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Blockchain-Based Supply Chain Tracking System Implementation of a Decentralized Smart Contract on Ethereum

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***Abstract*—In today's global economy, effective supply chain management is essential for product transparency, traceability, and security. Traditional products often rely on centralized data, which leads to drawbacks such as errors, fraud, and inefficiency. This project offers an on-chain solution using Ethereum smart contracts to overcome these challenges. Using blockchain technology, our system records all transactions of products in an immutable ledger, increasing accountability and transparency of the owners without the need for an intermediary. Unlike existing platforms that incur high operating costs, our solutions are designed to be lightweight and flexible, suitable for use by small and medium-sized businesses (SMEs). The approach includes the creation of smart contracts, real-time data integration via QR codes, and rigorous testing to ensure the accuracy and usability of the system. Conceptually, our approach is designed to improve product quality, reduce the risk of fraud, and ensure compliance with business regulations. Finally, the project aims to redefine supply chain management by leveraging blockchain technology to create a more secure, efficient and reliable system that will benefit all stakeholders. This innovation not only addresses current limitations but also paves the way for increased use of blockchain solutions in the supply chain environment.**

I. INTRODUCTION

In today's globalized and interconnected economy, the supply chain is more complex than ever, involving multiple stakeholders across multiple domains. As products flow from companies to suppliers, retailers, and end consumers, it is important to monitor the movement and status of products with transparency, accuracy, and security. Traditional inventory management systems often rely on centralized data, leading to errors, fraud, data falsification, and inefficiency. These systems may not have the immediate visibility stakeholders need to detect issues such as product returns, counterfeit goods, or defective products.

Our project proposes to use a distributed distribution system using Ethereum smart contracts to solve the shortcomings of traditional systems. The solution leverages blockchain technology to ensure that all changes or events in the supply chain are recorded in a decentralized ledger. This means that once information is added, it cannot be changed or deleted, creating an immutable audit. All parties in the supply chain, from suppliers to consumers, can verify information without the need for intermediaries, thus providing greater transparency, traceability, and accountability.

The decentralized nature of the system eliminates risks associated with centralized management, such as points of failure and potential information. Additionally, the use of smart contracts can lead to processes to ensure that preconditions are met before a transaction is confirmed, thus reducing operational failure and human error. Advances in automation and security help build trust and efficiency, benefiting all stakeholders.

The project aims to change the way products are tracked and managed by integrating blockchain technology into supply chain management, making them more secure and researching processes that promote trust. Ultimately, the system will help improve the quality of all electronic products, reduce the risk of fraud and ensure compliance with industry-wide regulations.

II. RELATED WORKS

Many blockchain-based solutions have been developed for supply chain management, including well-known ones such as IBM Food Trust and VeChain. These platforms have been effective in improving supply chain transparency, efficiency, and traceability, especially for large enterprises. However, many of the existing systems require infrastructure and high operating costs, making them difficult for small businesses to use. In addition, they often provide flexibility to customize product tracking policies, which is important for enterprises that need solutions that address their specific chain of thought.

The system aims to solve these problems by offering simpler and more flexible solutions. The system uses Ethereum smart contracts and is designed to be lightweight and flexible, allowing small businesses to adopt it without making a significant investment in infrastructure. Unlike larger platforms that will focus on general use, this solution will allow businesses to define their own products and policies, simplifying and managing their delivery processes.

By leveraging the decentralized nature of Ethereum, the system will provide the same level of security, immutability, and transparency as major blockchain solutions, but in a more cost-effective manner that is more suitable for small and medium-sized enterprises (SMEs). This balance of simplicity and functionality makes the proposed system an alternative for businesses looking to improve their supply chain management through blockchain technology, without suffering from the cost associated with complexity and overhead.

Recent studies have investigated blockchain-based chain tracking using Ethereum smart contracts. These systems provide advantages such as immutability, auditability, and transparency [1]; It solves the problems of application business analysis, data recovery efficiency, and informal query [1]. Smart contracts are used to simplify management processes and operations, making the system more efficient and transparent [2]. Platform-independent and general-purpose architectures have been proposed to improve product flexibility and elasticity [3]. Integration with IoT devices has been explored to improve tracking, monitoring, and clearing processes [4]. This blockchain system aims to overcome issues such as lack of trust, poor communication, and fraud in traditional supply chain management [4]. While promising, researchers have also noted the limitations and operational considerations of using these systems [1];[4].

A. *IBM Food Trust*

Blockchain technology has revolutionized food supply and safety in the global supply chain. The Food Trust platform, developed by IBM in collaboration with major food retailers and retailers, is providing significant improvements in food traceability and transparency [5] [6]. Walmart's pilot program is using IBM's blockchain solution to reduce the time it takes to ship mangoes from 7 days to 2.2 seconds [6]. This tool solves the problem in the food chain, where contamination can affect thousands of products [7]. The use of blockchain in the food industry can increase safety, reduce waste, and enhance security [6]. However, traditional food laws and related legal structures also need to be revised[5]. To fully utilize the potential of blockchain in the food industry, improving the management of data exchange through trust is essential for business growth and population satisfaction[8].

B. *VeChain*

VeChain is a blockchain technology used in chain management and information sharing. It aims to increase transparency and efficiency in various industries [9]. The vChain framework supports multiple Bollinger analysis queries from blockchain databases, solving storage costs and computing costs while ensuring data integrity [10]. In the maritime sector, VeChain has demonstrated the potential for secure, tamper-proof data sharing, especially in electronic costs of loading and automated transactions on ships and shores [11]. The technology is also being used for public transportation by VeSenChain, a blockchain startup designed to provide relevant, accurate, and transparent services. VeSenChain uses smart contracts and Stackelberg game methods to improve the processing times of applicants and employees [12]. These applications demonstrate VeChain's performance in improving security, efficiency, and trust in various areas.

III. METHODOLOGY

A. *Strategy for searching*

We performed searches in five major digital libraries to access a wide range of peer-reviewed studies:
1. IEEE Xplore
2. ScienceDirect (Elsevier)
3. Springer
4. MDPI
5. Google Scholar

A search strategy was developed to ensure that relevant information was collected. The study focuses on research published between 2018 and 2022, as this period marks the rise of blockchain applications in the industry, especially in food traceability.

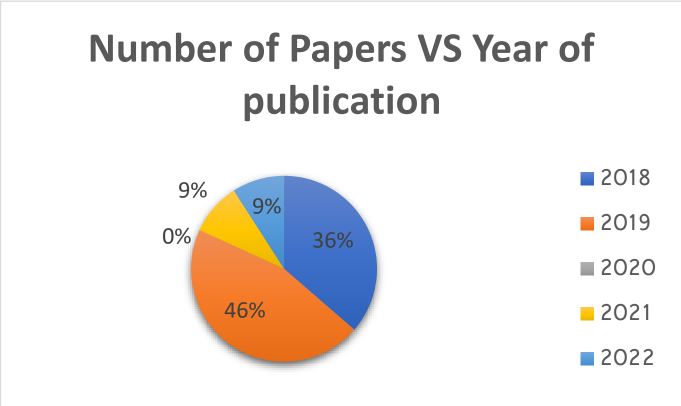

Fig.3.1 Selection of Papers

We have reviewed a total of 12 published papers from various sources. Out of those, majority of the papers were published in 2018 and 2019. 4 from 2018, 5 from 2019, 1 from 2021 and 1 from 2022. This was due to related research boom in the late 2010s.

B. *Setting up the project*

- Remix IDE
- Ganache
- MetaMask
- XAMPP
- Code Editor

The selection criteria focused on scalability, ease of integration, and relevance to the food traceability system.

C. *Implementation Phase*

1) *System Design*

The system is designed to integrate blockchain technology to ensure secure and transparent food traceability from farm to table. The major components include:

Blockchain Platform: Ethereum for smart contracts and immutable transaction records.

Frontend/Backend Design: Detailed explanation of the user interface for stakeholders to track and view data on food traceability.

2) Smart Contracts and Blockchain Deployment

A decentralized ledger was created to track each transaction across the supply chain. Smart contracts were developed using Solidity to automate tasks such as verification and validation at different stages of the supply chain.

Here are the important steps involved:

- Writing smart contracts to define rules for food traceability.
- Deploying the contracts on a test blockchain Ethereum using Ganache, Remix IDE, and MetaMask
- Testing functionality and data consistency.
- QR code integrations were employed to gather food status data in real time. The data was sent securely to the blockchain.

3) Data Processing and Results

The collected data was processed to generate insights such as food safety levels, authenticity verification, and the overall transparency of the supply chain.
The results were stored on the blockchain and accessible to all stakeholders.

D. Testing and Validation

After implementation, testing was conducted to ensure system accuracy. Several test cases were created, including:
System Response Testing:
How the blockchain network responds to high volumes of transactions.
Security Testing:
Ensuring data immutability and protection against unauthorized access.
Usability Testing:
Ensuring that end users can easily track food status using a user-friendly interface.

E. Challenges and Improvements

Blockchain technology offers the promise of providing chain traceability, transparency, accountability, and efficiency. It solves the problems of unreliable data and poor tracking in traditional systems. However, many obstacles stand in the way of adoption. These include lack of design and interoperability across platforms, scalability issues, and data security management. Other challenges in computing include access, access control, and data storage. There are also procedural constraints such as regulatory and stakeholder issues. Despite these issues, the benefits of blockchain for supply chain management are immense. Research continues to focus on developing strategic plans, appropriate controls, andinvestigating the role of regulators in the supply chain. Future directions include addressing capabilities, improving collaboration, and improving data management to enable widespread adoption of blockchain-based chain traceability systems.

IV. SYSTEM DESIGN

A. Contract Design

The most important information in the system is Material and State. Each object has metadata, including its creator, name, and production date. The event system stores information about the object at a specific time, including the operator and description of the change. This contract implements various functions, such as newItem (allows for the creation of new items) and addState (changes the state of the item). The SearchProduct function provides complete tracking of product history.

B. Architecture Overview

The system consists of smart contracts published on the Ethereum blockchain based on search results. Users can create new products, add conditions to these products, and search through product history. Each event involves a specific participant, providing clarity on ownership and performance.

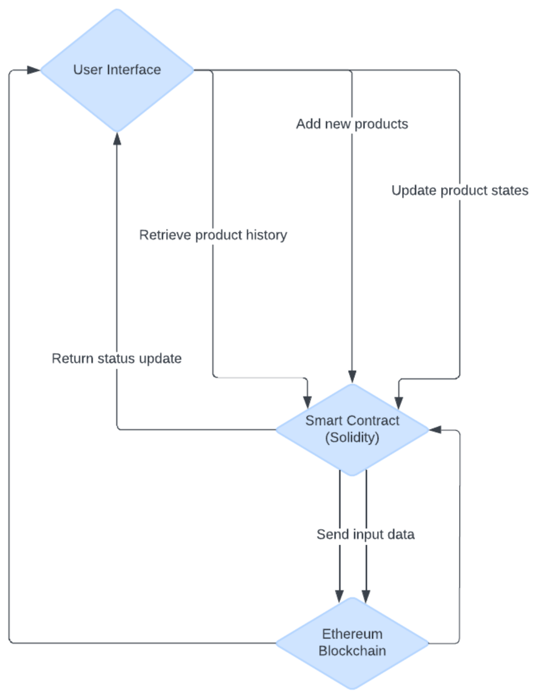

Fig. 3.2 System Architecture Diagram

V. IMPLEMENTATION

A. Solidity Smart Contracts

This contract is available in Solidity version 0.6.0. It uses a map to store objects, where each object can use another map to store multiple states. Solidity was chosen for this project because of its reputation and powerful tools for Ethereum-based applications. The contract has a concat function to hold the connection string needed to create a dynamic item history.

B. Functionality Explanation

Describe all important functions in detail.

- **newItem:** "This function allows users to register a new product. It records the product's creator, name, ID, and date, storing these details in the allProducts mapping."
- **addState:** "The addState function allows the object owner or other contributor to add a new state to the object, saving the state information and location of the person making the change."
- **searchProduct:**"This function stores all the information about the object, including its name, creation date, and events associated with it. Custom string concatenation function to dynamically generate output."

C. Frontend and Backend

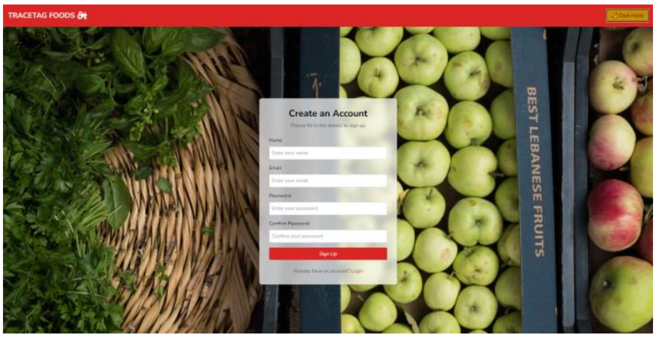

Fig. 5.1 User SignUp Page

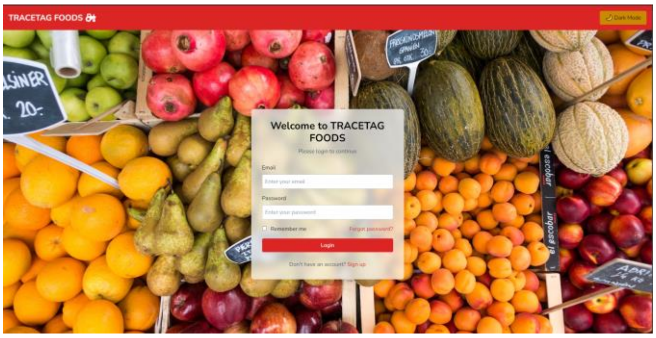

Fig. 5.2 User Login Page

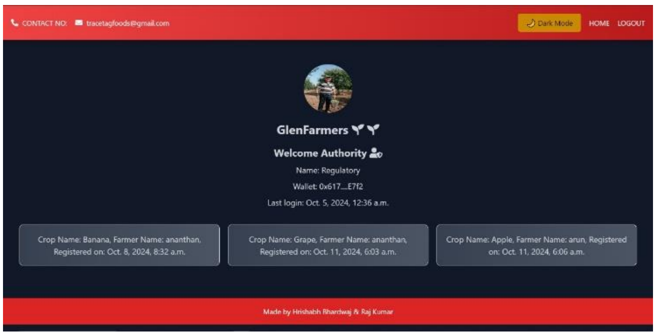

Fig. 5.3 User's Profile Page

Fig 5.4 Home Page where a farmer can register his/ her crops

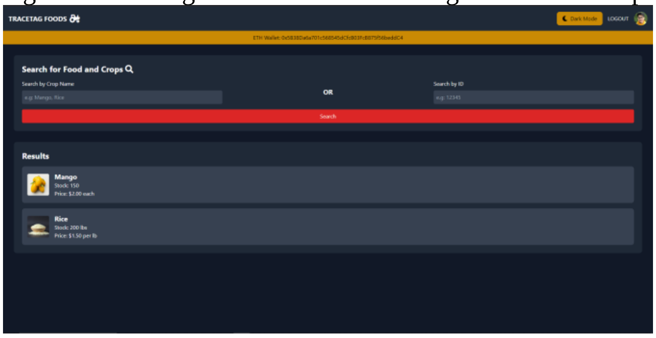

Fig 5.5 Page to search for Foods and Crops

VI. OTHER CONSIDERATIONS

A. Security Consideration

Security is an important consideration for these systems, as incorrect changes can cause malfunctions. The user agreement should include language that ensures users can only modify existing products and should check to prevent incorrect information from being added. The agreement also ensures that only authorized parties can add state to the object, preventing tampering by unauthorized users.

B. Gas Optimization

Gas optimization is a key factor in the development of this contract. To reduce cost, map is used in dynamic products and all connections of the connection string are run in the contract without repetition. Future optimizations may include using events instead of strings to release some data to reduce the storage chain.

VII. TESTING AND DEPLOYMENT

The contract was tested using the Truffle framework in a local Ethereum development environment. Quality Control tests were written to ensure that all functionality worked as expected, including cases such as trying to add state to a non-existent object. The contract was pushed to the Rinkeby test network for further testing and analysis. After careful integration testing, the application was tested as various users, such as farmers, wholesalers, retailers, consumers, and admin.

VIII. CONCLUSION AND FUTURE WORK

The project has successfully implemented a simple yet effective chain of custody application using blockchain technology. Rigorous integration testing was done to ensure that the application works under various conditions. The decentralized nature of the Ethereum blockchain ensures that all legal transactions are locked in a transparent and immutable manner. Future work may include creating an enhanced front-end interface for additional integrations such as user interaction, fuel development, or geo-tracking.

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