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Smart Contract-Based Agricultural Food Supply Chain Traceability

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ABSTRACT The complexity of a supply chain makes product safety or quality issues extremely difficult to track, especially for the basic agricultural food supply chains of people's daily diets. The existing agricultural food supply chains present several major problems, such as numerous participants, inconvenient communication caused by long supply chain cycles, data distrust between participants and the centralized system. The emergence of blockchain technology effectively solves the pain-point problem existing in the traceability system of agricultural food supply chains. This paper proposes a framework based on the consortium and smart contracts to track and trace the workflow of agricultural food supply chains, implement traceability and shareability of supply chains, and break down the information islands between enterprises as much as possible to eliminate the need for the central institutions and agencies and improve the integrity of the transaction records, reliability and security. At the same time, farmers record details of the environment and crop growth data in the InterPlanetary File System (IPFS) and store file IPFS hashes in smart contracts, which not only increases data security but also alleviates the blockchain storage explosion problem. This framework has been applied in Shanwei Lvfyngyuan Modern Agricultural Development Co., Ltd. Although there are still many defects, the framework has successfully realized functions such as disintermediation and tracing of agricultural product information through QR codes. Thus, the framework proposed in this paper is of great significance and reference value for enterprises to ensure product quality and safety traceability.

INDEX TERMS Blockchain, smart contract, agricultural food supply chain, traceability, food safety.

I. INTRODUCTION

The supply chain connects many entities, such as suppliers, logistics providers, processors, distributors, retailers, and consumers, forming a complex network chain structure. This complex supply chain may go through dozens or even hundreds of stages, leading to considerable time consumption and involving a wide range of regions. Therefore, in this case,

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if the product has safety or quality problems, the traceability process is extremely difficult. Especially in agricultural food supply chains, the process ensures the traceability of the final products, which not only guarantees consumer life and health but also improves user trust in the product and enterprise. In recent years, prevalent food safety accidents have caused people to devote more attention to food safety and quality. However, the current agricultural food supply chains are characterized by a long life cycle, numerous and complex links, and dynamic information, etc., so it is difficult to track and

trace problems in a certain link. Agricultural foods are foods produced by agriculture, such as sorghum, rice, peanuts, corn, and wheat, which form the basis of people's daily food, and their importance is self-evident. Subsequently, it is very important to establish and improve the agricultural food supply chain traceability system "from farm to fork" [1]–[3].

There are three major problems with the existing agricultural food supply chains. First, there are many participants in the supply chain, and the communication between them is not convenient, leading to a long cycle of the whole supply chain. Then, due to the large number of participants and distribution in different links, the information sharing is poor, and data is not trusted among participants. Finally, the agricultural food supply chain is a centralized system with power concentrated on the central manager and data easily tampered with. Although the central manager is under the supervision of government departments, there are always loopholes in human supervision [1], [4]–[6]. By reason of this situation, in order to effectively track product information, ensure product safety and quality, and thus ensure the safety of consumers, the research on advanced traceability technology and its systems wields important research value to guarantee the quality and safety of agricultural food. To date, many researchers have studied and developed supply chain traceability systems based on barcodes, QR codes and radio frequency identification devices (RFID), but most of these systems still have some problems. First, most of the traceability systems are developed based on a single enterprise, which is an internal traceability system by which information is not easily shared. Second, the majority of traceability systems are based on centralized development, and the information is opaque and asymmetric, with the risk of tampering by the administrator and low credibility. Finally, existing traceability systems have a single point of failure, and once a node fails, the whole system will crash. The emergence of blockchain technology effectively solves the pain point of the existing agricultural food supply chain traceability systems.

Blockchain is a distributed ledger system which consists of one-by-one blocks with timestamps in the form of a decentralized database in the point-to-point (P2P) network. Therefore, it has the characteristics of decentralization, immutability, anti-tampering and traceability. Blockchain technology is introduced into the agricultural food traceability system to track the information of the supply chain process, offering the advantages of reducing the management cost, improving the information credibility, realizing the visualization of the supply chain process data and the traceability of the information, etc. [2], [7]–[10]. In view of the many advantages of blockchain, the research on traceability systems based on blockchain is growing rapidly [11]. In the medical field, Yong *et al.* [12] developed a "vaccine blockchain" system based on the blockchain and machine learning technology, and can be used to address the problems of vaccine expiration and vaccine record fraud by using the traceability and smart contract of the blockchain. Tripathi *et al.* [13] proposed an smart healthcare system framework based on blockchain to

provide a secure and privacy-protecting healthcare system. In the field of protecting privacy, Chen *et al.* [14] proposed a novel on-chain and off-chain data storage model and developed a prototype system to verify the feasibility of the model, thus solving the problems of information redundancy and insufficient storage space in blockchain. However, this framework is only applicable to personnel information management system and has not been extended to more fields. Yang *et al.* [15] proposed a blockchain privacy-preservation crowdsensing system, which solves the risk that the existing crowd-testing system is vulnerable to attack, invasion and manipulation. In the field of traceability, Liu and Li [16], with respect to the background of cross-border e-commerce, proposed a framework based on blockchain and developed a set of corresponding technologies and methods to realize product traceability and transaction traceability in supply chain management. The key methods and algorithms, such as the information anchoring method, key distribution method, information encryption algorithm and anti-counterfeiting algorithm, are developed to solve the key recovery problem and effectively resist clone attack, counterfeit label attack and counterfeit product attack. However, this system is not implemented for actual business. Baralla *et al.* [17] proposed a traceability system for agricultural product supply chains based on the blockchain hyperledger Sawtooth technology, which implements the EU's "farm-to-fork" model. Consumers can learn detailed product information through QR code scanning and verify product quality and safety. However, the Sawtooth technology is not mature enough and lacks materials and applications. Yu and Huang [18] designed a foot ring based on blockchain and RFID technology to solve the problem of poultry food safety, which is conducive to timely detection of health problems in the poultry breeding process, and helps consumers to track information and quickly locate specific links in the poultry breeding life cycle when problems occur. Nevertheless, RFID technology is not mature enough and exhibits insufficient security and excessive cost: it is thus not practical for the full application to large poultry farms. Based on the research of RFID and blockchain technology, Tian [19] established a traceability system for agricultural food supply chains which covers the whole process of data collection and information management of all links of the entire supply chain, and also realizes the quality and safety monitoring, traceability and traceability management of agricultural supply chains. Similarly, because of the same shortcomings as those of the previous paper, the system cannot be widely used in all fields.

This paper proposes a framework based on consortium chain and smart contracts to track and trace workflows in agricultural food supply chains, implement traceability and shareability of supply chains, and disrupt information islands between enterprises as much as possible to eliminate the need for the central agencies and intermediaries and improve the transaction record integrity, reliability, and security. At the same time, farmers record the environmental information and details of crop growth data into the InterPlanetary File System

(IPFS). The file IPFS hash is stored in the smart contracts, which not only increases the data security but also alleviates the blockchain storage explosion problem. Besides, this framework has been applied in Shanwei Lvfyngyuan Modern Agricultural Development Co., Ltd. Although there are still many defects, it has successfully achieved decentralization and traced the information of agricultural products through QR codes, which will be briefly introduced in the following article.

The remainder of this paper is organized as follows. Section 2 reviews the related work. Section 3 introduces some basic knowledge. In Section 4, we discuss the design, system overview and entity sequence diagram. Then, Section 5 describes implementation details including algorithms for agricultural food sales between various participants using smart contracts. Finally, Section 6 presents the conclusions.

II. RELATED WORK

Food is the basis of people's survival, and food safety is closely related to people's health: thus, people are devoting increasing attention to food safety. In recent years, experts have become more interested in food traceability. The first technology applied to food safety traceability is Internet of Things (IoT) technology [20], [21], such as barcodes, QR codes, and RFID technology. Li *et al.* [22] proposed a food traceability system for the dairy supply chain based on QR codes, which improves the transparency from production to sales and builds a food traceability platform. However, QR codes are not suitable for living bodies, such as poultry and waterfowl, and are easily damaged by pollution. RFID is the most widely used technology in the IoT to realize food traceability due to its low cost and small size. De-an *et al.* [23] developed an RFID-based pork supply chain traceability system. A set of pork quality monitoring and tracking systems was constructed by using Structured Query Language (SQL) Server 2000 and intelligent identification technology to realize the information traceability of the entire pork production process. Yiying *et al.* [24] designed a complete life cycle food traceability system, which uses RFID technology to realize whole process monitoring from source to consumption. At the same time, the RFID fault-tolerant mechanism is designed to ensure the practicability of the system. Mondal *et al.* [25] used object-based validation protocols, real-time quality monitoring with RFID sensors at the physical level, and blockchain technology at the network level to create a transparent food supply chain. However, RFID technology also presents some defects such as immature technology, high cost, inconsistent technical standards and low security. In addition, most of the traceability system data based on the IoT are stored in SQL Server and other central databases, which leads to problems like information asymmetry, data tampering and escalating data volume, thus increasing the cost of centralized storage. Blockchain technology has the characteristics of decentralization, immutability, anti-tampering and traceability.

The application of blockchain technology in agricultural food safety traceability systems can store traceable data in chronological order, which is conducive to solving the problems remaining in the existing agricultural food traceability systems.

As a result, the combination of blockchain technology and food traceability has become a new trend in recent years. Tian [26] proposed the traceability of food supply chains based on hazard analysis and critical control points (HACCP) by combining blockchain and IoT. IoT technology automatically collects and stores information, improves the reliability of information and enhances food safety. Blockchain can ensure that data will not be tampered with after the chain, which improves the authenticity of the traceability information. However, since data quantities are constantly increasing, the blockchain cannot hold all of it. Hao *et al.* [27] studied a traceability storage scheme using IPFS and secondary databases. IPFS is a technique for storing and sharing data in a distributed file system. To retrieve data from the IPFS, the transaction hash must be accessed from the secondary database and then the IPFS hash must be retrieved from the blockchain. This approach solves the blockchain data explosion problem, but if the secondary database fails, the entire system will fail.

With the advent of the blockchain 2.0 era, the self-execution and self-verification features of smart contracts have made them widely used in food safety traceability systems. Wang *et al.* [3] proposed a product quality management system that uses smart contracts technology to permanently record all product transactions. In [28], the author presented a collaborative food safety traceability system based on blockchain and EPCIS, and adopted enterprise-level smart contracts to solve problems such as disclosure of sensitive information, data tampering and trust transfer. At the same time, the system also adopts the dynamic management of data on and off the chain to alleviate the problem of data explosion on the blockchain. Salah *et al.* [2] researched a method of using blockchain and smart contracts to execute business transactions, so as to realize traceability and visibility in the soybean supply chain. The solution aims to eliminate a trusted centralized authority, provide transaction records, and use smart contracts to manage and control transaction interactions between participants in the soybean supply system. These transactions are recorded and stored on the blockchain and connected to the IPFS, providing transparency and traceability to the soybean supply chain system in a safe and reliable manner. The huge advantage of smart contracts is not only widely used in food safety traceability. Omar *et al.* [29] presented a method based on blockchain, using Ethereum smart contracts and decentralized storage system to automate processes and information exchange, and capture the detailed algorithm of interaction between supply chain stakeholders, provides them with a compact, safe, reliable and transparent communication mode, has solved the Vendor Managed Inventory operation of data integrity, transparency, traceability and single point of failure. Zhang *et al.* [30] proposed a

novel secure billing protocol for online ride-hailing vehicles, which solved the difficult problem of fare estimation and automatic payment through smart contracts. Xuan *et al.* [31] proposed a data sharing incentive model based on evolutionary game theory using blockchain with smart contracts, which could dynamically control the excitation parameters and continuously encourages users to participate in data sharing. Tso *et al.* [32] introduced the first decentralized electronic voting and bidding systems based on a blockchain and smart contract, which improved the anonymity of participants, privacy of data transmission, and reliability and verifiability of data.

The consortium chain is a kind of blockchain which is managed by multiple organizations or institutions, and the data can only be read, written and maintain by these organizations or institutions. This disrupts the information islands between enterprises and is very suitable for agricultural food safety traceability systems. Ethereum and hyperledger are two popular consortium chain platforms [2] based on Ethereum, while Wal-Mart [33], the world's largest retailer, is experimenting with food traceability through IBM's hyperledger. Taking advantage of the key features of the blockchain and smart contracts, Shahid *et al.* [34] deployed the Ethereum blockchain network to propose a blockchain-based reputation system in the agricultural and food supply chain. In [35], the authors proposed a decentralized storage mechanism based on Ethereum. The use of IPFS overcomes the problems of centralized storage of sensitive data leaks and single points of failure. Before the data is stored in IPFS, the file is encrypted using the file encryption algorithm, and the ciphertext is uploaded to IPFS, which provides the hash value of the stored file recorded in Ethereum. However, due to the increased computing overhead, the proposed solution will not work effectively in an IoT scenario.

III. PRELIMINARIES

A. BLOCKCHAIN

As we mentioned above, blockchain is a distributed ledger system that consists of one-by-one blocks with timestamps in the form of a decentralized database in the P2P network [23], [24]. As the underlying technology of Bitcoin, blockchain technology has gradually emerged into the public consciousness. Although this new concept has become a hot topic in recent years, in fact, some technologies it relies on, such as asymmetric encryption technology and P2P network protocol, have existed for a long time. However, blockchain is a good combination of encryption technology, consensus algorithm, timestamp technology and smart contracts, forming a distributed system where users can be anonymous and data can be trusted. It offers the advantages of decentralization, immutability, anti-tampering and traceability, etc. It is widely applied in the fields of medical treatment, education, credit and supply chain traceability. Fig. 1 shows the blockchain structure.

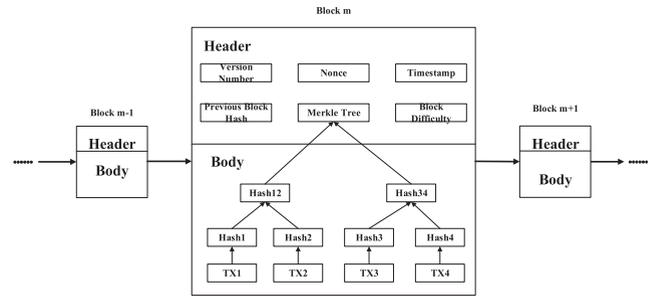


FIGURE 1. The structure of blockchain.

As can be observed from the diagram, the connection between blocks is produced by the hash value of the previous block, which is the unique identifier of each block. In this way, the connection from the latest block to the first block is created by the sequence of each block to its parent hash value, creating a form similar to a data structure. The block consists of a header and a body. The header contains a version number, nonce, timestamp, previous block hash, block difficulty and Merkle tree. The block difficulty determines the difficulty of mining. The nonce is the answer to the math problem the miners are looking for, and the previous block hash is used to connect the previous block. The timestamp is the generation time of each block, which corresponds to the authentication of each transaction record, ensuring the authenticity of the transaction record. The body mainly contains transaction data.

The Merkle tree appears to be very similar to a binary tree, and it can summarize and quickly verify all transaction data in a block. Each leaf node uses the hash of the data block as its tag, and each non-leaf node uses the encrypted hash of its child node's tag as its tag. As shown in the body area of the diagram, the respective hash values of each transaction are taken as leaf nodes, and the hash values of the two leaf nodes are combined for another hash calculation to generate the parent node, namely the Merkle root. When the transaction records are tampered with, the value will be inconsistent. Such a storage method not only enables the blockchain to quickly discover that the information has been tampered with but also enables it to quickly locate the specific transaction information.

B. CONSORTIUM CHAIN

The blockchain is divided into public chain, private chain and consortium chain. In the public chain, anyone can send transactions and participate in the consensus process. The whole network is open, without authorization, and characterized by "complete decentralization". The private chain is generally the blockchain within the enterprise, whose authority is completely in the hands of an organization or a person, with the lowest degree of decentralization. The consortium chain exists between the public chain and the private chain and is a special blockchain requiring registration and permission: it is only open to specific organizations or institutions, so it can maintain the distributed structure, limit the number of participants, and can only be verified in the blockchain through

pre-set nodes, thus enhancing security. The consensus algorithm is implemented by validating data and blocks through pre-selected nodes rather than by all nodes in the entire network, which accelerates the generation of blocks and shortens the time to reach consensus and validate data. Therefore, the consortium chain exhibits characteristics such as few consensus nodes, high system operation efficiency and rapid transaction speed. Agricultural food traceability systems have high requirements with respect to privacy protection, transaction speed and internal supervision: if every participant joins the consortium chain, these systems combined with the smart contracts technique can effectively solve the issue that existing agricultural food traceability systems are established on the basis of a single enterprise development, thus disrupting the information islands between enterprises to make the adoption of consortium chains in agricultural food traceability systems more suitable [36]–[40].

C. HYPERLEDGER

Hyperledger is an open source collaborative project initiated by the Linux Foundation in 2015 to promote blockchain digital technology and transaction verification. It is the first distributed ledger platform for enterprise application scenarios, involving technology and financial giants such as IBM, Intel, Cisco, and R3. Hyperledger can be divided into distributed ledger technology, libraries and tools. Fabric is the most important application project of Hyperledger technology, which is a general license blockchain with modular and extensible characteristics, follows the execution-sequence-validation paradigm and fundamentally deviates from the order-execution model. Fabric consists of four parts: (1) Describing the roles between nodes in the infrastructure; (2) Execution of the smart contracts; (3) Configurable consensus; (4) Membership services, whose modular structure provides a high degree of confidentiality, flexibility and extensibility applicable to any industry [41], [42]. HyperLedger establishes consortium chain through channel and uses membership service provider(MSP) to control the permissions of nodes. As an important communication mechanism, channel is an independent communication channel between members that transactions sent in it can only be seen by members belonging to the channel. There can be multiple channels in the network, and each channel maintains an account of its own channel.

IV. AGRICULTURAL FOOD TRACEABILITY BASED ON BLOCKCHAIN

In this section, we use the hyperledger fabric to build consortium chain and smart contracts named chaincode to track and execute transactions in the agricultural food supply chain. This method eliminates the need for a central authority, realizes decentralization, and provides complete, reliable and secure transaction records for the management and security of the agricultural food supply chain, ensuring the authenticity and reliability of the agricultural food information that ultimately reaches the consumer.

A. SYSTEM OVERVIEW

Smart contracts have the ability to integrate agricultural and agricultural food safety into an integrated intelligent system, thus ensuring the quality and safety of agricultural food and the health of consumers. This paper presents a framework for the use of automated smart contracts on the hyperledger platform. According to the information in the agreed contract, when the trigger condition is met, the smart contracts automatically send out the preset data resources, including the events of the trigger condition. This is a system of transaction processing modules and state mechanisms that do not generate or modify smart contracts but only enable a complex set of digital commitments with trigger conditions to be executed correctly according to the will of the participants. Smart contracts are executed by tens of thousands of nodes distributed around the world and are the result of consensus. Nodes are one of the components of the blockchain network, namely, participating entities in the agricultural food supply chain. These nodes can collect, validate, and execute transactions, and store the data and results of these transactions in a ledger, which will eventually be replicated and synchronized by all nodes. As a result, all nodes have the same ledger information without contingency. As mentioned earlier, smart contracts receive transactions and trigger events in the form of function calls, enabling participating entities to continuously monitor, track, and receive appropriate alerts when violations occur. Fig. 2 depicts a general overview of the system architecture presented in this paper, with the main participating entities including the agricultural bureau, farmer, processor, quality supervision bureau, distributor, retailer, consumer, and blockchain implementing smart contracts.

As shown in Fig. 2, in order to achieve traceability of agricultural food, information is recorded using hyperledger smart contracts, and all participants in the agricultural food supply chain are added to the process. The agricultural bureau records farmer information, seed information, plot information and yield information, etc., and carries out unified management of farmers' production to ensure the authenticity of source information. Farmers cultivate crops and record the environment and growth detail data of the crops in IPFS, where the growth images of the crops are marked with timestamps. Timestamps represent complete and verifiable data that already exists at a given point in time, providing the user with electronic proof of when some of the user's data was generated. The file IPFS hash is stored in smart contracts. When the crops mature, the farmer harvests them and then sells them to a processor for a series of processing steps. The quality supervision bureau supervises the processing to ensure the safety and quality of agricultural food. The finished agricultural foods are purchased in bulk by a distributor, stored and sold to a retailer, who buys agricultural food from a distributor and sells it directly to the customer in small quantities.

Data stored in the blockchain or IPFS is encrypted by the entity storing the data using a digital signature, which offers the following advantages: (1) Anti-tampering: After signing,

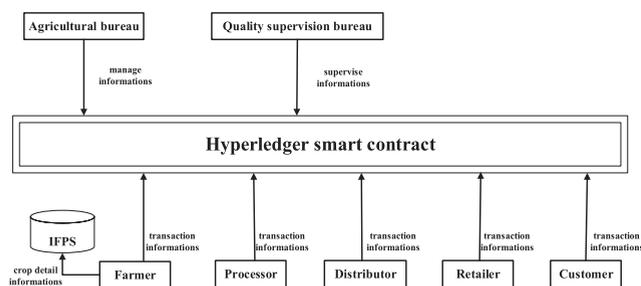


FIGURE 2. A system overview for agricultural food traceability using hyperledger smart contracts.

the authenticity of the data is determined through the calculation and verification of the signature to ensure the integrity of the data; (2) Non-repudiation: A digital signature can be used as the identity authentication of the stored data entity, or as the evidence of the signer's operation; (3) Confidentiality: Data loss is likely to lead to data leakage, but the digitally signed data needs to be decrypted to obtain the original data. Entities are responsible for their own data, the blockchain automatically executes programs through smart contracts, and entities will execute punishment measures if they commit illegal activities. In the planting stage, farmers use a variety of sensors to upload the growing environment information and details of crops directly to the server in real time. The data is not processed by human beings, which enhances the authenticity and anti-tampering characteristic of the data and enables the data to be audited and trusted.

B. SYSTEM DESIGN

The agricultural food supply chain completes the entire production and transportation process “from farm to fork”, involving many participating entities, and forming long and complex characteristics that make tracking the entire process very cumbersome. Therefore, for traceability purposes, we record the information and add the unique identity and lot number of the food to each subsequent transaction when the transaction is initiated, and record the hash value to ensure the authenticity of the transaction. A batch is a group of foods in a warehouse whose batch number is the unique identifier. To address the blockchain data explosion and IPFS limitations, the hash of the data is stored in the hyperledger, and the transaction data is stored in the IPFS. Access control policy is adopted to restrict blockchain reads and writes, ensuring that transactions are executed by authorized users and enhancing data security. Similarly, smart contracts allow only specific entities to execute. Entities are registered in the system and interact through the smart contracts. The processing of the entity in the agricultural food supply chain is shown in Fig. 3, and the description of each entity is as follows:

1) AGRICULTURAL BUREAU

The agriculture bureau is an organization that manages farmers, keeping records of farmers' information, seed information, plot information and yield information to ensure the

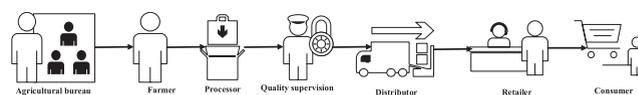


FIGURE 3. The simple agricultural food process in the agricultural food supply chain.

authenticity of source information. The information is stored in the IPFS, and its hash value is stored on the chain.

2) FARMER

The farmer is responsible for planting crops, using sensors to monitor and record details of crop growth, such as water, air, sunlight and soil quality in the growing environment, and storing the information regarding the process of crop growth in IPFS in the form of images or MPEG files. In addition, the farmer is responsible for creating smart contracts and storing IPFS data hashes in smart contracts.

3) PROCESSOR

The farmer harvests crops and sells them to the processor, who processes the raw crops into produce purchased by the final consumer, and stores the batch information, quantity, and inspection information of the finished products in IPFS. The data hash is stored in the blockchain, and the data label is finally generated and pasted on the product packaging.

4) QUALITY SUPERVISION BUREAU

The quality supervision bureau mainly manages the processing and guides the quality supervision and inspection, and is responsible for the implementation of product quality supervision and compulsory inspection of the production enterprises. To investigate and punish violations of laws and regulations concerning standardization, measurement and quality, and crackdown on illegal activities related to counterfeiting and shoddy goods, its information is recorded on the IPFS, and the hash value is stored on the blockchain.

5) DISTRIBUTOR

The finished product may go through multiple levels of distribution before reaching the retailer. The distributor is responsible for storing processed agricultural products and selling them to retailers in batches. Company information, product selling time, price and other information is stored in IPFS, and like the situation for the quality supervision bureau, the hash value is stored in blockchain to ensure that the subsequent data is not tampered with.

6) RETAILER

The retailer buys processed produce from the distributor and sells it in small quantities to consumers. Basic information of the retailer, time of selling, quantity sold and other information is recorded in IPFS, and the hash value is also recorded in the blockchain.

7) CUSTOMER

Consumers are the users who purchase and consume the final agricultural food, and can obtain the complete supply chain information of the agricultural food according to the barcode,

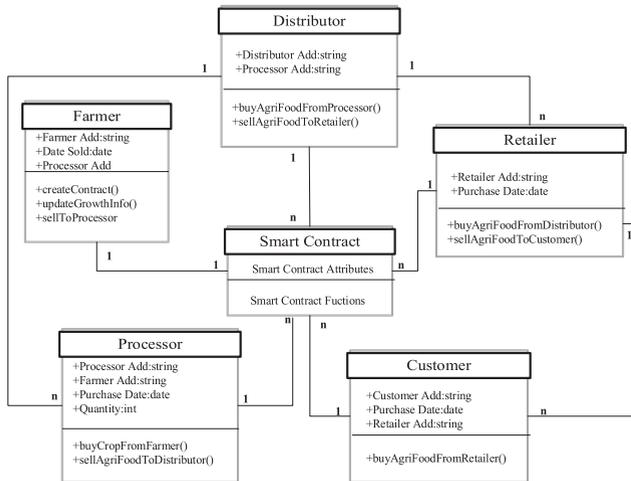


FIGURE 4. Entity relationship diagram.

RFID or QR code on the product package to realize the traceability function of agricultural food information.

C. ENTITY SEQUENCE DIAGRAM

The relationships between entities, as shown in Fig. 4, show some of the key properties and capabilities of the smart contracts, as well as the relationships between entities and smart contracts. Each participating entity in the agricultural food supply chain participates by calling a function in the smart contracts. The smart contracts are created by the farmer, who grows the crop and uploads the growing environment, details and images to the IPFS by calling *updateGrowthInfo()*, which is stored in the IPFS hash, and updates the *updateGrowthInfo()* until the crop is ready for harvest. When the crops are harvested, the trade begins between the farmer and the processor. Once the farmer and the processor have negotiated the details of the agreement, the farmer agrees and sells the crop to the processor. Fig. 5 shows the sequence diagram of the farmer and processor executing the *sellToProcessor()* and *buyCropFromFarmer()* functions, respectively. First, the processor executing the *buyCropFromFarmer()* function, passing processor address, quantity and sales date parameters to activate the smart contract trigger the *CropRequested()* event to notify the participants, and passing and recording these parameters. Then, the farmer executing the *sellToProcessor()* function, passing the farmer address, processor address, quantity and sales date parameters, the smart contract trigger the *CropSold()* event to notify closing the transaction, and passing and recording these parameters.

Fig. 6 shows a sequence diagram of the processor and distributor collaboration using smart contracts. The distributor is a warehouse that buys processed produce in bulk from various processors and sells it to retailers. Firstly, the distributor trigger *AgriFoodRequestedByDistributor()* event, passing distributor address, processor address, quantity and sales date parameters to notifies the processor selling agricultural food to it, then the farmer performs the *sellAgriFoodToDistributor()* function, passing processor address, distributor address,

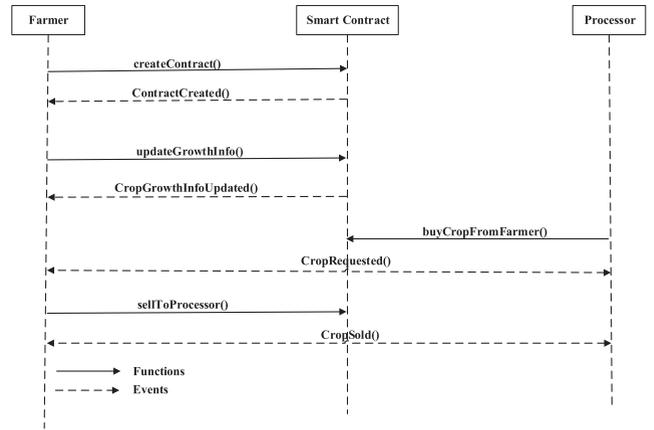


FIGURE 5. Sequence diagram showing interactions among farmers, smart contracts, and processors.

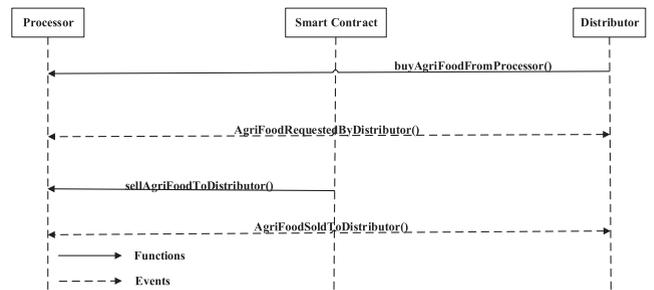


FIGURE 6. Sequence diagram showing interactions among processors, smart contracts, and distributors.

sales quantity and sales date parameters to activate the *AgriFoodSoldToDistributor()* event to notify interaction entities. Retailers buy agricultural food from distributors, executing the *buyAgriFoodFromDistributor()* function, and passing retailer address, distributor address, quantity parameters. The activation *AgriFoodRequestedByRetailer()* event notifies the distributor, the distributor then performs the *sellAgriFoodToRetailer()* function to sell agricultural food to the retailer, and activated event *AgriFoodSoldToRetailer()* notifies the relevant participant of this process. At the same time, passing the addresses of both parties, quantity, batch number and sales date parameters. Finally, the retailer sells the agricultural food to the customer by executing the *sellAgriFoodToCustomer()* function, passing retailer address, customer address, agri-food name and sales date parameters, and broadcasts the process for the agricultural food via the *AgriFoodSold()* event. Fig. 7 shows a sequence diagram of distributor, retailer and customer.

V. IMPLEMENTATION

As mentioned above, the smart contracts are created by the farmer. In the initial state of establishing the smart contracts, the smart contracts will check whether the farmer is registered. The processor then issues a purchase request, at which time the contract status is *buyCropFromFarmer*, and two conditions need to be checked: (1) Whether the requested

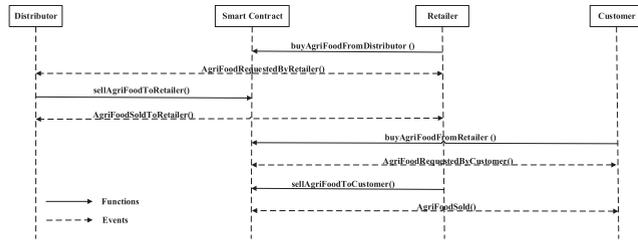


FIGURE 7. Sequence diagram showing interactions among distributors, smart contracts, retailers and customers.

processor is a registered entity; (2) Whether the processor has paid the fee. If these two conditions are satisfied, the contract status changes to *CropRequestAgreed*, the processor status is now *WaitForCropFromFarmer*, the farmer status changes to *SellCropToProcessor* and all active entities receive information from the farmer about selling crops to the processor. If the above two conditions are not met, the contract state becomes *CropRequestFailed*, the processor state is *RequestFailed*, and the farmer state is *CancelRequestOfProcessor*. Algorithm 1 describes the process by which farmers sell their crops to processors.

Algorithm 1 Farmer Sell Crops to Processor

Input: ‘rp’ is the list of registered Processors
Address of Processor,
Address of Farmer,
Quantity, DatePurchased, CropPrice

- 1 Contractstate is *buyCropFromFarmer*
- 2 State of the processor is *CropRequested*
- 3 Farmer state is *WaitForSellCropToProcessor*
- 4 Restrict access to only $rp \in Processor$
- 5 **if** *CropSale is agreed and CropPrice = paid* **then**
- 6 Contract state changes to *CropRequestAgreed*
- 7 Change State of the processor to *WaitForCropFromFarmer*
- 8 Farmer state is *SellCropToProcessor*
- 9 Send a notification of crop sale to processor
- 10 **end**
- 11 **else**
- 12 Contract state changes to *CropRequestFailed*
- 13 State of processor is *RequestFailed*
- 14 Farmer state is *CancelRequestOfProcessor*
- 15 Send a notification stating request failure
- 16 **end**
- 17 **else**
- 18 Reset contract and displays an error message.
- 19 **end**

The processor then sells the processed crop to a distributor, who in turn sells it to retailer, as shown in algorithm 2. At this point, the production date, sales quantity and purchase date of the agricultural food are important parameters of the current stage. First, with respect to recognition address and the states of the distributor and retailer, due to the distributor

having just finished the trade with the customer, the smart contract status is *AgriFoodSoldToDistributor*, and the state of the distributor is *AgriFoodReceivedFromProcessor*. The status of the retailer is *ReadyToPurchase*, which must satisfy two conditions: (1) Whether the requested retailer is a registered entity; (2) Whether to agree to the sales agreement and whether the agricultural food payment has been completed. If these two conditions are satisfied, the contract will automatically execute the transaction with the contract status changed to *SaleRequestedSuccess*, distributor status changed to *AgriFoodSoldToRetailer*, and retailer status changed to *AgriFoodDeliveredSuccess*. Upon completion of the transaction, the deed will send a notification of successful delivery to the retailer. If the above two conditions are not satisfied, the contract status is changed to *SaleRequestDenied*, the distributor status is changed to *RequestFailed*, the retailer status is changed to *AgriFoodDeliveryFailure*, and the contract sends a notification of failure to all participants.

Algorithm 2 Distributor Sell Agri-Food to Retailer

Input: ‘rr’ is the list of registered Retailer
Address of Distributor,
Address of Retailer,
DateManufactured, Quantity,
DatePurchase

- 1 Contractstate is *AgriFoodSoldToDistributor*
- 2 State of the distributor is *AgriFoodReceivedFromProcessor*
- 3 Retailer state is *ReadyToPurchase*
- 4 Restrict access to only $rr \in Retailer$
- 5 **if** *Sale is agreed and Price = paid* **then**
- 6 Contract state changes to *SaleRequestedSuccess*
- 7 Change State of the distributor to *AgriFoodSoldToRetailer*
- 8 Retailer state is *AgriFoodDeliveredSuccess*
- 9 Send a ‘success’ notification to retailer.
- 10 **end**
- 11 **else**
- 12 Contract state changes to *SaleRequestDenied*
- 13 State of distributor is *RequestFailed*
- 14 Retailer state is *AgriFoodDeliveryFailure*
- 15 Send a ‘failure’ notification to all participants.
- 16 **end**
- 17 **else**
- 18 Reset contract and displays an error message.
- 19 **end**

Algorithm 3 describes the algorithm for consumers to purchase agricultural food from retailers. First, the consumer’s initial state is *ReadyToBuy*. Thanks to the successful dealings between retailers and distributors, the smart contract state is *SaleRequestAgreedSuccess*, while retailer status is *AgriFoodDeliveredSuccess*. Similarly, smart contracts restrict customers who register with retailer to make purchase requests. The important parameters at this stage are customer address,

retailer address, purchase date, sales ID, and AgriFood ID. When consumers successfully pay agricultural food prices, contract status changes to *AgriFoodSoldToCustomer*, retailer status to *SuccessfulPurchaseAgriFoodSaleSuccess*, and customer status to *SuccessfulPurchase*. If the payment is not successful or the paid price is incorrect, the contract status will be changed to *SaleOfAgriFoodDenied*, the retailer status will be *AgriFoodSaleFailure*, and then the customer status will be changed to *FailedPurchase*.

Algorithm 3 Customer Buys From Retailer

```

Input: Address of Retailer,
        Address of Customer,
        SalesID, AgriFoodID,
        DatePurchased
1 Contractstate is SaleRequestAgreedSuccess
2 State of the retailer is AgriFoodDeliveredSuccess
3 Customer state is ReadyToBuy
4 Restrict access to only Customers
5 if Price = paid then
6     Contract state changes to AgriFoodSoldToCustomer
7     Change State of the retailer to
       SuccessfulPurchaseAgriFoodSaleSuccess
8     Customer state is SuccessfulPurchase
9     Send a 'purchase success' notification.
10 end
11 else
12     Contract state changes to SaleOfAgriFoodDenied
13     State of retailer is AgriFoodSaleFailure
14     Customer state is FailedPurchase
15     Send a 'purchase failure' notification.
16 end
17 else
18     Reset contract and displays an error message.
19 end
    
```

VI. RESULTS AND ANALYSIS

A. APPLICATION EXAMPLE INTRODUCTION

Shanwei Lvfengyuan Modern Agriculture Development Co., Ltd., is committed to crop planting, processing, and agricultural technology promotion services, etc. Based on this, on the basis of the field survey of the enterprise, a smart farm cloud platform was built to manage and track the buckwheat supply chain information. The system adopts browser/server (B/S) structure, uses the VMware virtual machine to deploy the blockchain network, and uses IPFS to store data with the Hyperledger Fabric platform to realize distributed deployment. System development languages include Go, JavaScript, HTML and CSS, with data processing and sending in JSON format based on Nodejs and Bootstrap framework development.

Fig. 8 shows the monitoring interface. Video monitoring equipment and high-definition cameras are installed on the farm. The administrator can remotely view and monitor the



FIGURE 8. Monitoring interface.

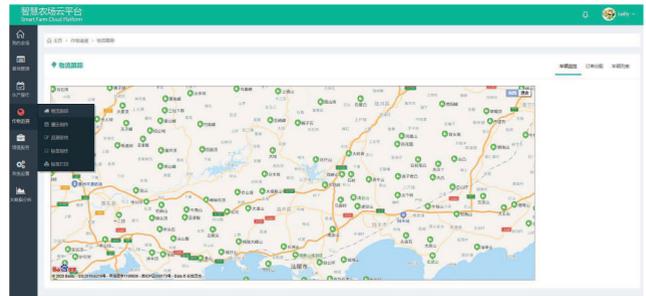


FIGURE 9. Traceability interface.

绿丰源纯天然无添加荞麦

生产时间：2020年3月23日

生产厂家：绿丰源公司

香味浓郁 营养健康



FIGURE 10. Traceability QR code.

crop situation and agricultural production situation in real time. For the sake of reducing the use of agricultural pesticides and ensuring the safety of agricultural food, the early warning function for diseases and pests was designed. An image recognition algorithm was adopted to match a large number of image libraries of diseases and pests to quickly and accurately identify pests for early warning and prevention.

Fig. 9 shows the crop traceability process, including uploading crop information and creating a QR code and attaching it to the crop package. When the crops are transported to the next link, the logistics manager can also check them in the background, so as to clearly understand the flow direction of the crops. In case of any problems, crops can be locate quickly and rapidly recalled, thus effectively avoiding the spread of crops with problems and greater losses being suffered by the enterprise.

The information on the final product packaging purchased by the consumer includes not only the product name, production time and manufacturer's name but also a pasted



FIGURE 11. Tracing the specific information of buckwheat.

traceable QR code, such as the buckwheat traceability QR code generated by the above platform as shown in Fig. 10. Upon scanning the QR code, the information shown in Fig. 11 will appear, including planting information, farm information, enterprise qualification and on-link information, etc. This platform can trace the entire life cycle of buckwheat from planting to consumer, and guarantee the consumers' right to know almost all information. The cultivation, production and processing of transparent buckwheat increase the trust between consumers and enterprises. Meanwhile, the application of blockchain technology also prevents data tampering. In general, the platform built based on blockchain technology realizes buckwheat information traceability, which increases the trust between consumers and maximizes the interests of both sides while also

providing reference significance for various researchers and enterprises.

B. COST ANALYSIS AND PROBLEM DISCUSSION

Smart contracts in Ethereum exist in the form of accounts. The successful deployment of a smart contract will create a smart contract account. After that, the smart contract is called, that is, a transaction is initiated to the smart contract account, which consumes a number of gas. Gas is the unit of calculation for all calculations in Ethereum. In [3] and [29], the authors used Ethereum smart contracts to solve the researched problems, and conducted detailed testing and analysis. The results showed that the use of Ethereum smart contracts can cost-savings and increase stakeholder profits. However, unlike the Ethereum smart contract, the Hyperledger smart contract is directly deployed on each node without built-in tokens, so it does not need to consume tokens to terminate the execution of the smart contract. The payment model of Ethereum can avoid the abuse of resources. Once you have to pay for each operation, you will write the code as concise and efficient as possible; the existence of Gas can also prevent attackers from flooding the Ethereum network through invalid operations (unless the attacker is willing to pay a large sum of money to perform invalid operations), but if the gas is consumed, the contract will fail to execute and the consumed fee will not be refunded. The Hyperledger smart contract uses a timer scheme, which uses time as a standard to measure whether a contract has entered an infinite loop: if the contract has not terminated normally before the timeout period is reached, then it is considered to have entered an infinite loop and forced to terminate. Therefore, the Hyperledger smart contract can save resource consumption. Although the timer can partially solve the downtime problem, in a distributed system, the execution time of each node may not be guaranteed to be consistent, and the performance and load of each node are different, resulting in the judgment of whether the contract runs overtime. Inconsistencies occur, which greatly increases the failure rate of the consensus algorithm, which is an important disadvantage of the timer solution.

In addition, smart contracts also have some common security issues, which reduce the security guarantees for constructing agricultural food traceability systems. Firstly, smart contracts cannot be modified once deployed, so they are vulnerable to security vulnerabilities. Secondly, the open source code of smart contracts reduces the attack cost of hackers and becomes vulnerable to attacks. Finally, due to the late start and short development time of smart contracts, there are still some shortcomings, such as the lack of rigorous code will cause loopholes. Therefore, in the future, research can be conducted on these security issues of smart contracts.

VII. CONCLUSION

We propose a framework for tracking and executing transactions by using hyperledger smart contracts, which changes the centralized model, eliminates intermediaries and

intermediate nodes, and realizes the decentralized model of the agricultural food supply chain, thus meeting the demand for traceability of agricultural food. With respect to agricultural food safety problems, this paper expounds the importance of food safety traceability, summarizes related research, introduces blockchain and consortium chain, and presents a framework using hyperledger smart contracts to track and implement the agricultural food trade; it presents system architecture design and describes the relationship between the agricultural food supply chain entities and the interaction between entities. In the end, the smart contracts algorithms are implemented in order to realize tracking and tracing of the agricultural food supply chain, and the practical application in Shanwei Lvfynguan Modern Agricultural Development Co., Ltd., is introduced, cost analysis and problem discussion. However, regarding the existing problems of blockchain scalability, privacy and regulation, we have presented a solution which does not take into account the reliability and auditability of data transactions and payments, and with the development of the agricultural food supply chain, the decentralized automatic payment mechanism is needed to ensure that all system entities abide by the promise of deficiencies in the deal. As a goal of our future work, we plan to study related problems and to be able to ameliorate and solve them.

REFERENCES

- [1] X. Zhang, P. Sun, J. Xu, X. Wang, J. Yu, Z. Zhao, and Y. Dong, "Blockchain-based safety management system for the grain supply chain," *IEEE Access*, vol. 8, pp. 36398–36410, 2020.
- [2] K. Salah, N. Nizamuddin, R. Jayaraman, and M. Omar, "Blockchain-based soybean traceability in agricultural supply chain," *IEEE Access*, vol. 7, pp. 73295–73305, 2019.
- [3] S. Wang, D. Li, Y. Zhang, and J. Chen, "Smart contract-based product traceability system in the supply chain scenario," *IEEE Access*, vol. 7, pp. 115122–115133, 2019.
- [4] F.-F. Hu and Z.-H. Wu, "Research on grain supply chain mode innovation: A case study of China non-primary grain-yielding areas," in *Proc. Int. Conf. Manage. Service Sci.*, Aug. 2010, pp. 1–4.
- [5] C. Chen, J. Zhang, and T. Delaurentis, "Quality control in food supply chain management: An analytical model and case study of the adulterated milk incident in China," *Int. J. Prod. Econ.*, vol. 152, pp. 188–199, Jun. 2014.
- [6] Y. P. Tsang, K. L. Choy, C. H. Wu, G. T. S. Ho, and H. Y. Lam, "Blockchain-driven IoT for food traceability with an integrated consensus mechanism," *IEEE Access*, vol. 7, pp. 129000–129017, 2019.
- [7] X. Li, F. Lv, F. Xiang, Z. Sun, and Z. Sun, "Research on key technologies of logistics information traceability model based on consortium chain," *IEEE Access*, vol. 8, pp. 69754–69762, 2020.
- [8] H. Xu, Q. He, X. Li, B. Jiang, and K. Qin, "BDSS-FA: A blockchain-based data security sharing platform with fine-grained access control," *IEEE Access*, vol. 8, pp. 87552–87561, 2020.
- [9] S. Li, T. Qin, and G. Min, "Blockchain-based digital forensics investigation framework in the Internet of Things and social systems," *IEEE Trans. Comput. Social Syst.*, vol. 6, no. 6, pp. 1433–1441, Dec. 2019.
- [10] L. Wang, Z. Hu, S. Liu, Z. Zheng, L. Cao, L. Xu, and X. Li, "Application of non-orthogonal multiple access for IoT in food traceability system," in *Proc. IEEE 4th Adv. Inf. Technol., Electron. Autom. Control Conf. (IAEAC)*, vol. 1, Dec. 2019, pp. 104–109.
- [11] J. Al-Jaroodi and N. Mohamed, "Blockchain in industries: A survey," *IEEE Access*, vol. 7, pp. 36500–36515, 2019.
- [12] B. Yong, J. Shen, X. Liu, F. Li, H. Chen, and Q. Zhou, "An intelligent blockchain-based system for safe vaccine supply and supervision," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 102024.
- [13] G. Tripathi, M. A. Ahad, and S. Paiva, "S2HS—A blockchain based approach for smart healthcare system," *Healthcare*, vol. 8, no. 1, Mar. 2020, Art. no. 100391.
- [14] J. Chen, Z. Lv, and H. Song, "Design of personnel big data management system based on blockchain," *Future Gener. Comput. Syst.*, vol. 101, pp. 1122–1129, Dec. 2019.
- [15] M. Yang, T. Zhu, K. Liang, W. Zhou, and R. H. Deng, "A blockchain-based location privacy-preserving crowdsensing system," *Future Gener. Comput. Syst.*, vol. 94, pp. 408–418, May 2019.
- [16] Z. Liu and Z. Li, "A blockchain-based framework of cross-border e-commerce supply chain," *Int. J. Inf. Manage.*, vol. 52, Jun. 2020, Art. no. 102059.
- [17] G. Baralla, A. Pinna, and G. Corrias, "Ensure traceability in European food supply chain by using a blockchain system," in *Proc. IEEE/ACM 2nd Int. Workshop Emerg. Trends Softw. Eng. Blockchain (WETSEB)*, May 2019, pp. 40–47.
- [18] W. Yu and S. Huang, "Traceability of food safety based on block chain and RFID technology," in *Proc. 11th Int. Symp. Comput. Intell. Design (ISCID)*, vol. 1, Dec. 2018, pp. 339–342.
- [19] F. Tian, "An agri-food supply chain traceability system for China based on RFID & blockchain technology," in *Proc. 13th Int. Conf. Service Syst. Service Manage. (ICSSSM)*, Jun. 2016, pp. 1–6.
- [20] A. Vangala, A. K. Das, N. Kumar, and M. Alazab, "Smart secure sensing for IoT-based agriculture: Blockchain perspective," *IEEE Sensors J.*, early access, Jul. 27, 2020, doi: 10.1109/JSEN.2020.3012294.
- [21] N. Bore, A. Kinai, P. Waweru, I. Wambugu, J. Mutahi, E. Kemunto, R. Bryant, and K. Weldemariam, "ADW: Blockchain-enabled small-scale farm digitization," 2020, *arXiv:2003.06862*. [Online]. Available: <http://arxiv.org/abs/2003.06862>
- [22] H. B. Li, B. Zhang, L. Zhang, Y. Xue, M. He, and C. Ren, "A food traceability framework for dairy and other low-margin products," *IBM J. Res. Develop.*, vol. 60, nos. 5–6, pp. 10.1–10.8, Sep./Nov. 2016.
- [23] Z. De-An, T. Cui-Feng, and W. Xian-Wang, "Design of traceability system for pork safety production based on RFID," in *Proc. 2nd Int. Conf. Intell. Comput. Technol. Autom.*, vol. 3, Oct. 2009, pp. 562–565.
- [24] Z. Yiyi, R. Yuanlong, L. Fei, S. Jing, and L. Song, "Research on meat food traceability system based on RFID technology," in *Proc. IEEE 3rd Inf. Technol., Netw., Electron. Autom. Control Conf. (ITNEC)*, Mar. 2019, pp. 2172–2175.
- [25] S. Mondal, K. P. Wijewardena, S. Karuppuswami, N. Kriti, D. Kumar, and P. Chahal, "Blockchain inspired RFID-based information architecture for food supply chain," *IEEE Internet Things J.*, vol. 6, no. 3, pp. 5803–5813, Jun. 2019.
- [26] F. Tian, "A supply chain traceability system for food safety based on HACCP, blockchain & Internet of Things," in *Proc. Int. Conf. Service Syst. Service Manage.*, Jun. 2017, pp. 1–6.
- [27] J. Hao, Y. Sun, and H. Luo, "A safe and efficient storage scheme based on blockchain and IPFS for agricultural products tracking," *J. Comput.*, vol. 29, no. 6, pp. 158–167, 2018.
- [28] Q. Lin, H. Wang, X. Pei, and J. Wang, "Food safety traceability system based on blockchain and EPCIS," *IEEE Access*, vol. 7, pp. 20698–20707, 2019.
- [29] I. A. Omar, R. Jayaraman, K. Salah, M. Debe, and M. Omar, "Enhancing vendor managed inventory supply chain operations using blockchain smart contracts," *IEEE Access*, vol. 8, pp. 182704–182719, 2020.
- [30] H. Zhang, E. Deng, H. Zhu, and Z. Cao, "Smart contract for secure billing in ride-hailing service via blockchain," *Peer-Peer Netw. Appl.*, vol. 12, no. 5, pp. 1346–1357, Sep. 2019.
- [31] S. Xuan, L. Zheng, I. Chung, W. Wang, D. Man, X. Du, W. Yang, and M. Guizani, "An incentive mechanism for data sharing based on blockchain with smart contracts," *Comput. Electr. Eng.*, vol. 83, May 2020, Art. no. 106587.
- [32] R. Tso, Z.-Y. Liu, and J.-H. Hsiao, "Distributed E-voting and E-bidding systems based on smart contract," *Electronics*, vol. 8, no. 4, p. 422, Apr. 2019.
- [33] R. Kamath, "Food traceability on blockchain: Walmart's pork and mango pilots with IBM," *J. Brit. Blockchain Assoc.*, vol. 1, no. 1, pp. 1–12, Jul. 2018.
- [34] A. Shahid, A. Almogren, N. Javaid, F. A. Al-Zahrani, M. Zuair, and M. Alam, "Blockchain-based agri-food supply chain: A complete solution," *IEEE Access*, vol. 8, pp. 69230–69243, 2020.
- [35] S. Wang, Y. Zhang, and Y. Zhang, "A blockchain-based framework for data sharing with fine-grained access control in decentralized storage systems," *IEEE Access*, vol. 6, pp. 38437–38450, 2018.

[36] S. Zhang, M. Pu, B. Wang, and B. Dong, "A privacy protection scheme of microgrid direct electricity transaction based on consortium blockchain and continuous double auction," *IEEE Access*, vol. 7, pp. 151746–151753, 2019.

[37] X. Zhang and D. Wang, "Adaptive traffic signal control mechanism for intelligent transportation based on a consortium blockchain," *IEEE Access*, vol. 7, pp. 97281–97295, 2019.

[38] Z. Jin, R. Wu, X. Chen, and G. Li, "Charging guiding strategy for electric taxis based on consortium blockchain," *IEEE Access*, vol. 7, pp. 144144–144153, 2019.

[39] Z. Yu, D. Xue, J. Fan, and C. Guo, "DNSTSM: DNS cache resources trusted sharing model based on consortium blockchain," *IEEE Access*, vol. 8, pp. 13640–13650, 2020.

[40] W. She, Z.-H. Gu, X.-K. Lyu, Q. Liu, Z. Tian, and W. Liu, "Homomorphic consortium blockchain for smart home system sensitive data privacy preserving," *IEEE Access*, vol. 7, pp. 62058–62070, 2019.

[41] X. Zeng, N. Hao, J. Zheng, and X. Xu, "A consortium blockchain paradigm on hyperledger-based peer-to-peer lending system," *China Commun.*, vol. 16, no. 8, pp. 38–50, Aug. 2019.

[42] Y. Jiang and S. Ding, "A high performance consensus algorithm for consortium blockchain," in *Proc. IEEE 4th Int. Conf. Comput. Commun. (ICCC)*, Dec. 2018, pp. 2379–2386.



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