Enhancing Cybersecurity in Smart Agriculture through Blockchain for Imaging Data Security

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Abstract

Smart agriculture (SA) is an emerging technology that integrates the Internet of Things (IoT) with a range of intelligent technologies, including drones, ground robots, and sensor systems. The incorporation of technological advancements in SA has resulted in a rise in cybersecurity concerns, particularly the safeguarding of crucial agricultural image data. Developing an efficient security system is vital to combat multiple risks and guarantee the confidentiality of SA network systems. The result will eventually improve the efficiency, profitability, and sustainability of agricultural production, and promise food safety and security. Therefore, this study conducted an overview of blockchain technology's potential to protect agricultural imaging data to address these issues. The decentralized and immutable nature of blockchain makes it a promising alternative for safeguarding data integrity and deterring unauthorized alterations. This paper investigates the current adoption of blockchain technology in agriculture, evaluating its feasibility, scalability, and challenges in practical implementation. The paper also forecasts potential future advancements, emphasizing the imperative of ongoing collaboration and innovative thinking to enhance the cybersecurity infrastructure of SA. We examine blockchain technologies in this study, including Practical Byzantine Fault Tolerance (PBFT) and Inter-Planetary File Systems (IPFS), which address the unique requirements of dependable transaction processing and large-scale agricultural data storage. Furthermore, to improve data security and privacy, we look at integrating blockchain technology with cryptographic methods like Elliptical Curve Cryptography (ECC) and zero-knowledge proofs. The Recurrent Neural Elliptical Curve Blockchain (RNECB) framework's implementation shows how ECC, blockchain, and Recurrent Neural Networks (RNNs) may be used to enhance IoT communications in agriculture.

Keywords
smart agriculture, cyber security, blockchain, deep learning, IPFS, digital images, IoT sensors, computer vision

1 Introduction

Due to the rise in adoption of smart sensor technology in agriculture there are significant cybersecurity concerns, particularly regarding the protection of sensitive agricultural data. Smart sensors in agriculture are deployed in land and air for data decision driven agriculture i.e. Smart Agriculture (SA). SA integrates advanced technologies like Internet of Things (IoT) with the use of robots (both ground and aerial) and Computer Vision (CV) models for image processing, often developed based on Neural Networks using Deep Learning (DL). The data acquired from these sensors are crucial for identifying stress zones for precision management and breeding resistant cultivars.

This agricultural data like images collected using drones, genomic sequences of resistant cultivars hold economic value for various stakeholders, making it vulnerable to ransomware attacks, data breaches, and unauthorized access. Maintaining the security and integrity of agricultural data depends on addressing these risks. With its decentralized and immutable structure, Blockchain technology is a viable way to protect agricultural imaging data and guarantee its security, integrity, and transparency (Lin et al., 2020; Zhang et al., 2020).

As agriculture adopts more advanced technologies, the complexity and volume of data generated increase exponentially. This not only enhances the potential for precision agriculture but also amplifies the risk profile, necessitating advanced solutions such as blockchain. Blockchain technology provides a commanding solution with its secure, tamper-evident recording of data transactions. By employing algorithms like Proof of Work (PoW) or Proof of Stake (PoS), blockchain enhances data consistency and reliability across all nodes, strengthening the resistance of agricultural data systems against cyber threats (Lin et al., 2020; Zhang et al., 2020; Williamson & Leonelli, 2023)

Our investigation also delves into specialized blockchain architectures suitable for the unique challenges of the agricultural sector's expansive and remote operational fields. The use of lightweight consensus algorithms like Delegated Proof of Stake (DPoS) and sharding techniques not only enhances transaction throughput but also reduces latency, crucial for the real-time data processing needs of IoT devices scattered across rural landscapes (Hassija et al., 2021; Zhang et al., 2020; Mahalingam & Sharma, 2024).

The remaining portions of this study are organized as follows: Section 2 presents an overview of blockchain technology and the process of securing agricultural data, including practical applications. Section 3 concludes the paper with some future directions and potential areas for further research.

2 What is Blockchain Technology?

To operate as a public record for Bitcoin transactions, Satoshi Nakamoto utilized blockchain technology, also known as Distributed Ledger Technologies (DLTs), in 2008. Using a network composed of several computers, this system records transactions as a decentralized digital ledger. This configuration ensures that transactions cannot be changed once entered. Fig. 1 represents the overall blockchain framework for securing agricultural data.

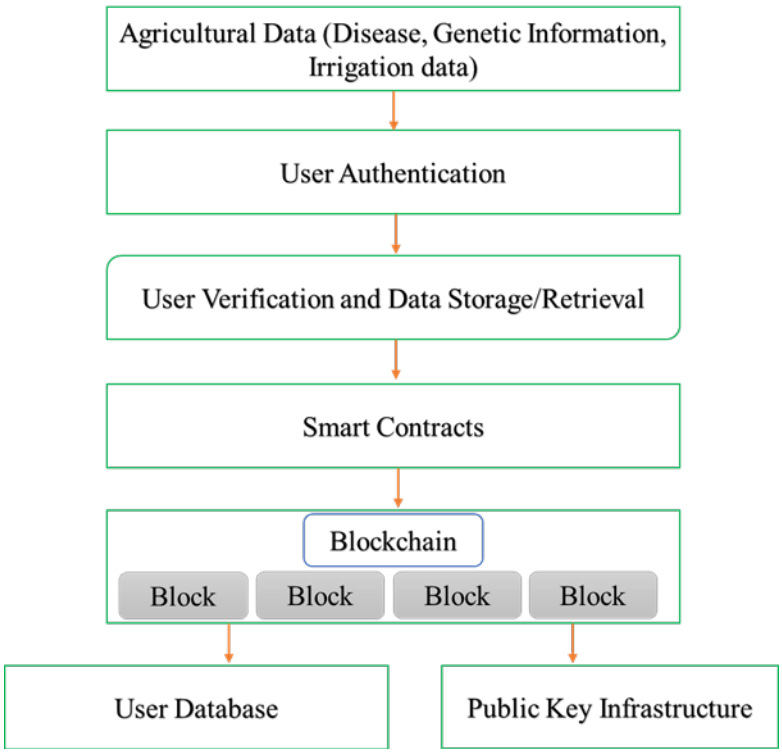

Fig. 1: Overall blockchain framework for securing agricultural data.

Blocks, which are the fundamental building blocks of a blockchain, contain records of transactions. These blocks are linked together through cryptographic hashes, which detect tampering by altering the hash and thus breaking the chain (Lin et al., 2020; Zhang et al., 2020; Williamson & Leonelli, 2023). Cryptographic algorithms known as hash functions provide each block a unique identity, or hash, which is essential for preserving data integrity and facilitating quick data verification. The hash of one block is integrated into the next, creating a safe connection between them (Zhang & Wu, 2023). Consensus mechanisms, or methods that guarantee that all nodes in the network consent on the present state of the digital ledger, further bolster the security of blockchain technology (Hassija et al., 2021; Mahalingam & Sharma, 2024). Commonly used consensus techniques include Proof of Stake (PoS), in which nodes are selected to validate transactions according to their stake in the network, and Proof of Work (PoW), in which nodes must solve challenging cryptographic puzzles. These mechanisms support the blockchain's security and durability while assisting in preventing the problem of double spending. Blockchain also offers another novel feature: smart contracts. These are contracts that run on their own initiative, with the conditions of the agreement written right in the code. When certain criteria are satisfied, smart contracts initiate transactions automatically, eliminating the need for middlemen and increasing operational efficiency and confidence. They are essential for process automation and transparent rule compliance (Hassija et al., 2021; Lin et al., 2020; Zhang et al., 2020).

Blockchain applications in practical scenarios

In agriculture, blockchain applications improve dealing with supply chains and IoT-based systems. To help small-scale farmers, such applications include food safety, food security, traceability for waste reduction, food quality monitoring and control, and dependable operational data analysis. Lightweight blockchain alternatives like Inter-Planetary File Systems (IPFS) and Sharding have been developed to address the resource-intensive features of standard blockchains. These blockchain models are lightweight and easily deployable on System on Chip (SoC) architectures, which can be utilized in agriculture (Kassanuk & Phasinam, 2022; Zeeshan & Liu, 2023). The blockchain is divided into smaller, simpler pieces known as shards using the sharding approach. By processing a portion of transactions, each shard increases scalability and lessens the computational burden on individual nodes. Data security and retrieval speed are improved via the

decentralized Inter-Planetary File System (IPFS). By distributing the storage of data among several nodes, IPFS's distributed file system protects against failures and threats. Large amounts of data, like images of crops, may be stored effectively and safely when IPFS and blockchain are used together (Ren et al., 2021). A Blockchain-Based Scheme for Privacy-Preserving and Secure Sharing of Medical Data emphasizes the use of the Practical Byzantine Fault Tolerance (PBFT) consensus algorithm to maintain data consistency and security across distributed nodes, as well as zero-knowledge proofs and proxy re-encryption to ensure privacy-preserving data sharing. Using sharding and IPFS for decentralized storage, this lightweight blockchain-based technique for detecting and preventing man-in-the-middle attacks in mobile edge computing environments suggests maximizing resource consumption while preserving security. Secure data access and transaction management are automated by smart contracts (Huang et al., 2020). To help with automatic image annotation and increase consistency and efficiency, the DL-Based Smart Imagery Framing and Truthing (SIFT) System blends a multi-layer perceptron neural network with a convolutional neural network-based Mask R-CNN (Guo et al., 2023). High-quality annotations for neural network training may be ensured by adapting this method to agricultural imaging data.

Blockchain in IoT for Agricultural Data Security

By extending data integrity, security, and transparency, the Internet of Things (IoT) and blockchain technologies have transformed agricultural data management (Zeng et al., 2023). In smart agriculture (SA), IoT devices are widely utilized for data collection and real-time monitoring of temperature, humidity, and soil moisture levels. According to Zeng et al. (2023), water resources are effectively monitored and managed by this framework, ensuring precision nutrient management. The information that IoT sensors gather and send in real time on soil moisture and water levels is encrypted via a blockchain network. The data becomes tamper-proof once it is stored on the blockchain. The data transactions are visible to users under the same network (Mahalingam & Sharma, 2024).

Self-executing contracts, or smart contracts, have the conditions of the contract explicitly encoded into the code (Lin et al., 2020). By automating procedures and upholding agreements without the need for middlemen, smart contracts improve operational effectiveness and lower the risk of fraud. Hassija et al. (2021) present a blockchain and Deep Neural Network (DNN)-based framework aimed at enhancing crop protection. Integrating blockchain with DNNs ensures secure, incentivized data sharing and accurate crop disease detection, enhancing agricultural productivity and protection.

The architecture for safeguarding IoT-based agricultural data, known as Recurrent Neural Elliptical Curve Blockchain (RNECB), was proposed by Mahalingam & Sharma (2024). This concept combines blockchain technology with Elliptical Curve Cryptography (ECC) and Recurrent Neural Networks (RNNs). While the ECC facilitates safe communication between IoT devices and the blockchain network, the RNNs are utilized to forecast crop yields, identify pests and illnesses, and track weather trends. The key features of the RNECB framework include data preprocessing to ensure quality by removing unwanted features and noise from collected data, continuous monitoring by IoT devices with encrypted data storage on the blockchain to ensure data integrity and security, the use of cryptographic techniques to protect data from unauthorized third parties, and performance validation that shows high accuracy, low error rates, and efficient encryption and decryption times in tests.

Blockchain Technology for Safeguarding Plant Breeding Data

Plant breeding data consists of genetic information, phenotypic data, and field trial results which are crucial for developing new crop varieties. Samaniego et al. (2019) proposed a blockchain-based system for managing access control in image-based plant phenotyping. The system integrates the Ethereum blockchain to allow users to be administrators of their data, granting or denying access permissions independently, without relying on a central administrator. This decentralized approach ensures that the plant trait data access is controlled and monitored transparently by respective groups. The system is part of the Plant Phenotyping and Imaging

Research Centre (P2IRC) and aims to improve collaboration in breeding programs by providing a trusted environment for data sharing. Kassanuk and Phasinam (2022) present a blockchain-based framework that emphasizes the importance of a decentralized ledger to eliminate intermediaries, reducing financial loss and crop contamination risks. Zhang et al. (2020) propose a storage architecture for high-throughput crop breeding data using improved blockchain technology within the Golden Seed Breeding Cloud Platform (GSBCP). The architecture ensures efficient and secure storage of breeding data by using light blockchain for key data and proxy encryption for enhanced security. Different blockchains store various types of breeding data, balancing data security with system performance. The architecture supports high concurrency and easy data acquisition, making it scalable and efficient for large data volumes. Williamson & Leonelli, (2023) discusses the challenges of linking plant trait data across various growth stages of the breeding process. Blockchain technology ability to handle large datasets securely makes it suitable for managing extensive breeding data and linking different data sources effectively (Williamson & Leonelli, 2023). Table 1 summarizes the applications of blockchain technology in the agricultural sector as discussed in this section.

Table 1: Summary of Blockchain Applications in Agriculture

Type of Blockchain	Application in Agriculture	Advantages	Reference
Lightweight Blockchain (IPFS + Sharding)	Management of farmers' supply chains and IoT systems data Efficient storage of large imagery data	Reduces resource demands, improves scalability, and is easily deployable on SoC architectures	Kassanuk & Phasinam, 2022; Zeeshan & Liu, 2023; Ren et al., 2021; Zhang et al. 2020
Blockchain with Smart Contracts and DNN Framework	Secure private data sharing and data access control management.	Automates contract enforcement and reduces the need for intermediaries. Maximizes resource use while maintaining security	Huang et al. 2020, Hassija et al. 2021, Samaniego et al. 2019
DL-based SIFT System	Automatic image annotation	Enhanced consistency and efficiency in data annotation	Guo et al. 2023
RNECB	Efficient storage and securing of IoT-based data	Enhanced security and traceability.	Mahalingam & Sharma, 2024

3 Conclusion

In most countries, agriculture is the primary source of employment. The demand for food is increasing with the rapid increment in populations. Therefore, most of the agricultural industries are currently using cutting-edge technologies to maintain food security. These smart agricultural industries heavily rely on data (image data, sensor data, etc.). This data must be secured from unauthorized access to secure the smart agricultural system and maintain food security. Currently, blockchain is one of the best solutions to secure sensitive agricultural data. By using a blockchain-based system, we can improve data dependability in collaborative contexts by doing away with the requirement for a central validation unit. This is because data is validated by the blockchain network itself, not by a single server. Additionally, because data is copied to the blockchain network and transactions are authenticated by the whole blockchain network, the distributed nature of blockchain-based systems allows for trusted collaborative environments for data sharing.

Future Directions

Scalability may be increased by creating consensus methods that are more effective and by making blockchain algorithms more capable of handling massive amounts of data. By enhancing scalability, sidechains and sharding techniques help blockchain networks handle more transactions per second. To improve data security and analytical capabilities, future research should concentrate on combining blockchain with other emerging technologies, such as DL and CV. Implementing energy-efficient protocols to reduce the environmental impact of blockchain technology is crucial.

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