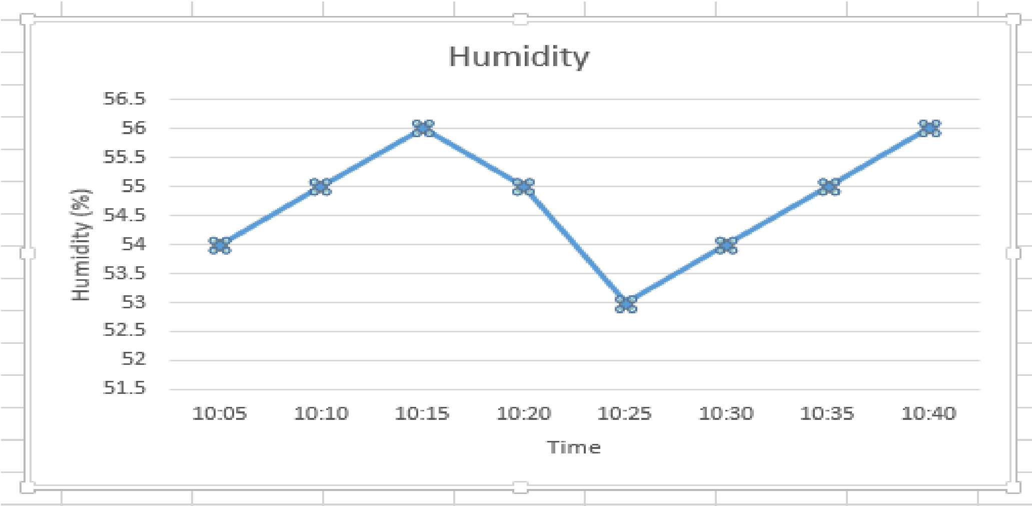



Figure. 4. System output: (a) Temperature Variation during System Testing (b) Humidity Variation during Experimental Evaluation

The recorded temperature ranged from 26.4°C to 27.3°C, while humidity varied between 53% and 56%, demonstrating stable environmental monitoring during pharmaceutical handling. These measurements were securely linked to block chain transaction records, enabling continuous monitoring and product traceability.

## V. DISCUSSION

The experimental results confirm the successful integration of IoT devices with a permissioned Multi Chain block chain for pharmaceutical supply chain monitoring. The ESP32 nodes reliably generated pharmaceutical transactions, while the Flask middleware provided secure communication with the block chain. The web dashboard enabled real-time visualization and verification of immutable block chain records. The developed prototype demonstrates that combining low-cost IoT devices with block chain technology provides an effective solution for improving pharmaceutical traceability, transparency, and data integrity while reducing the risk of counterfeit drug distribution.

## VI. CONCLUSION

This paper presented the design and implementation of a permissioned Multi Chain block chain-based security solution for pharmaceutical supply chain transparency. The architecture integrates ESP32 IoT devices, DHT11 environmental sensors, Flask middleware, a Multi Chain block chain, and a web-based dashboard to provide secure transaction recording and real-time monitoring of pharmaceutical products.

Experimental evaluation verified that the developed prototype successfully monitored environmental conditions, securely recorded pharmaceutical transactions, and maintained immutable block chain records throughout the supply chain. The system improved transparency, traceability, and data integrity while providing a practical and cost-effective solution for pharmaceutical monitoring.

Future work will focus on integrating additional environmental sensors, RFID or QR-code identification, and large-scale deployment to further enhance block chain scalability and pharmaceutical supply chain management.

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