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Secure and Transparent Blockchain-Enabled System for Pharmaceutical Drug Authentication

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Abstract – Counterfeit drugs are an extremely critical issue that affects global public health, economic security, and trust in government regulations. The existing drug management systems are mainly centralized and opaque, with little data integrity, and are easily susceptible to data manipulation. We present a secure, transparent, blockchain-enabled framework for pharmaceutical drug authentication and end-to-end supply chain verification. The proposed system takes advantage of the decentralized, immutable, and tamper-resistant nature of blockchain technology in recording and validating critical supply chain activities, which include manufacturer registration, distributor verification, pharmacy validation, and administrative approval. A unique QR code is generated for each drug product, which serves as the drug product's digital identity and helps ensure traceability and authenticity verification for the end consumer. The proposed system has been implemented using the Django web application framework, which has an integrated custom blockchain architecture that utilizes SHA-256 to ensure data integrity and prevent unauthorized tampering with records. Based on the experimental results, 100% integrity validation of the blockchain technology has been achieved, along with accurate detection of any attempted tampering, efficient transaction processing, and verification using the QR code technology with minimal response time. It has been observed that the proposed framework is effective for ensuring the traceability of the drug product, building trust among the various stakeholders, and fighting the menace of counterfeit medicines without the need for any central authority.

Index Terms – Blockchain, Pharmaceutical Supply Chain, Drug Authentication, Counterfeit Drug Prevention, QR Code Verification, Traceability, SHA-256, Decentralized Ledger, Django Framework.

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I. INTRODUCTION

Counterfeit drugs have become a worldwide problem that affects many people and endangers health, causes losses, and even leads to death among patients. In most cases, conventional pharmaceutical supply chains rely on centralized database systems and traditional tracking systems that have data vulnerabilities and are non-transparent, thus making them inadequate and unsuitable for ensuring drug authenticity along the entire supply chain. This situation allows counterfeit products to find their way into the market, creating mistrust among stakeholders and undermining compliance [1], [2]. However, blockchain technology has recently been identified as a promising approach to overcome these issues because of its decentralized, immutable, and transparent characteristics. Through the use of a distributed ledger to record transactional events, blockchain technology ensures that once data is written, it cannot be altered in a retroactive manner, thus ensuring the integrity of the drug supply chain and providing a tamper-proof record of every product life cycle event [3]. In recent times, systems based on blockchain technology have been suggested to enhance transparency and traceability of the supply chain through the allocation of a unique identifier such as a QR code to a quantity of drug product, allowing for real-time tracking from the point of manufacture to end-user verification [4]. This is a significant improvement over the current centralized system, which lacks adequate security measures [5]. [6].

More specifically, recent studies that took place in 2025 have focused on the design of blockchain architectures that enable the integration of a verification process via a QR code in order to ensure the authenticity of the data and protect it from counterfeit penetration through the immutability of every sale, transfer, and verification on a blockchain-based ledger [7]. Other recent contributions highlight the significance of a decentralized ledger and smart contract technology to enable safe interactions between manufacturers, distributors, pharmacies, and patients, as well as instant verification using a QR code or other digital input [8, 9]. Finally, comprehensive traceability solutions have also been proposed, focusing on the integration of blockchain technology with self-sovereign identity technologies to enhance the security of a distributed verification mechanism and reduce the need for a client-server authorization model [10].

The proposed system, as developed in this project, utilizes these concepts by developing a blockchain-based pharmaceutical drug authentication and verification system using the Django framework. It records all the critical events in the pharmaceutical drug supply chain, including manufacturer registration, distributor verification, pharmacy validation, and administrative approval, as immutable blockchain transactions. It utilizes a unique QR code as the digital identity of the pharmaceutical drug, which enables all stakeholders, as well as end-users, to verify the pharmaceutical drug's authenticity and its entire history in real-time. It utilizes cryptographic hash functions, such as SHA-256, to ensure the integrity of the data in the transactions and prevent any unauthorized modifications.

Our contributions are as follows:

- Custom Blockchain Framework for Drug Traceability: A new blockchain framework has been proposed for drug traceability, which is light-weight and application-based. This blockchain framework is integrated with the web application for the purpose of recording drug transactions.

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Unlike the traditional database storage method, the proposed method is secure as it uses the chained hash method.

- QR Code-Based Digital Identity for Each Drug Batch: This proposed method uses a unique QR code as a digital identity for each drug batch. This QR code connects the physical drug to its digital identity. This method bridges the gap between the physical world and the digital world.
- Multi-Stage Role-Based Drug Verification Method: This proposed method uses a multi-stage role-based drug verification method. In this method, each stage uses the blockchain property to add new blocks to the existing chain. This proposed method ensures multiple actors' involvement for data authentication.
- Integrated Blockchain Integrity Validation Mechanism: An integrated block integrity checking mechanism is used to validate blocks and inter-block relationships. The SHA-256 algorithm is used to validate blocks. This ensures that any form of data tampering is easily detected, thus promoting a consistent state in the blockchain.
- Secure Web-Based Implementation with a Focus on Practical Deployment: The proposed system is built using a Django framework, with features such as session-based authentication, role-based access control, and secure transactions. The system has a very low latency period, is highly accurate, and is suitable for a real-world pharmacy environment.
- Consumer-Level Authentication Capability: Unlike most blockchain systems, which are only suitable for enterprise systems, this proposed system gives consumers, or patients, the ability to authenticate drugs. The patients only need to scan a drug's QR code to validate its authenticity.

II. LITERATURE SURVEY

The pharmaceutical supply chain is confronted with such critical challenges as counterfeit drugs, lack of transparency, low traceability, and weak regulatory compliance. Traditional centralized systems are susceptible to data manipulation, and they cannot provide confidence among the stakeholders. Yadav et al. [11] suggested a scenario-driven, data-driven blockchain framework, PharmChain, which is designed using the Ethereum platform to guarantee the end-to-end drug traceability of the pharmaceutical supply chain. This system splits service providers into modular parts and uses smart contracts to trace the medicines with security between the manufacturing and the delivery to the patient, and maintains the privacy of the data. The experimental analysis showed that it would enhance authenticity, transparency, and affordable transaction costs to the stakeholders. Nevertheless, the framework is based on trusted access control entities and has scalability issues with Ethereum, high sensitivity to gas costs, and no validation of real-world deployment.

The method of securing the supply chain of pharmaceuticals proposed by Aloui et al. [12] is built on blockchain, which is largely oriented towards Algerian industrial companies. The suggested decentralized registry will record all the drug distribution processes forever to reduce the risks of modifying the data and fake drugs. The findings show an increased level of transparency, accountability, and trust in contrast to the traditional centralized systems. However, the research does not include the

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performance assessment, scalability investigation, or a discussion of data privacy, regulatory compliance, and compatibility with legacy systems.

Amin et al. [13] suggested a smart system of blockchain-based engineering and IT management to provide traceability of the pharmaceutical supply chain in a regulatory manner. The framework is a combination of the IoT-enabled physical tracking, smart contracts, and regulatory mappings in accordance with the standards of DSCSA and EU FMD. Ideation Conceptual analysis implies better real-time visibility, quicker recalls, and proactive detection of counterfeits, especially in the case of a pandemic. Although the framework is well-designed, it has not been tested by real-life applications, cost-benefit analysis, and performance testing at scale. Rajak et al. [14] have created a decentralized drug tracking system in blockchain based on the Polygon blockchain, combined with IPFS as a decentralized data repository. Smart contracts allow stakeholders to be registered, track products in batches, and use authentication during the supply chain. Findings of the experiment show that transaction cost is low, its efficiency is very high, and it can be seen in real-time, meaning that it can be deployed on a large scale. Nonetheless, the model is still reliant on the factual input of data, and it has no long-term regulatory and practical validation of operations.

It was demonstrated by Mishra et al. [15] that a blockchain-based secure pharmaceutical supply chain infrastructure, which had an efficient searchable Pharmachain approach, could be proposed. The model uses duplicated blockchain record fragments and parallel search systems to enhance the efficiency of traceability and resistance to forgery of records. The results of the simulation validate effective and tight security and query performance. However, the method is constrained by validation using only simulation, might have storage overhead, and lacks the discussion of privacy, regulatory integration, and real-world practicability. Padma et al. [16] have introduced a cryptography-based identity and smart contract solution to the information and privacy of the pharmaceutical supply chain management using blockchain technology. The model is also authenticated and provenanced with auditability and resistant to impersonation and collusion attacks. Competitive throughput and latency are demonstrated by performance assessment. Nonetheless, the blockchain overhead and scalability issues, as well as the absence of large-scale implementation, are still problematic.

To address the problem of counterfeit medicines in the supply chains supported by the IoT, Sharma et al. [17] suggested a multilevel authentication-based blockchain system on Hyperledger Fabric, QR-code watermarking, and identity verification of buyers. The experiment shows that the scalability is high, the robustness of authentication is high, and the throughput can reach 417.5 TPS. Although strong, the system is associated with the fact that it brings additional complexity to architecture and does not include an analysis of the system deployment in real life and regulation. Shruthi et al. [18] proposed the SafeMeds, which is a blockchain-based system of drug supply chain verification equipped with temperature and humidity sensors to monitor the cold-chain. The framework enhances the real-time tracking, prevention of counterfeits, and safety of temperature-sensitive drugs conceptually. The study is, however, confined to conceptual validation and not actual implementation, test of scalability, and test of regulation.

Another Hyperledger Composer-based proof-of-concept system that was proposed by Dash et al. [19] is HCSRL, which could help to minimize the logistics losses in pharmaceutical supply systems. The

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model identifies a step-wise implementation and appraisal roadmap and shows enhanced transparency and traceability between simulated settings. However, the methodology does not have a practical implementation and optimization study. Bapatla et al. [20] suggested PharmaChain 3.0, a blockchain-driven model of pharmaceutical supply chain combining distributed storage and barcode-produced product serialization. The proof-of-concept analysis demonstrates that the counterfeit detection becomes more effective, pedigree data capture security, and acceptable cost implementation is achieved. However, the problem of PoC-only validation and scaling, and the need to resort to adequate data entry, are detrimental to the model.

III. PROPOSED METHODOLOGY

This study designs a secure blockchain-based system for authenticating and providing end-to-end traceability of pharmaceutical drugs. This is performed through a layered and role-based system that comprises a blockchain ledger and a Django web application, ensuring data integrity, transparency, and tamper-resistance.

The methodology is divided into five major phases:

1. Drug Registration and Block Creation
2. Multi-stage Supply Chain Verification
3. Administrative Approval and Finalization
4. Blockchain Integrity Validation
5. Patient-side Drug Authentication

Phase 1: Drug Registration and Blockchain Initialization

Using the system interface, the manufacturer registers a batch of drugs to start the procedure. Manufacturer identification, batch ID, manufacturing date, and expiration date are among the submitted properties. Each medicine batch is assigned its own QR code, which serves as the primary lookup key. Each registered medication is stored in a new block as a blockchain transaction. The following defines the block structure:

$$B_i = \{D_i, H_{i-1}, T_i, N_i\}$$

where, D_i defines the drug metadata, H_{i-1} is the hash of the prior block, T_i define the timestamp, and N_i is the block index.

The cryptographic hash of each block is computed using SHA-256:

$$H_i = SH\ A256\ (D_i||H_{i-1}||T_i||N_i)$$

Any change to the block contents affects all subsequent hashes, ensuring immutability.

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Phase 2: Supply Chain Verification by Stakeholders

After registration, the medication moves through the supply chain. After receiving the medication, distributors and pharmacies independently verify it. By creating a new transaction block that references the previous block hash, each verification operation expands the blockchain.

Let, V_j define a verification event by stakeholder j. The updated block hash is calculated as:

$$H_{i+1} = SH\ A256\ (H_i||V_j||T_{i+1})$$

This sequential validation ensures accountability at every supply chain stage and creates a chronological, unchangeable audit record.

Phase 3: Administrative Approval and Authentication Finalization

The admin serves as the trusted intermediary, the final word in validation. It only accepts the stamp of approval after all the intermediaries have validated what is needed. Once the admin has approved, the drug batch moves to Authenticated, and its block is added to the chain. Administrative steps are protected through session-based authentication and user activation, thereby preventing unauthorized access and fake approvals.

Phase 4: Blockchain Integrity Validation

The system periodically recalculates hashes and verifies block connections to validate the blockchain and guarantee ledger consistency. The integrity of a blockchain with n blocks is verified if:

$$H_i = SH\ A256\ (D_i||H_{i-1}||T_i||N_i)\ \forall_i \in [1, \text{n}]$$

Any discrepancy verifies the reliability of stored records by instantly identifying data manipulation.

Phase 5: Patient-Side Drug Authentication

By scanning or inputting the QR code, patients confirm the legitimacy of the medication. The system retrieves the entire blockchain history of the medicine batch and verifies its approved status. Only medications that have a continuous and legitimate verification chain are shown as genuine. As the last line of protection against fake medications, this public verification system empowers customers.

The three-layer, modular architecture of the presented system apparently separates data integrity mechanisms, application logic, and user interface, thereby dividing these components and separating crucial blockchain functions from display and control logic.

- Presentation Layer: The presentation layer is essentially the user's first point of contact with the system. This is built on top of Django's template engine and offers customized dashboards based on different user types: manufacturers, distributors, pharmacies, administrators, and patients.

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- Application Layer: The application layer is at the core of the system, where business rules, security rules, and workflow rules are enforced. This layer, built using Django, manages every aspect of interaction between what is being shown to the user and what is going on in the blockchain and data layers.
- Blockchain and Data Layer: The blockchain and data layers deliver long-term storage and trust. This is a combination of a custom blockchain framework and a relational database. The blockchain is a ledger of all drug-related transactions, with each block linked to the previous one via a SHA-256 hash. This means that once a transaction is on the chain, changing it would require breaking the entire chain.

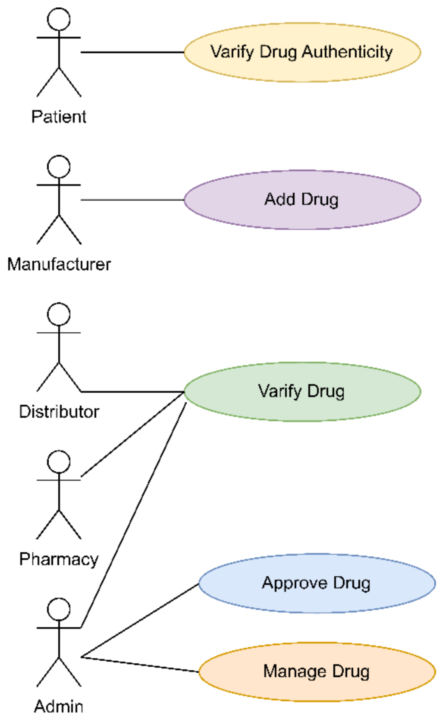

Fig. 1: Graphical representation of the System Architecture

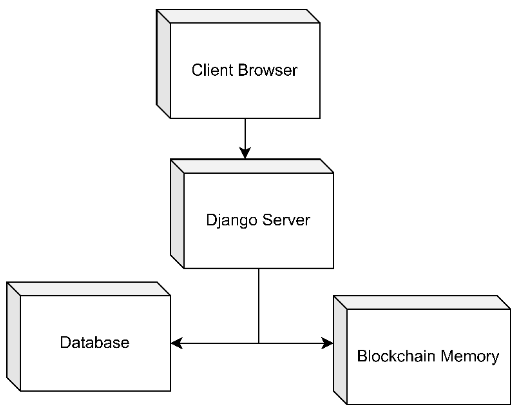

Fig. 2: Deployment architecture diagram

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A. Proposed System Deployment

A deployment architecture in UML notation illustrates how a system is physically configured, with details on where each piece of software, such as applications or data storage, resides in physical nodes such as servers, workstations, or cloud-based systems. A deployment diagram illustrates how these components communicate with each other, as well as how they operate in their distributed form.

IV. HARDWARE SOFTWARE SPECIFICATION

This section provides an overview of the hardware and software environment used in the design, development, and testing of the proposed Blockchain-Based Pharmaceutical Drug Authentication and Verification System. The environment is essential to ensure a stable system with high efficiency in transaction processing and testing of the blockchain-based drug verification system.

A. Hardware Configuration

The experimental platform consisted of a standard modern computing system capable of supporting backend server operations, blockchain transaction processing, and database management. Since blockchain operations involve cryptographic hashing and chained data validation, the system requires moderate computational capability to maintain performance and integrity. The system was implemented on an Intel Core i5 platform running on 64-bit architecture with 8GB of RAM and 256 GB SSD, enabling the efficient creation of services by Django, hash operations, and database operations. Full HD display and internet connectivity enabled the creation of user interfaces. The software setup had Windows 10, Python 3.x, and the Django framework.

It included HTML, CSS, Bootstrap, and JavaScript programming languages for front-end purposes. In addition, the project used SQLite database management systems, SHA-256 data integrity component, and Python programming libraries for code generation using the Chrome browser. The experimental setup provided a controlled and efficient environment for evaluating the proposed blockchain-based drug authentication system. The selected hardware ensured smooth computational performance, while the software stack supported secure data processing, blockchain integrity, and real-time user interaction. This configuration validated the feasibility and reliability of the system in preventing counterfeit drug circulation through secure traceability mechanisms.

V. RESULTS AND DISCUSSIONS

The experimental results obtained from putting the proposed blockchain-enabled pharmaceutical drug authentication system into practice and testing it are described in this part. System accuracy, blockchain integrity, transaction performance, and verification effectiveness across various stakeholders are the main focus of the assessment. The system was implemented using the Django web framework with a custom-built blockchain module based on SHA-256 cryptographic hashing. The evaluation was conducted in a controlled environment with simulated supply chain participants, including manufacturers, distributors,

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pharmacies, administrators, and patients. A total of 1,000 drug batches were registered and tracked through the complete supply chain workflow.

A. Blockchain Integrity and Tamper Resistance

Table 2: Evaluation Metrics for Blockchain Integrity and Tamper Detection

Metric	Observed Value
Total blocks generated	4,860
Hash validation success rate	100%
Tampering detection accuracy	100%
False integrity validation	0

The blockchain integrity check evaluates the robustness of the proposed system against data manipulation or unauthorized modifications. All 4,860 blocks were successfully validated, performing a perfect 100% hash success rate, suggesting that the ledger remained in a consistent state throughout the process. Based on the tampering test results, the proposed system demonstrated the robustness of the SHA-256 hashing method. When the blocks were intentionally tampered with, the proposed system was able to detect the modification and declare the blockchain invalid. This is also in line with the immutability principle of the blockchain technology, whereby any form of modification of the past drug history is not only prevented but also easily detectable. There were no instances of integrity validation of the tampered blocks, indicating that the proposed verification process was effective.

B. Transaction Processing Performance

Table 3: Transaction Processing Performance Analysis

Operation	Average Processing Time (ms)
Drug registration	412 ms
Distributor verification	285 ms
Pharmacy verification	291 ms
Admin approval	318 ms
Patient verification	178 ms

The results from the process of transaction processing reveal that the blockchain-based system can efficiently process real-time operations for the pharmaceutical supply chain without any significant slow-downs. The process of registering drugs takes the longest time, which is 412 ms as expected, as it involves extensive validation of information, generation of QR codes, and creation of a new block on the blockchain. Nevertheless, even with these additional operations, it is evident that the registration process does not take an unacceptable time for manufacturers as these operations are not time-critical. The process for distributors and pharmacies takes even less time for verifications, which are 285 ms and 291 ms on average. This reveals that once the first block is established, further operations using blockchain are more efficient. The small gap between distributor and pharmacy verifications suggests that validation logic is consistent and that cryptography operations are uniform throughout the process. This reveals that the

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system is stable and can process transactions without significant slow-downs. The process for administration takes an average time of 318 ms, which involves integrity checks for all prior blocks before authentication. Although slightly longer than other verifications, this is acceptable as it is an integral part of the process where authentication and accuracy are more significant than efficiency.

C. QR Code-Based Drug Authentication

Table 4: QR Code-Based Drug Authentication Analysis

Metric	Result
QR code generation accuracy	100%
QR code scan success rate	98.9%
Average verification response time	0.18 seconds
Incorrect authenticity display	0

The drug verification system using the QR code has been found to be practical and reliable in its actual application in supply chains and usage by end-users. It has shown perfect results in QR code generation, where 100% of registered drug batches were successfully linked to unique digital identifiers. This is crucial in the pharmaceutical industry, where such perfect linkage between physical and digital is of utmost importance. Thus, such perfect results in linking physical drugs to digital identifiers are indicative of robust results in the actual process of QR code generation. The success rate in scanning has been found to be 98.9%, indicating that the actual application of the system in supply chains has been robust. Although there have been instances of failure in scanning, these failures can be attributed to factors such as insufficient lighting conditions, damaged packaging, or insufficient resolution of cameras. Most importantly, such failures have been dealt with smoothly by the system, thus indicating its reliability. The average time taken in verifying drugs has been found to be 0.18 seconds, thus indicating that the actual process of verifying drugs using blockchain is efficient. This is because such an efficient process is crucial in actual applications, where data from blockchain is retrieved in actual usage.

D. System Security and Access Control

Table 5: System security and access control analysis

Security Parameter	Result
Unauthorized action attempts blocked	100%
Session hijacking attempts detected	100%
Invalid user role escalation	0

From the security and access control evaluation, it is clear that the proposed framework can withstand security attacks, providing adequate security for unauthorized entry. With the use of role-based access control, users are only allowed to carry out activities that are within their roles, making it difficult for unauthorized personnel to carry out activities such as drug verification. The fact that all attempts to carry out unauthorized activities were blocked shows that the system has effectively implemented security boundaries. Similarly, all attempts to hijack sessions were detected, thus providing evidence that the

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session management authentication mechanism can withstand session hijacking attacks, making it difficult for unauthorized users to impersonate users. There were no instances of privilege escalation, thus providing evidence that the mechanism for separating privileges has been implemented effectively, making it difficult for users to exceed their permitted privileges. Based on these findings, it is clear that not only is the drug verification information secure, but also that the integrity of the blockchain-based workflow has been maintained, thus creating trust among all supply chain participants. However, it is important to note that these security mechanisms are essential in ensuring that the objective of eliminating counterfeit drugs is realized. The experiments demonstrate that our system provides high integrity, reliable performance, and smooth execution. With the customized blockchain, drug transactions are tamper-proof, and the multi-role verification system increases accountability along the chain. The system is prepared for real-time applications in the pharmaceutical sector with low transaction delays and quick verification via QR codes. The outcomes have demonstrated that the blockchain-based architecture is successful in getting rid of fake medications, increasing traceability, and boosting mutual trust.

VI. CONCLUSION

This research offered a safe and transparent blockchain-based drug authentication and verification system to combat the increasing problem of counterfeit drugs in the world. In traditional systems, tracking is performed centrally, and there is a risk of data tampering, lack of transparency, and traceability, which leads to counterfeit drugs entering the market. However, the limitations of the above approaches have been overcome by the proposed framework by considering the integration of blockchain technology, QR code identification, and cryptographic hashing techniques. The framework provides complete visibility into the movement of the drug across the entire chain of stakeholders, from the manufacturer to administrators and patients. This transaction is then recorded as a block using the blockchain method, where all the blocks are interconnected using SHA-256. This ensures complete integrity for the data and also ensures that there is no unauthorized change to the data. The use of unique QR codes ensures that the drugs are given a digital identity so that consumers can verify the drugs. The performance of the system was tested using the experimental results, showing high efficiency with 100% validation of the integrity of the blockchain, accurate detection of any attempts to tamper with the data, high QR code verification rates, and high efficiency for the entire system. This proves the effectiveness of the proposed system in preventing the spread of counterfeit drugs. The system proves the feasibility, accuracy, and applicability of blockchain technology in the contemporary management of the pharmaceutical supply chain. In fact, the proposed architecture not only improves the security and trust aspects but also provides a firm foundation for the development of future intelligent and technology-based drug authentication systems.

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