Grenze International Journal of Engineering and Technology, June Issue

AI-Driven Blockchain-based Smart Agricultural Supply Chain System

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***Abstract*— Agricultural supply chains face challenges such as a lack of transparency, data tampering, and inefficient logistics. This paper proposes an AI-driven blockchain-based system to enhance traceability, security, and decision-making. Blockchain ensures immutable and tamper-proof data storage, while Artificial Intelligence enables demand prediction, anomaly detection, and quality assessment. The system provides role-based dashboards for stakeholders, enabling real-time tracking and efficient resource management. Experimental results demonstrate improved transparency, reliability, and overall supply chain efficiency.**

***Keywords*— Blockchain Smart contracts, Agricultural supply chain, Artificial intelligence, Anomaly detection, Demand prediction, Quality prediction, Traceability, Food fraud prevention, Decentralized syst.**

I. INTRODUCTION

Blockchain technology provides a secure and immutable way of storing supply chain data, preventing tampering, and ensuring transparency [1]. Artificial Intelligence (AI) enables predictive analytics, anomaly detection, and quality assessment in agricultural systems [3]. The integration of blockchain and AI helps in improving trust, efficiency, and decision-making in modern supply chains [4].

- Objectives: The focus of the research is to design a blockchain-based agro-supply chain system for agricultural products using artificial intelligence. This system incorporates algorithms for anomaly detection, demand prediction, and quality management to improve system performance.
- Challenges: These issues include incorporating the use of blockchain within the AI model, making sure that there is data privacy despite ensuring transparency, and scaling the platform. Furthermore, creating reliable AI models and ensuring usability throughout the platform were key factors in the process.
- Significance: The significance of this work lies in addressing critical challenges in agricultural supply chains, including a lack of transparency, data tampering, and inefficiencies. Blockchain technology ensures secure and immutable records, preventing fraud and enhancing trust among stakeholders [1]. Additionally, the integration of Artificial Intelligence enables better decision-making through predictive insights and early detection of issues [3]. The proposed system improves visibility across the supply chain, supports farmers in making informed production decisions, and enhances overall efficiency and reliability. By leveraging these technologies, the system contributes to a more transparent, secure, and intelligent agricultural ecosystem [4]

Grenze ID: 01.GIJET.12.2.523_26

II. Background

Blockchain technology enables decentralized and tamper-proof data storage, ensuring transparency in supply chains [2]. However, blockchain alone cannot perform predictive analysis, which is achieved using Artificial Intelligence techniques [3]. The combination of these technologies results in a more efficient and intelligent agricultural supply chain system [4].

III. Related Works

There have been a few attempts to explore the idea of implementing the Blockchain concept in food chain management, particularly focusing on using IoT devices to monitor temperature and humidity in transport [2][5]. Moreover, there have been a few implementations involving Artificial Intelligence, especially related to demand forecasting and anomaly detection within the dataset [3]. While there have been some attempts at integrating blockchain and AI, these technologies have mostly been implemented individually in existing systems [4][6]. This research intends to fill that gap by developing an innovative integration of blockchain and AI technologies for data security and prediction purposes.

IV. Methodology

The proposed system integrates blockchain technology and Artificial Intelligence to ensure secure data storage and intelligent decision-making [4]. Blockchain is used to record all transactions immutably, while AI models such as ARIMA, LOF, and Random Forest are used for prediction and analysis [3].

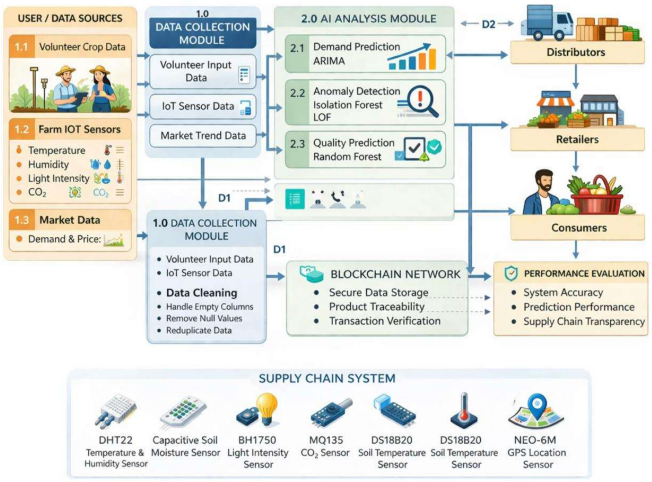


Fig 1: System architecture

Design of a blockchain-based IoT and AI-enabled Smart Agriculture scheme.

In this research work, the proposed architecture is built with modern web, database, and promising technologies for an efficient and secure system. The system backend is developed using FastAPI, employing asynchronous processing and using RESTful APIs for communication between the components of the system. The frontend of the system is developed using React.js for developing the dashboard. The dashboard will be dynamic and user-friendly with different role-based dashboards, i.e., the farmer, distributors, and consumers. For data storage, SQLite, a lightweight relational database, is used for storing the product details, user details, hub capacity, and transaction details. Further, to increase trust and transparency, the products, their demand, and respective transaction details will be stored in a fake Ethereum blockchain, i.e., each transaction will be cryptographically hashed and stored in the blockchain. Also, the proposed system integrates various artificial intelligence techniques, including ARIMA for demand prediction, Local Outlier Factor (LOF) for anomaly detection, and Random Forest for the prediction of product quality in a smart agriculture system, along with a custom logistics algorithm that analyzes the route based on the capacity of the warehouse to prevent it from getting overloaded. RESTful API will be used for smooth data exchange, and data visualization will be performed using various charts. Also, the architecture takes into account the input from sensors, temperature, and humidity sensors for IoT-based input for improvement in the future.

- Farmer Module: The Farmer Module allows farmers to interact with the system. It facilitates farmers to register and register their crop harvests, by securely uploading data related to the quantity, provenance, type of crops, and triggers the logistics process. Farmers can track the status of their shipments in real time and trigger cancellation and recall procedures when necessary [7]. The module is vital to ensure an efficient interaction of a farmer in the digital supply chain, reducing manual effort and increasing visibility in the system.
- Distributor Module: The Distributor Module is the core operational unit of the system that manages both the storage and transportation operations. This module allows the distributor to visualize the warehouse capacities in real-time and to track and update the status of goods in transit. The module can help identify bottlenecks and overloaded hubs, allowing to manage the operations of the supply chain more efficiently.
- Consumer Module: The Consumer Module enables users to access a transparent marketplace where they can view the available agricultural products and the entire traceability information [8]: from the origin of the harvest to the immutable proof of purchase. The module empowers users to be sure of the origin of the products they are buying and track their journey in the supply chain.
- Auth & Role Management Module:The Auth & Role Management Module allows for secure access to the system by enforcing strict role-based controls [9]. It divides the system functionalities between farmers, distributors, and consumers, and ensures that no role can access functionalities outside their scope. This module is vital to securing the system and ensuring the privacy of the users' data.
- Logistics Engine Module: The Logistics Engine Module optimizes the routing of agricultural products within the constraints of warehouse capacities [10]. Real-time computations are used to make decisions about which storage facilities are appropriate to select and how traffic flow is to be regulated, such that overloading is avoided through reduced capacity.
- Blockchain Ledger Service: The Blockchain Ledger Service maintains a permanent record of all the events relating to the supply chain transactions on the blockchain ledger. Hashing is carried out for all events, such as the transfer of goods, to ensure data integrity and non-repudiation.
- Notification & Alerts Module: The Notifications & Alerts module monitors system activity around the clock and issues alerts in the event of any activity that takes place, especially when there is a case of overcapacity. Such alerts come in handy in handling cases of overcapacity in the chain.
- Data Model Module (Database): The task of the Data Model Module is to ensure systematic data storage about the system in a relational database. The Data Model Module stores product data, customer data, hubs, and transactions systematically, hence preserving data integrity. The Data Model Module is the backbone of the system's data.

V. IMPLEMENTATION ANALYSIS

The proposed architecture for the solution relies on the stack technology model using FastAPI, React.js, SQLite, and a simulated blockchain network. The system is designed to process and store data related to crops, storage locations, and transport logistics. The prediction of demand, detection of anomalies, and evaluation of the quality of products are performed through AI models [3], while the transactions are made secure by implementing blockchain [4]. The app is developed using the stack web architecture that includes FastAPI, React.js, SQLite, and Blockchain Sandbox. The website was released with three dashboards depending on user role, including farmers, distributors, and consumers. Each of the dashboards has specific capabilities. The Farmer Dashboard allows users to add new harvests by inserting the name, quantity, and origin of the harvest, after which users can monitor the progress of the harvest using "My Harvest Overview."

The Distributor Dashboard helps monitor system statistics in real time, including the number of hubs, storage capacity, and alerts for storage capacity issues. Additionally, this dashboard enables features concerning logistics tasks, such as pending harvesting allocations and transports. Conversely, the Consumer Dashboard showcases the marketplace, enabling consumers to view existing products, gain insight into the quality of each individual product, and trace the entire lifecycle of a product from creation to storage using blockchain technology. All processes are done behind the scenes using RESTful APIs, and the logistics engine is used to find out the best path based on capacity constraints. Meanwhile, all transactions are stored in the blockchain to ensure transparency and immutability. This project was implemented locally, showing how this project exhibits real-time capabilities, secure data processing, and seamless integration among all components.

This framework is found to be capable of effectively handling the supply chain management of agriculture-based systems in real-time with the use of blockchain and intelligent logistics technologies. In this framework, there are various kinds of users by offering several dashboards to make sure that the exchange of data is done

efficiently. From the experimental findings, it is found that the framework performs well in managing harvest data, making decisions about hub selection based on capacity constraints, and finding bottlenecks. The security of data is maintained through blockchain, and traceability information is made available to consumers.[4]

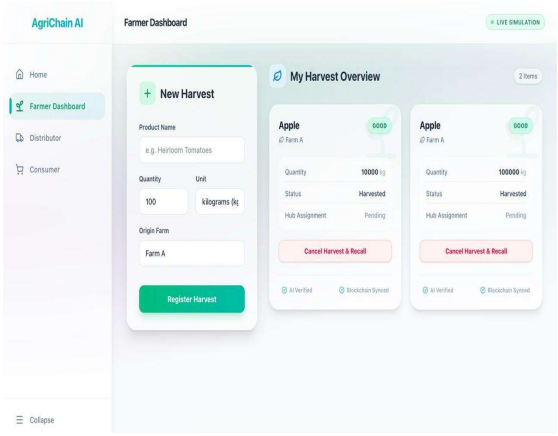


Fig 2: Farmer Dashboard – Harvest Registration and Tracking

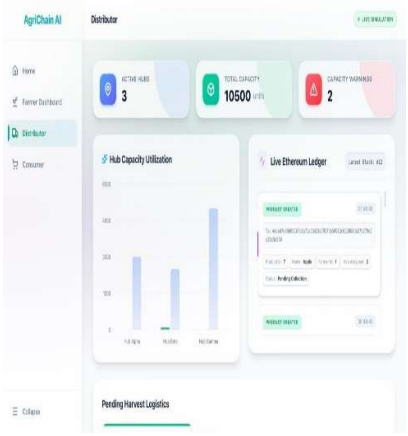
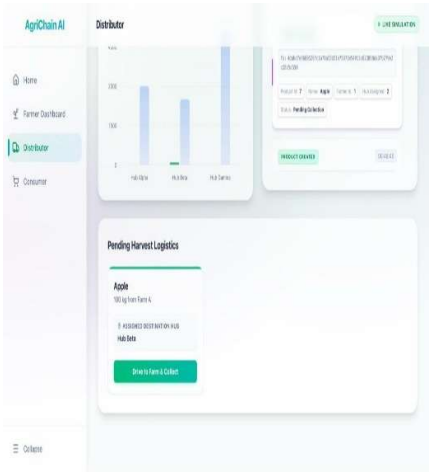


Fig 3: Distributor Dashboard – Hub Capacity Visualization



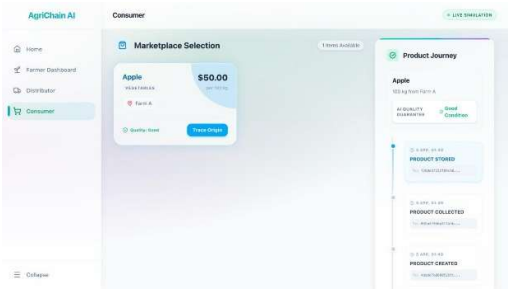


Fig 4: Logistics Module – Pending Harvest Assignment

Fig 4: Consumer Dashboard – Product Traceability View

VI. Discussion

The use of blockchain technology, along with Artificial Intelligence, provides solutions for many vital issues in connection with the process of managing the agricultural supply chain. Thanks to blockchain technology, the handling of information will become transparent and possible to avoid any fraudulent actions and breaches of data. The use of Artificial Intelligence will help in predicting the demand for products, identifying all anomalies, and assessing the quality of the product [11]. Experimental studies showed that operation within the system is quite effective and provides reliable predictions. Nevertheless, some challenges might arise, including scalability, security, and sensor input dependence. Despite everything mentioned above, the suggested method is incredibly efficient and smart [12].

VII. Conclusion

It proves that there is a lot of possibility to have digitized the agriculture routing method because this project clearly shows the effectiveness of this venture. As soon as the inclusion of the volumetric capacity constraint into the system is made using blockchain technology, the probability of getting the product spoiled because of bad transportation becomes lower. This project accomplishes all those objectives by presenting the visualization of logistics performed by Distributors and verified by Consumers using cryptographic methods.

FUTURE ENHANCEMENT

Predictive AI Modeling (Machine Learning): In the next iteration, we will apply predictive analysis using Python's scikit-learn package for analyzing historical records of customer purchase behaviors to predict the particular hub that will experience capacity limitations during different harvest periods.
IoT Sensor Simulation: Implement real-time sensor simulation (sensors for temperature and humidity) when the item is in the IN-TRANSIT stage to give early warnings to the Distributor, indicating a problem with their truck's refrigeration system to prevent spoilage.
Solidity Smart Contracts: Upgrade the basic hash chain algorithm in Python to utilize Solidity smart contracts for conducting automatic cryptocurrency payment between the Consumer and Farmer upon delivery of the item.

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