Blockchain and smart contract for IoT enabled smart agriculture (#54436)

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Blockchain and smart contract for IoT enabled smart agriculture

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The agricultural sector is still lagging behind from all other sectors in terms of using the newest technologies. For production, the latest machines are being introduced and adopted. However, pre-harvest and post-harvest processing are still done by following traditional methodologies while tracing, storing, and publishing agricultural data. As a result, farmers are not getting deserved payment, consumers are not getting enough information before buying their product, and intermediate person/processors are increasing retail prices. Using blockchain, smart contracts, and IoT devices, we can fully automate the process while establishing absolute trust among all these parties. In this research, we explored the different aspects of using blockchain and smart contracts with the integration of IoT devices in pre-harvesting and post-harvesting segments of agriculture. We proposed a system that uses blockchain as the backbone while IoT devices collect data from the field level, and smart contracts regulate the interaction among all these contributing parties. The system implementation has been shown in diagrams and with proper explanations. Gas costs of every operation have also been attached for a better understanding of the costs. We also analyzed the system in terms of challenges and advantages. The overall impact of this research was to show the immutable, available, transparent, and robustly secure characteristics of blockchain in the field of agriculture while also emphasizing the vigorous mechanism that the collaboration of blockchain, smart contract, and IoT presents.

Blockchain and Smart Contract for IoT Enabled Smart Agriculture

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ABSTRACT

The agricultural sector is still lagging behind from all other sectors in terms of using the newest technologies. For production, the latest machines are being introduced and adopted. However, pre-harvest and post-harvest processing are still done by following traditional methodologies while tracing, storing, and publishing agricultural data. As a result, farmers are not getting deserved payment, consumers are not getting enough information before buying their product, and intermediate person/processors are increasing retail prices. Using blockchain, smart contracts, and IoT devices, we can fully automate the process while establishing absolute trust among all these parties. In this research, we explored the different aspects of using blockchain and smart contracts with the integration of IoT devices in pre-harvesting and post-harvesting segments of agriculture. We proposed a system that uses blockchain as the backbone while IoT devices collect data from the field level, and smart contracts regulate the interaction among all these contributing parties. The system implementation has been shown in diagrams and with proper explanations. Gas costs of every operation have also been attached for a better understanding of the costs. We also analyzed the system in terms of challenges and advantages. The overall impact of this research was to show the immutable, available, transparent, and robustly secure characteristics of blockchain in the field of agriculture while also emphasizing the vigorous mechanism that the collaboration of blockchain, smart contract, and IoT presents.

INTRODUCTION

Steady food supply across the world is solely dependent on agricultural activities around the world. The whole process of cultivation involves a lot of direct and indirect actors. Farmers, agricultural product sellers, and manufacturers are directly involved with the framework of cultivation. Furthermore, indirect actors are people who are depending on the production, e.g., the people who buy them to eat or use them as raw material to produce other variations of food or product. The process of agriculture is divided into two segments, the pre-harvest, and the post-harvest segment. The pre-harvest segment is basically the cultivation process. And, post-harvest is composed of distribution and open market consumption of agricultural goods. However, the process gets initiated when seeds are brought to the storage. Seed storage has an enormous effect on seed quality, and seed quality has a direct impact on production. So, it is vital that seed storages are bought under monitoring. Data collection and regular interpretation of those data is a must to ensure a quality maintaining seed storage. Data should also be collected from cultivation fields for finding further insights. Distribution and market prices need proper monitoring. Ensuring the availability of traceable data for consumers is also necessary. Blockchain has already proven its capability in terms of safety where smart contracts bring automation, remove intermediate actors, and ensure proper regulation over the process. We can improve the overall agricultural system, which is also the primary motivation for this research.

Agricultural process in the pre-harvest segment includes processing the soil for seeding by sowing and watering, then adding fertilizers and composts, and the rest of the process involves irrigation and constant care-taking while expecting a fair amount of resulting crop to be harvested. However, it's not the case every time that a farmer ends up with the expected quantity of production even after following the appropriate orders and method of cultivation. Several factors might be involved in not having an expected amount of production, for instance, soil quality, low-grade seed and fertilizers, sudden drought or flood. Whichever among these reasons are causing low production of crops or sometimes completely demolishing the production, the farmers are always the one to hit hard and suffer. Farmers are always in a constant state of risk starting from the very beginning of cultivation until he sells his product. Contrarily, the farmers are the lowest paid seller in the whole chain. The price in retail shops is much higher, sometimes twice or thrice, than that the price sold by the farmers. Although, the heart of the agricultural structure are the farmers, who keep the wheel of agriculture running.

Many farmers get disrupted, and they are not specialized in any other sector, which might have helped them for a swift profession shift. This condition of farmers creates depression, anxiety, and helplessness, often resulting in a very frustrating incident like suicide. A scoping review by Hagen et al. (2019) shows that approximately 225 million farmers in a year suffer from mental illness worldwide, where stress was most frequently found among farmers with a factor of 41.9%, followed by suicide with a factor of 33.1%. Nicole et al. (2020) showed that the suicide rate among farmers was increased to 37% between 2011-2017 in New Zealand.

The post-harvest part is significantly associated with the open market business. Agribusinesses are mainly targeted towards the consumers. The consumers around the world demand total identification and verification of agriproducts for better judgments of the products they buy from retail shops. The sudden growth of food-related hazards, diverse location of cultivation, and genetically modified organisms (GMO) have created a sense of awareness for which the consumer community nowadays is more conscious about having substantial evidence of the agriproducts being safe and nutritious. (Opara 2003). On the other hand, the pricing of the product varies on different layers of distribution, which needs more central control. There is a big question of which actor should be given what price in the range varying from farmers to retail shops.

What does “this” refer to? Starting a paragraph with “For ensuring this” can cause ambiguity”.

For ensuring this, it is vital to trace the agriproduct starting from the inception point of seed storage, passing through the whole process of cultivation, and finally reaching the hands of mass. Agriproducts that the consumer buys should have concrete verifiable data, and the data will not only increase transparency but can also be used to monitor and manipulate the system. For instance, the quality of seed and the optimum environment for seed storage have an impact on food production. According to Kumar and Kalita (2017), approximately 50%-60% of cereal grain can be lost due to the low maintenance of seeds. Pradhan and Badola (2012) showed how different storage conditions and storage period affects the seed germination process of Swertia chirayita, a Himalayan plant. Contrarily, they found that 4° is the optimum temperature for storing this seed for a long time. (Pradhan and Badola 2012) So, there is a clear need for using technology that monitors the environment of storages that stores the seed and other agricultural products (e.g., fertilizer, pesticides).

Solving these problems in the agricultural system is very important in order to keep continuous food supply running without facing the global food shortage. Technology like blockchain (Nakamoto 2019), along with Smart contracts (Szabo 1997) integrated with IoT (Internet of Things) devices, can solve these problems by providing a distributed network of connected sellers and buyers. An organization or suitable authority will monitor all the relative information in the system and set the prices of agricultural goods and services. IoT devices will monitor the quality of seed and fertilizer and trigger events in the Blockchain network if anything goes wrong along the process of farming. The smart contract will be deployed inside the Blockchain network so that it cannot be changed or tampered by anyone. The business terms and conditions applied in agricultural transactions become solid and immutable.

The main contribution of this paper is as follows.

- Ensure traceability of agricultural products from root to retail.
- Ensure temper proof data acquisition from storage, field level, and while distributing.
- Remove intermediate processors and controlling market prices.
- Gain more control over the process by Smart Contracts.
- Automation of the process while removing intermediate third-party processors.
- And lastly, secure environment implementation with blockchain for better security of valuable data.

The paper is arranged in 6 sections and several sub-sections. The rest of the paper is arranged in the following manner. Section 2 contains the literature review where we have discussed blockchain, smart contracts, IoT devices while focusing on using these technologies to improve processes and enhance security. Section 3 contains an extensive overview and the design of our system. How blockchain and the other supporting tools like MQTT network protocol and IoT devices interact with the system have been described in this section. Section 4 includes the implementation and testing where we have shown the implementation details along with the algorithms that we have used. The system test outputs have been displayed in this section. In section 5, we have analyzed our model in terms of advantages and disadvantages. We also showed a gas cost analysis of the operations. Finally, the conclusion section (section 6) contains the outcomes and future research directives.

LITERATURE REVIEW

Blockchain and smart contracts have already proven its capability for process development that requires transparency and concrete evidence-based record keeping. While blockchain establishes a sturdy trust, the smart contract makes sure that the necessary logics and rules are implemented automatically without human manipulation and intervention from a third-party. On the other hand, IoT devices provide excellent technical support when it comes to monitoring a process by collecting and sending data over the network. This section will be doing a comprehensive literature review of blockchain, smart contract, and their ability in terms of tracing, monitoring, and overall development of real-world scenarios.

Blockchain

Blockchain is a disruptive technology that has been entitled as the ”the most important technology since the internet itself” by an influential Silicon Valley Capitalist Marc Andreessen. (Crosby et al. 2016) This extremely robust technology is well described by the naming of itself. Blockchain is nothing but a chain of connected and verified blocks where each block contains some transaction data (generally represented as Merkle tree) and the cryptographically hashed address of the previous block along with the timestamp. (Zheng et al. 2017) The first block is named the genesis block. The structure of the blockchain is shown in figure 1.

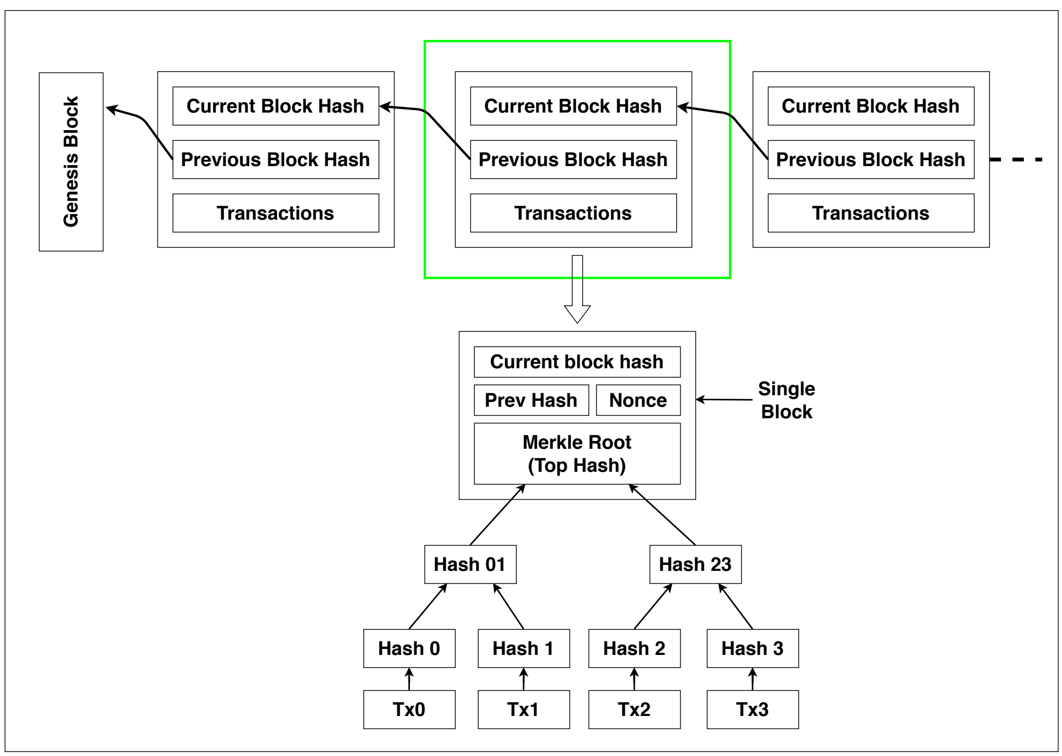

Figure 1. Structure of Blockchain.

The most popular and well-known usage of blockchain goes by the name of bitcoin. An unknown quantity of people under the name Satoshi Nakamoto first published the whitepaper of bitcoin on 31st October 2008 (Nakamoto 2019), and the first business implementation was in action in the following year. Timestamping the digital payments by the use of cryptographic hash is the paramount convenience of blockchain. On the other hand, blockchain solves some significant problems in digital payments. Double spending is the idea of spending the same digital payment token more than once. The dilemma of double spending is created by making false claims and distorting information to create a disguise. (Hoepman 2010) However, blockchain strictly handles this situation and does not allow any distortion in the data to be stored in the blockchain. This tamper-proof mechanism is implemented through a distributed consensus algorithm. (Nakamoto 2019) Every transaction is validated by most of the users connected in that blockchain network. So falsifying information is nearly impossible in blockchain technology. After the first block (The genesis block), each and every block is added through distributed consensus along with the cryptographic footprint and timestamp. (Nofer et al. 2017) This information is updated in every user node connected to the blockchain. So, double spending becomes absurd with the usage of blockchain technology. Transaction in the blockchain is shown in figure 2.

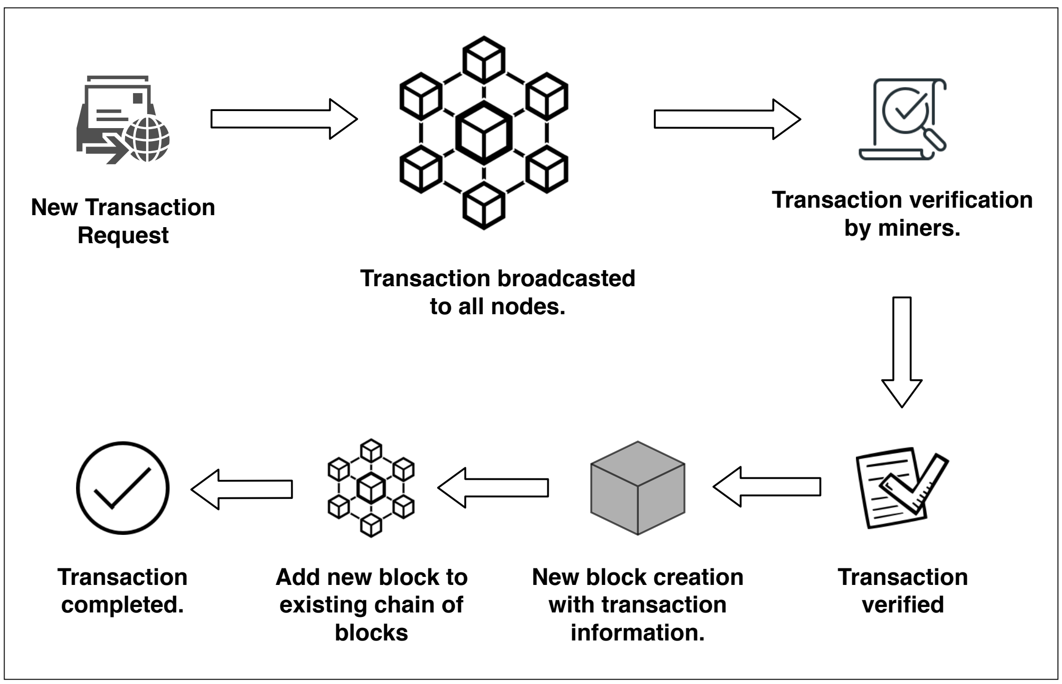

Figure 2. Transaction in blockchain.

Blockchain has specific characteristics which are not only applicable for securing digital payments but also suitable for abolishing third-party based trust models in businesses and organizations. (Nofer et al. 2017). While using blockchain, third-party as a financial processor is no longer required. The process is automated through smart contracts and tamper proofed by the blockchain itself. Each transaction history is logged into the blockchain and accessible at any time in the future. (Nofer et al. 2017) The research community is working on applying this technology for real-world problems that require more sophistication in the transaction and payment process. Blockchain seems to have great potential in the future of digital transactions for use cases like insurance (Raikwar et al. 2018; Lamberti et al. 2018) and banking (Eyal 2017; Peters and Panayi

2016). Blending real-world online payment systems with blockchain often bring about the problem of scalability in terms of the number of transactions and computational power. Studies now prove that implementing blockchain-based systems with a feasible number of payments and computational power can be done (Zhang et al. 2018) while also establishing scalability by reducing block weight and ledger size in global peers. (Biswas et al. 2019) Another problem in digital platforms is the gap between payment and receiving goods or services in exchange, which is known as payment lead time. Chang et al. (2019), showed a process of re-engineering the supply chain using the blockchain technology while reducing payment lead time in the digital payment system. Thus, blockchain presents splendid capability for online transactions in terms of security and transparency while eliminating the existing complications in digital payment systems.

Contrarily, blockchain shows immense prospect in the sectors that do not necessarily involve digital payments but uses the characteristics of blockchain, for instance, distinctions of types(public, private, permissioned), access control (centralized, decentralized), persistency, validity, identity control, transparency control(closeness or openness), superior security. (Zheng et al. 2018) A practical implementation of blockchain-b[illegible] agri-food traceability has been shown by Caro et al. (2018). They showed how a transparent, fault-tolerant, immutable, and audible tracing could be done using blockchain and IoT devices. Manupati et al. (2020) showed how the use of a distributed ledger system of blockchain reduces total cost as well as carbon emission in a multi-echelon supply chain. Blockchain has been used in storing and processing information. File security in the blockchain is far better than any other existing cloud storage system, while the transmission delay is significantly lower. (Li et al. 2018) File loss rate in currently available cloud storage architectures can be up to 100%, where it is nearly 0% in the blockchain.(Li et al. 2018) Decentralized storage (Blockchain) of Interplanetary file system to store and share industrial spare parts data has been implemented by Hasan et al. (2020). By far, blockchain is the most secure way to deal with any kind of data. Substantial security in the mobile cloud data of Electronic Patient Record Systems (EPRs) is shown by Nguyen et al. (2019) using blockchain technology. Implementing blockchain in real-world use cases shows excellent future potential, as discussed in this section.

Remove “a”

The essential idea of blockchain was to create a robust online transaction system. Blockchain’s fundamental aspects have presented so many sturdy prospects of excellent technical support over distributed systems in terms of security and transparency. However, blockchain does not have an integrated system for automatically processing the data in a distributed system. We can achieve this by integrating a smart contract with blockchain.

[illegible]t Contract

Use “is called” instead of “we”.

[illegible] help of blockchain, we can assuredly discard intermediaries, but the promises [illegible] boundaries between the contributing parties frequently present the requirement of what we call a smart contract. (Macrinici et al. 2018) Like traditional contracts, the smart contract is also a collection of organizational terms and conditions that regulate the trust between the parties involved within the scope of that contract. The only difference is that a smart contract is coded with a programming language. The rules, terms, and conditions are implemented via controlled coding, reflecting the exact agreement approved by all the parties. (Szabo 1997)

The idea of smart contracts was there from the 1980s, but the only thing it lacked was the removal of intermediaries. Nick Szabo first published the whitepaper of smart contracts in 1996. According to Nick,

"The basic idea of smart contracts is that many kinds of contractual clauses (such as liens, bonding, delineation of property rights, etc.) can be embedded in the hardware and software we deal with, in such a way as to make breach of contract expensive (if desired, sometimes prohibitively so) for the breacher." (Szabo 1996)

So, the main objective of smart contract was to embed the contractual clauses inside a combination of hardware and software so that breaching becomes difficult, and the cost of a contractual breach becomes prohibitive, ultimately increasing the safety of contracts and decreasing the possibility of an attack. The idea of smart contracts and the real-life implementation of it was popularized in 2016 by Ethereum blockchain. Ethereum is a decentralized Turing-complete blockchain which has integrated tools and environment for implementing smart contracts. (Nakamoto 2008) The gap that Ethereum has filled has made Nick Szabo's statement possible in a real-life scenario. Szabo described smart contracts as a "contractual breach cost increasing mechanism" that reflects the actual contract. As Ethereum itself is a blockchain, storing the contract inside the blockchain makes it tremendously challenging to break in and tamper with the contract. A typical smart contract building and its execution steps are shown in figure 3.

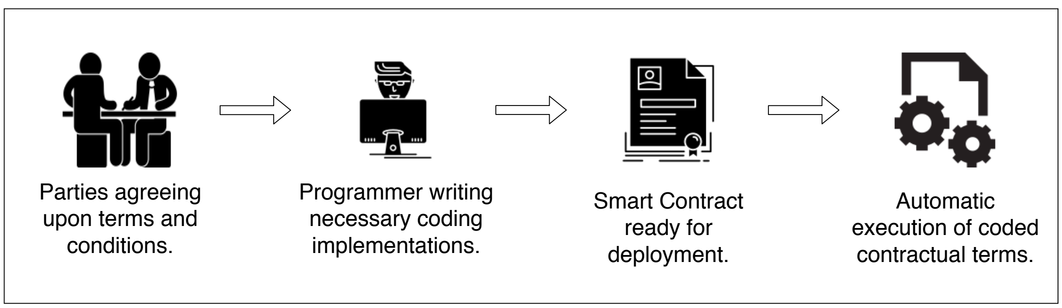

Figure 3. Steps of building a typical smart contract.

A smart contract, in other words, is the automation mechanism of blockchain technology. This very idea of storing the contract inside the blockchain has opened the door to several other implementation possibilities of blockchain in real-world problems. Chang et al. (2019) uses smart contracts as their core of system design to automate the processes involved within the system. The automation includes the real-time tracing of products in a supply chain and overall control over all the steps involved. Hasan et al. (2020) integrates smart contracts in their industrial spare parts traceability research work to implement the necessary function, modifiers, and events inside their proposed system, which mainly controls the logical flows that automate the process by using the smart contract.

The essential need for trust establishment be[illegible]e achieved through smart contracts by securing the contract inside [illegible]. (Bader et al. 2019) has proposed an implementation of a smart contract-based car insurance ecosystem named CAIPY in which the smart contracts implements step by step process of the insurance policy as well as interacts with the tamper-proof IoT devices for keeping information about the car condition. Intellectual rights management can be done using smart contracts. Zhao and O'Mahony (2018) show the implementation of a music copyright management system named BMCProtector that uses blockchain and smart co… contract in their system implements the necessary function starting … yalty distribution. As the contract has been distributed inside … possible to break in and change it, which justifies absolute … a smart contract inside the blockchain environment. (Bader et al. … and … ahony 2018)

Sections will mean previous sections in the paper. Use "usecases or implementations" to make it clear what is being referred.

From the above two sections, it is quite clear that the combination of blockchain and smart contract results in an ingenious, automated, and highly secured system. While blockchain provides a robust platform to store and track the system's data, a smart contract implements the business logic and controls the access distribution. In our project, several necessary data come from outside the system. We intend to use IoT sensors for this purpose.

Blockchain, IoT, and Smart Contract for traceability and process development

A smart contract, united with blockchain and integration of IoT devices, has been proven as a smart, secure, and reliable course of action to trace and monitor over processes and operations. Without these technologies, the current scenario lacks a well-proved medium for tracing or monitoring systems while contributing significantly to the quality control and development of the process with robust security. Smart contracts have opened a door towards this development with all the necessary digital means of support intending to automate the tracing process and establish a trustless rigid contract between parties involved. One of the major drawbacks in the traditional process management and traceability is that the data can be manipulated at any stage, and there is no security that the business rules will be strictly followed in the future.

To secure data inside the blockchain, accumulation must be done in the first place. IoT devices have already been proven excellent for monitoring and collecting data with low power and minimum cost. (Pavithra and Balakrishnan 2015; Tapashetti et al. 2016; Baranwal et al. 2016). Effective and cost-friendly home automation using IoT devices has been implemented by Pavithra and Balakrishnan (2015). A low-cost air quality monitor system that collects data from open-air and analyzes the data is an adequate use of IoT devices which has been shown by Tapashetti et al. (2016). Although IoT-based devices have many issues regarding information security (Miloslavskaya and Tolstoy 2019; Vashi et al. 2017), using blockchain as the secured backbone solves these issues. (Mohanty et al. 2020)

Traceability of a supply chain or production using IoT, Blockchain, and Smart Contracts can resolve many business processes to make them smooth and save our valuable time. The research community also has much interest in integrating those technologies to solve some life-associated problems. Kim et al. (2018) showed how to design a food traceability system using IoT, integrate with blockchain, and smart contract. Lin et al. (2018) showed how Blockchain and IoT based food traceability models could be introduced in the smart agriculture ecosystem. A case study conducted by Lucena et al. (2018) shows that the grain quality assurance tracking using a real scenario with a Blockchain-based business network, which will append the valuation around 15% of

GM-free soy in the grain exporter business network in Brazil. Tracing supply chain or a process contributes towards the quality of management of these processes. (Chen et al. 2017) proposed a four-layered architecture to improve supply chain management's quality by adopting blockchain, where IoT devices(GPS & Sensors) are applied in the very initial layer. All these researches indicate a positive future of blockchain in the management of supply chains and processes.

The most crucial feature of blockchain is immutability, which can safeguard these accumulated data as no data can be manipulated inside the blockchain without altering the whole sequence or history. (Galvez et al. 2018; Casino et al. 2019) Moreover, real-time tracing of any process can be done using blockchain. (Tian 2017) Complex and sophisticated industrial processes can be automated and tracked by real-time data using blockchain technology. (Westerkamp et al. 2018) Modern-day enterprises require symmetric information flow along the way, proper regulation, and availability of legacy information. To date, blockchain provides the perfect solution to these requirements. (Kim et al. 2019) The advantages of blockchain and smart contracts are being applied to sectors like precast construction (Wang et al. 2020), medical services (Chen et al. 2018), and transportation (Humayun et al. 2020) sector. Wang et al. (2020) uses blockchain to improve the current scenario in precast construction where low fragmentation and scarcity of real-time data becomes a problem. They automated the data sharing process and ensured information traceability and transparency in precast construction. The research community has shown the profound prospects of blockchain ranging from medical record keeping with absolute security (Chen et al. 2018) to intelligent logistic support for transportation systems (Humayun et al. 2020).

Blockchain possesses excellent potential in terms of transparency in food-related processes. (Kamilaris et al. 2019) Better traceability of a food supply chain using blockchain has been shown by Wang et al. (2019). Their system implements a response mechanism for various events for an improved, validated, and guaranteed transaction. In a survey paper, Lin et al. (2020) showed how Blockchain and IoT-based systems contribute to food safety, food security, food quality monitoring, and control to support small-scale farmers. Legacy information is vital for making decisions about a product as food can be categorized and sometimes prohibited for several reasons. Tan et al. (2020) proposed a traceability system for halal food chains to ensure that the food processing steps follow strict measurements so that the food remains halal from frame to fork.

Quality control and quality improvement is a must for sectors like agriculture. The existence of humankind is significantly related to the sustainable food supply. The use of technologies like IoT, Blockchain, and smart contracts will facilitate the improvement of the current scenario in agriculture. These improvements are inevitable to have a traceable, rigid, and secure agricultural process while gaining more control over the whole process.

PROPOSED BLOCKCHAIN-BASED MODEL

System overview

We propose the usage of IoT enabled smart actors for a better mechanism of necessary data flow across the system. IoT devices will be used to monitor the quality and condition of the products stored in the large storehouses. They will also monitor and send data about the pricing of agricultural goods and services for both pre-harvesting and post-harvesting periods. IoT devices will also provide information during the cultivation process. Blockchain is used to safely store this monitored data while a Smart Contract will be used to automate the process, trigger events, and set the necessary implementation of terms and conditions for all the parties. The general system overview is shown in figure 4.

Numbering the steps to represent the order will be more helpful for reader

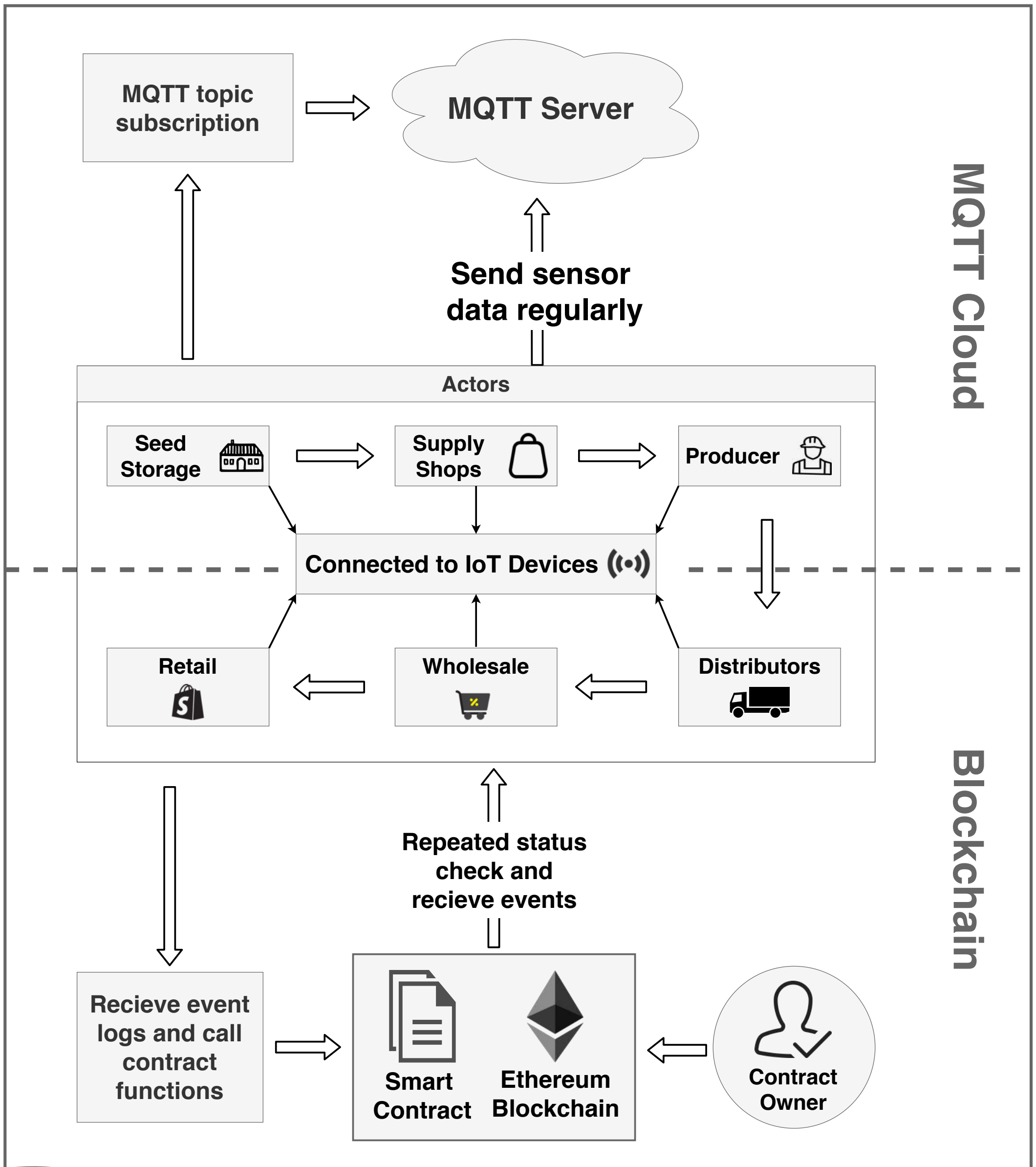

Figure 4. Overall system overview.

MQTT is explained in a section later in Section D of System Design..It will be good if MQTT and reason for choosing it is explained here to set the context.

...n figure 4, the main actors in the system are the storage warehouses, ...pply shops, p...cers, distributors, wholesalers, and retailers. The system actors are connected to an MQTT (Message Queue Telemetry Transport) (Hunkeler et al. 2008) cloud storage by creating a topic-based subscription-publish system. MQTT aids the purpose of storing, sharing, and publishing data that enables aggregation of data among all the parties within our system.

System Design

The system consists of actors like seed storages, supply shops, producers, distributors, wholesalers, and retailers. Another factor here is the contract deployer. Several components will achieve the interaction mechanism between the actors and the system. The role of each actor and components is demonstrated in the sections below.

Actors

The heterogeneity of several actors imposes a common threat of a reliable, immutable, and verifiable system. Our proposed model connects these actors via multiple technological resources. The characteristics of the actors are discussed below.

- **Contract owner** : The contract owner has superior power over the system. The owner deploys the contract on the system and monitors if the regulation has been implemented correctly or not.
- **Seed Storage** : The storages primarily store seed and other agricultural products. Sensitive (sun exposure, temperature) seeds and agricultural products are stored on a large or medium scale in storages for a comparatively long [illegible].
- **Supply Shops**: The supply shops collect a large amount of seeds, [illegible], and all other necessary agricultural products and sell them to the produces. The storage period is shorter for this supply shops.
- **Producers** : The farmers are the primary level producer. They execute all the tasks related to planting and harvesting crops.
- **Distributor** : Distributors are responsible for navigating the crops safely from one place to another.
- **Wholesaler** : The wholesalers buy crops and agriproducts on a large scale and sell them to retailers.
- **Retailer** : Retailers buy the crops and products from the wholesalers and sell them in open markets directly to the consumers on a small scale.
- **Consumer** : Consumers are the mass people who depend on agricultural products and play an essential role in the system by continually creating demand.

The main endeavor is to build a system where these actors interact in such a way that contributes toward the overall traceability of these products.

Components

Several components will be used to implement the system requirements. Blockchain, smart contract, IoT enabled environment, MQTT server is the fundamental components of our system. The components are described below.

A. Blockchain

Blockchain abets the authenticity and reliability of the system. The data accumulated in our system is primarily stored in the MQTT server. MQTT lacks security in some of its steps, where it does not encrypt the data. (Andy et al. 2017) As one of our main motives for this work is to increase the transparency of the trackable data of agricultural products, tamper-proofing the historical data is a must. We use blockchain specifically for this sole purpose. The diagram below(Figure 5) shows the system interaction with the blockchain.

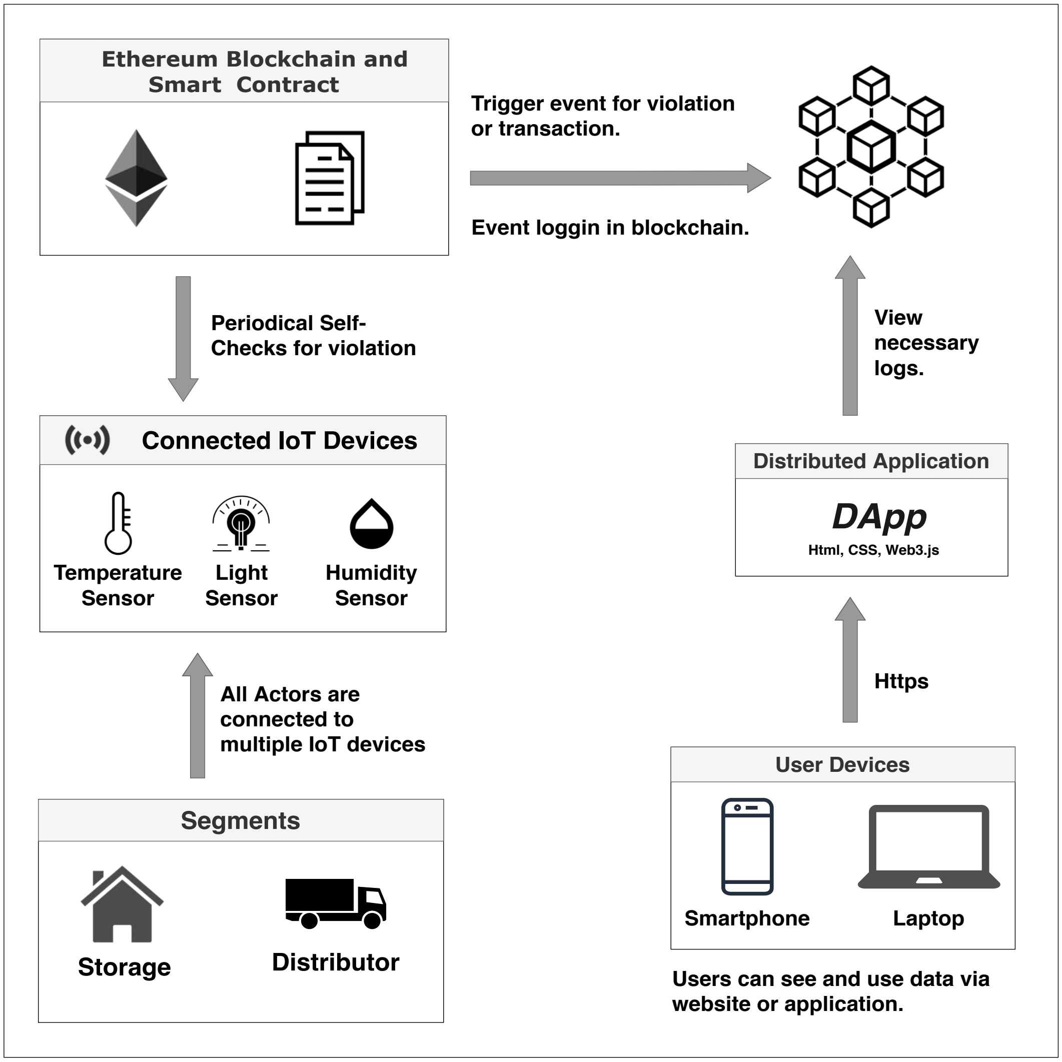

Figure 5. System interaction with blockchain.

Several events are triggered during some essential steps of the agricultural process, and the data is logged into the transaction log of the blockchain. This data can never be changed or tampered with without breaking the chain of blocks. So, traceable data becomes secure with blockchain.

B. Smart Contract

The system implements two smart contracts written in solidity programming language and uses Ethereum based Blockchain technology as the core apparatus of our work. The first contract is for storage, and the second contract is for distribution. The storage contract optimum values ata collection and event logging from the storage that we store in the b he contract can self-check for the data and compare it with the optimum. Based on the result, the contract automatically logs events inside the blockchain, securing verifiable information for future buyers and quality measurements. The second contract is used to track the agriproducts after the production. One of the major problems that our system tries to solve is authenticity in trackability data of agriproducts and making it auditable to the general customers. The second contract can also be used to monitor the pricing. In every step from producer to customer, this contract will keep track of the dates along with the price and quantity sold.

Figure 6 shows the attributes, functions, events, and modifiers that the storage smart contracts hold, possess and implement.

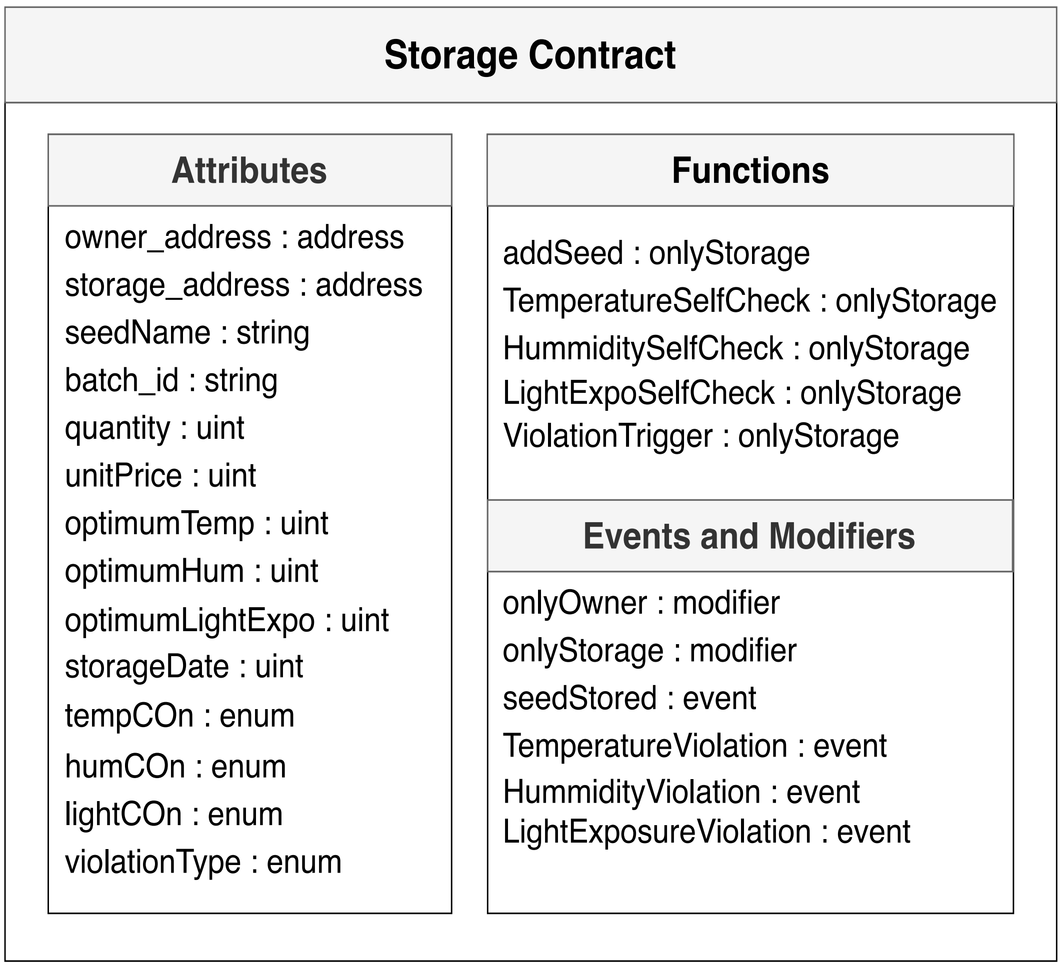

Figure 6. Smart Contracts used for storage in the system.

Figure 7 shows the attributes, functions, events, and modifiers that the distribution smart contracts hold, possess and implement.

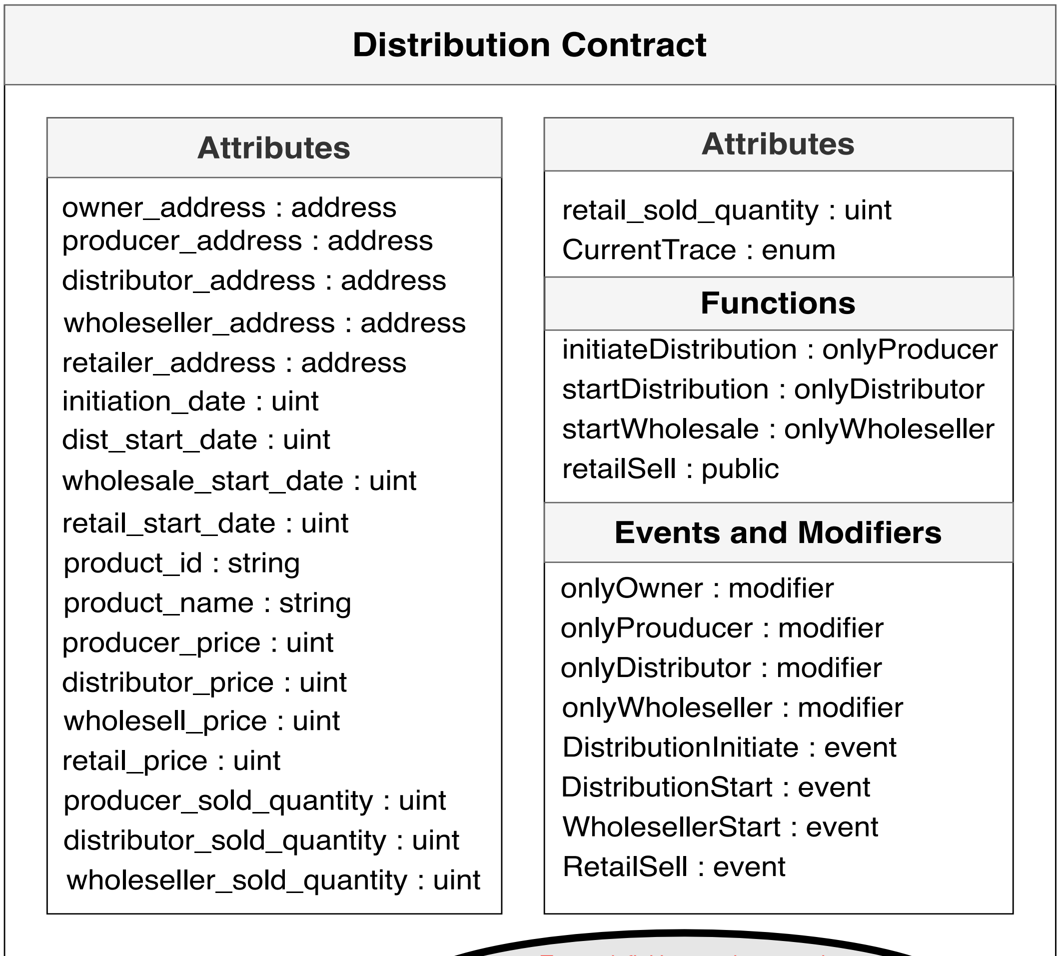

Figure 7. Sma

Terms definition can be moved to section where smart contracts are introduced or to appendix so that flow of system design description is not interrupted.

The meaning of the programming terms used in smart contracts is as follows.

- **Attributes** : Attributes are the storage variables. A solidity programming language allows attributes for different primitive data types (int, char, string, double), mapping, address, and enumerators. Variables will store values like optimum temperature, current temperature, humidity, seed name, and dates.

- **Methods** : Method represents a mechanism or task inside the system. Once a method is called, the task that has been written inside the method body will be executed. The storage contract has methods for self-checking different weather data (temperature, humidity, and light exposure). The distribution contract has methods for tracking the dates of distribution in different levels of the chain.

- **Modifiers**: Modifiers represent the access power on the actors or components. While the contract owner has supreme modification power, other actors or components can be given some specific modification or access power by the contract. In both the contracts we used, several actors like storages, distributors, wholesalers, and producers have been declared modifiers in the contract.

- **Events** : Events can be anything starting from inserting seed information to the blockchain until the consumer buys a product. When an event happens or is emitted, the data passed on the event gets logged in the transaction logs of the blockchain. By this mechanism, historical data of the system is accumulated. This event trigger mechanism makes the system auditable.

C. IoT enabled environment

IoT devices, mainly low power sensors, will be used to update regular real-time data from the environment. The diagram below(Figure 8) shows how the integrated IoT devices interact with the MQTT server and show how the published data can be conveyed or routed towards users.

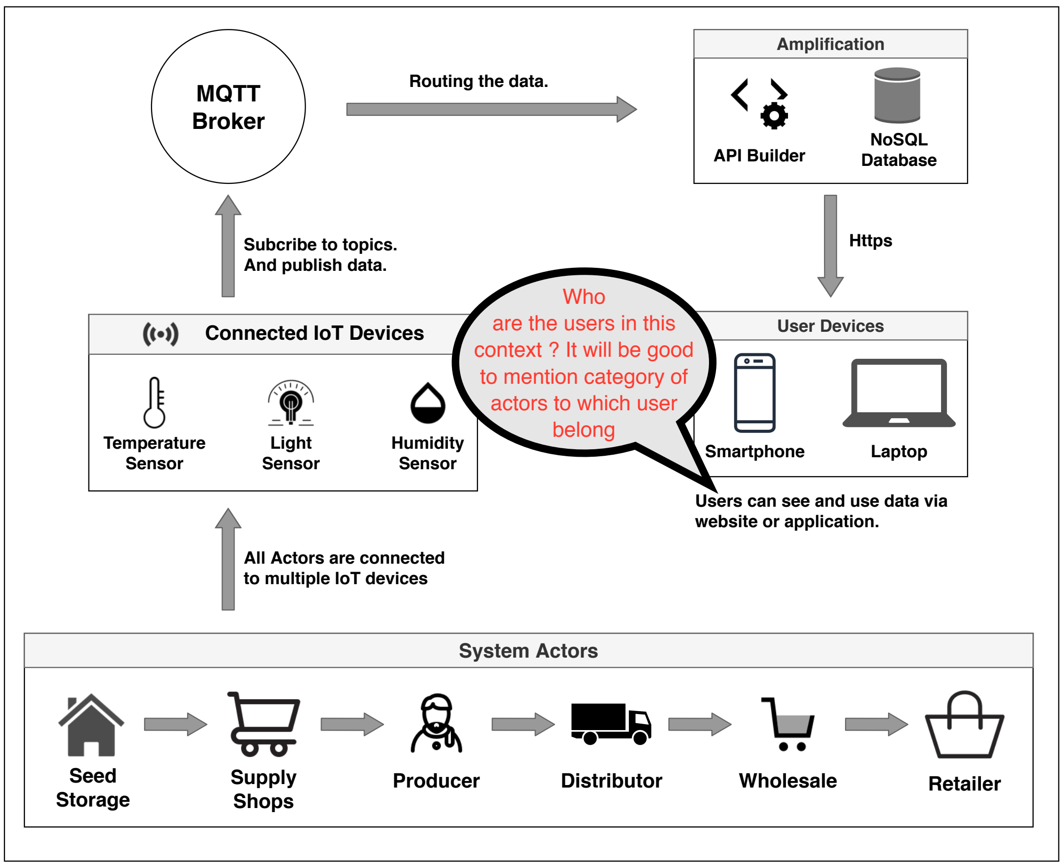

Figure 8. IoT enabled environment interaction with the MQTT server.

D. MQTT Network Protocol

For fabricating a collaborative behavior among the sensors, the blockchain, and the actors, we suggest using an MQTT (Message Queuing Telemetry Transport) network protocol. MQTT is a network protocol that requires minimal bandwidth and consumes very low memory. IoT devices or the sensors will read data like temperature, humidity, and light exposure from the environment, and that data needs to be shared across the whole system eventually to the users. MQTT protocol provides such functionality that enables us to do that. MQTT provides a subscription and publishes based model. The system will have several topics on the MQTT server, and the clients will subscribe to specific topics for looking into the data and publishing data frequently to the server under that topic.

IMPLEMENTATION AND TESTING

We used an Ethereum, blockchain-based environment to implement and test the mechanism of blockchain. For writing smart contracts, we selected solidity. The remix environment was used for creating and testing the core implementation of the proposed system. Building the whole system is not the purpose of our interest. However, an architecture directive approach is demonstrated throughout our paper. In this section, we shall discuss the implementation in detail and also show the testing results.

Implementation

The objective of our work is to show the applicability and opportunity of blockchain in the field of agriculture while ensuring traceability. The fundamental goal of this paper is to demonstrate how the use of blockchain and smart contracts can trace the agricultural products from field level production and continue tracing until the product reaches the consumer base. The system also monitors the pricing along the process. Figure 4,5 and 7 shows clear interaction among the system components and actors. We considered the process into segments, the pre-harvesting period, and the post-harvest period. The working procedure in both segments is discussed below.

A. Pre-Harvest

In the pre-harvest period, the system monitors the storage condition that directly impacts the quality of seed, that is, temperature, humidity, and light exposure. Smart contract can execute self-checks for these values and perform a violation trigger. Self-check follows the algorithm below.

Algorithm 1: Self Check Algorithms.

```
Result: Smart contract conducts a periodical self checks.
Data: value read by IoT device.
if caller == owner then
    if value > optimumValue then
        call violationTrigger() method with violation type and category ;
        return a string describing the high value violation ;
    else if value < optimumValue then
        call violationTrigger() method with violation type and category ;
        return a string describing the low value violation ;
    else
        call violationTrigger() method with violation type and category ;
        return a string describing that the value is optimum ;
    end
else
    Do Nothing ;
end
```

Algorithm 1: Self Check Algorithm.

Registered storage is equipped with IoT sensors that will provide these data to the system on a periodical basis that is essentially stored in the MQTT server. Through the smart contract, the system can auto-check these data using the temperatureSelfCheck(), hummiditySelfCheck() and lightExpoSelfCheck() method while comparing the observed value with pre-defined optimum values. These methods use another trigger method named violationTrigger() to emit events in blockchain so that any violation during storage is stored inside the blockchain along with the violation timestamp. Violation trigger follows the algorithm below.

Algorithm 2: Violation trigger algorithm.

```
   Result: Smart contract emits a violation event.
   Data: ViolationType and ViolationCategory
1  if caller == owner then
2      if violation type == Temperature then
3          if category == 1 then
4              set the temperature condition Enum to Over ;
5              set the violation type Enum to temperature ;
6              emit TemperatureViolation event describing that the temperature is
                 over the threshold;
7          else if category == 0 then
8              set the temperature condition Enum to Under ;
9              set the violation type Enum to Temperature ;
10             emit TemperatureViolation event describing that the temperature is
                 under the threshold ;
11         else if category == 2 then
12             set the temperature condition Enum to Optimum ;
13             set the violation type Enum to Non;
14             emit TemperatureViolation event describing that the temperature is
                 optimum;
15         else
16             Do Nothing ;
17         end
18     else if violation type == Humidity then
19         follow statement 3-18 with associated values, parameters and conditions
             ;
20     else if violation type == Light Exposure then
21         follow statement 3-18 with associated values, parameters and conditions
             ;
22     else
23         Do Nothing ;
24 else
25     Do Nothing ;
```

Algorithm 2: Violation trigger algorithm.

The violationTrigger() method is called with the type of violation (temperature, humidity or light exposure) and the category value with ”1” being over, ”0” being under, and ”2” being optimum with respect to the pre-defined optimum value. According to the violation type, the enumerator value is set to Temperature, Humidity, or Light Exposure, and according to the value of category, events are logged into the blockchain accordingly.

B. Post-Harvest

In the post-harvest, the system tracks all the necessary information and logs events in the blockchain. Information includes departure dates, prices along the way, and quantity in every layer that the product crosses till it gets to the retail. Tracking starts by invoking initiateDistribution() method. This method takes information like product id, name, price, and quantity. The method sets the date as the current timestamp of the block and sets the trace enumerator to the producer. Distribution starts by invoking the startDistribution() method, and the previous information gets updates accordingly while setting the trace enumerator to Distributor. The same mechanism is applied to the other layers of agriproduct supply. Figure 9 shows how every information is timestamped within blockchain.

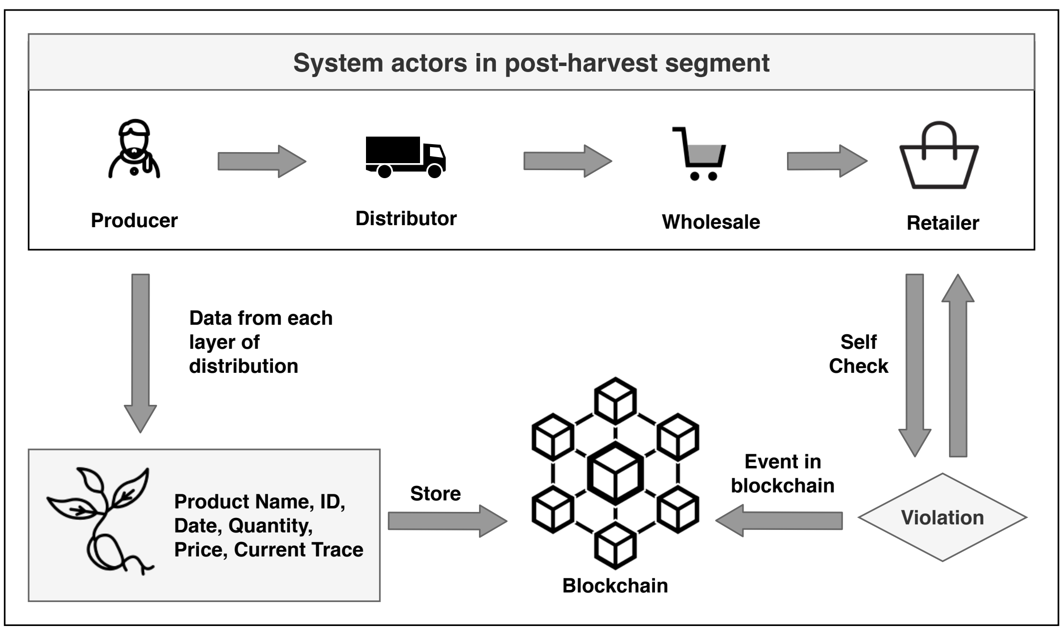

Figure 9. Timestamping distribution data to blockchain.

As we can see from Figure 9, tracing data in our system starts from the production level. As farmers sell his product, the product information and the block timestamp are stored by emitting events in the blockchain so that these data remain secure and become verifiable. As the algorithm is the same in all the steps, only the producer level algorithm(Algorithm 3) is shown below to demonstrate the process.

Algorithm 3: Product trace initiation algorithm.

Result: Product distribution starts.

Only producer account can start the distribution process.

if *caller* == *owner* **then**

  Set the product CurrentTrace enumerator to producer ;

  Set initiation date to the current timestamp of the block ;

  Set name, id, price, quantity to the associated variables ;

  emit DistributionInitiate method with producer address and a message describing the product distribution starting ;

else

  Do Nothing ;

end

Algorithm 3: Product trace initiation algorithm.

The above algorithm(Algorithm 3) is applied to the other layers of distributed tracing. Only the relevant data and authority changes.

Testing

We provided the system architecture, and our implementation includes the smart contract interaction with Ethereum blockchain. Remix is a web-based IDE that provides Ethereum wallet as well as accounts loaded with dummy ether cryptocurrency and the environment to write smart contracts with the help of solidity programming language. Remix also provides us the environment to run and deploy the contract inside the Ethereum blockchain, which matches our fundamental requirements and aims. In this section, we provide a demo of our contracts interacting with the blockchain, and we will also demonstrate the mechanism it follows.

In the post-harvesting period, seed information is inserted into the system and, with the help of IoT devices, corresponding autority or monitoring body can check for the current status of temperature, humidity, or light exposure periodically. Based on the self-checked data, the contract calls events to store the favou[illegible] or violation along with their type and condition. Where type is te[illegible], or light exposure and condition values can be indicated as bel[illegible] than the threshold). The figure below(Figure 10) shows the succ[illegible] Fig 10.a) and demo of a self-check result(Fig 10.b).

How is seed batch tracked during distribution and supply? Example: Barcode or QR code on the package

Using the *addSeed()* method, necessary seed information is stored inside the [illegible]lockchain for a secure safeguard of legacy data. For demonstration purpose, an entry of a batch of potato seed has been inserted into the blockchain as shown in Fig 10.a. All the registered seed storages will insert seed data as soon as seeds are brought for storage purpose.

Several conditioning reason will be monitored using IoT devices. Our system implement checks for crucial factors like temperature, hummidity and light exposure. All these monitored data will be stored in clouds but for establishing an absolute trust-based decision making, it's important to know that these data are not corrupted or altered or hampered in any way. So, the storage smart contract conducts periodical self-checks for this contributing factors. Self-check data is analyzed and detailed information is stored via events in blockchain. Figure 10.b shows a demo of the contract executing a

Figure 10. Add seed to the system.

self-check for temperature.

The optimum temperature was set to 38. When the contract checks with value 40(read by IoT devices), it finds a violation in temperature value and instantly emits the *TemperatureViolation()* event. The event gets logged in the transactional history along with the address(which storage) and violation information (what kind of violation).

The contract also triggers violation event whenever any violation is encountered by the system. Based on the violation type and category of violation, event are logged into the blockchain. Log data are retrievable and farmers will be able to see and make decision based on these historical data of any particular storage. Trigger testing is shown in figure 11.a. As depicted in 11.a, the *violationTrigger()* method successfully logged the violation of temperature attribute in the blockchain.

In the post-harvest segment, the system tracks every product by storing data in each and every step of distribution, starting from the production level to retail. These information is essential for the customers to know the origin and distribution of products before buying it. From producer to distributor then wholesaler and finally retailer, every step does a similar fashion of interaction with the system. The producer level demonstration is shown in the figure 11.b.

As shown in Figure 11.b, using the *initiateDistribution()* method, the process of distribution has been started. The log shows all the data related to the agriproduct from producer level. Product id, date, price, and current trace is logged into the blockchain. All the other steps of distribution does the same thing with relevant data from the product's current trace, finally, the product reaching to retail shops.

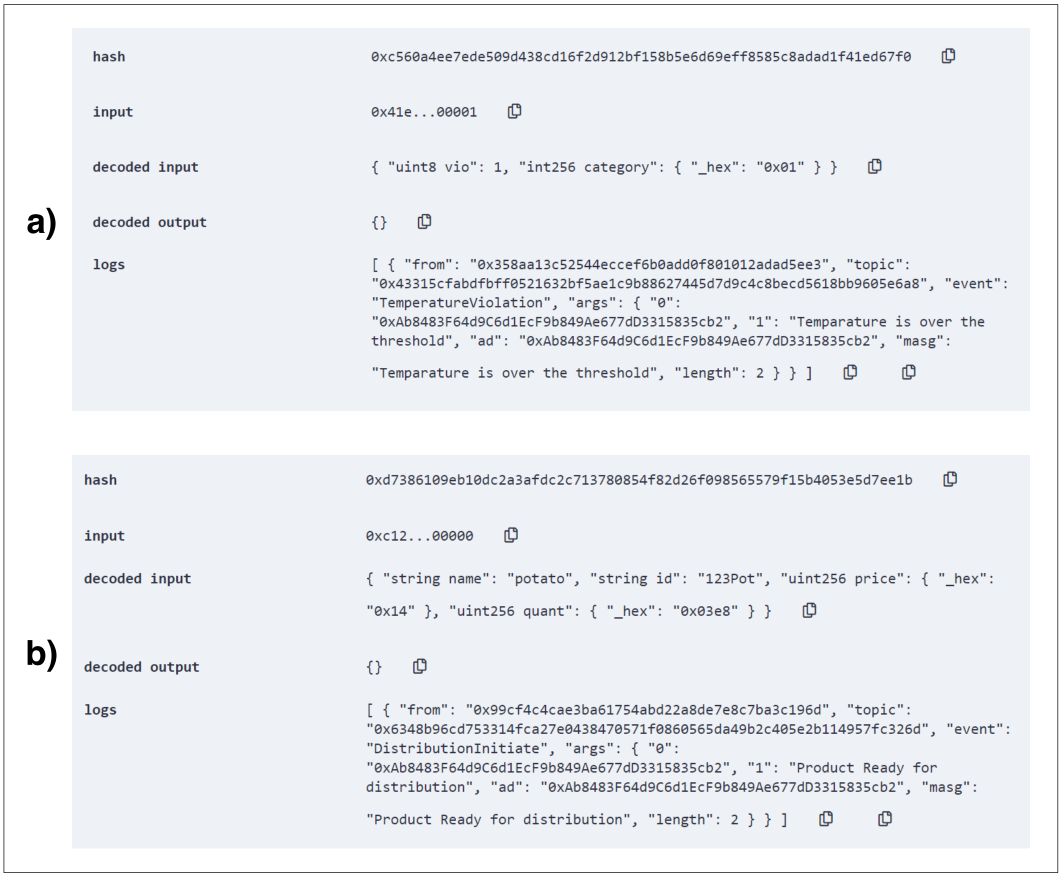

Figure 11. self-check example for temperature condition.

ANALYSIS

Though transaction with blockchain has been popularized bitcoin, implementing it in a real-world use-case, with the integration of other technologies like IoT, still has several issues to solve and several purposes of the meeting. (Casino et al. 2019) The use of IoT in agricultural traceability is being encouraged by the research community. (Lezoche et al. 2020; Hiromoto et al. 2017; Abdel-Basset et al. 2018; Ben-Daya et al. 2019) Though our system tries to avoid dubious conditions by implementing smart regulatory contracts, there are still some flaws in the system. As blockchain is still in its inception stage, there's an issue of optimizing it for real world systems. (Casino et al. 2019) Table 1 show a comparison analysis of our system with recent works in the field of agriculture using blockchain. The challenges and advantages represent the analysis of our system. A gas cost analysis has also been attached in table 2.

A. Advantages

- Authorization is never compromised. Only the person allowed by the smart contract can execute or invoke a task.
- Monitored data has been secured and solidified in two ways. IoT devices automatically push data to the MQTT server and the blockchain periodically self-checks these data via smart contract and logs every event and violation.

Outcome	Tian (2017)	Caro et al. (2018)	Kim et al. (2018)	Lin et al. (2018)	Devi et al. (2019)	Salah et al. (2019)	Umamaheswari et al. (2019)	Kamble et al. (2020)	Bumblauskas et al. (2020)	Shahid et al. (2020)	Proposed System
Provide System Implementation	✗	✓	✗	✗	✓	✓	✗	✗	✓	✓	✓
Traceability	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓
Control over the system (Smart Contract)	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓	✓
Enable Informed purchase decision ability of customers	✓	✓	✗	✗	✗	✗	✗	✗	✓	✗	✓
Real-time data	✓	✗	✓	✓	✓	✗	✓	✗	✗	✗	✓
Reduce fraud	✓	✗	✓	✓	✓	✓	✓	✗	✓	✓	✓
Remove third party	✓	✓	✓	✓	✗	✓	✓	✓	✓	✓	✓
Fair pricing	✗	✗	✗	✗	✗	✗	✓	✗	✗	✗	✓

Table 1. System comparison with existing methods.

- Data security within the blockchain is robust. Several types of data from pre-harvest and post-harvest segments are stored in the blockchain so that they remain unchanged as any data saved into the blockchain can hardly be changed or tampered.
- Authenticit[illegible]re by the smart contracts. The smart contract automatical[illegible]different segments and saves the result within the blockchain.

Is blockchain being referred here? It is not clear what is the central source?

- A central source of information is created, and everyone can check the necessary data at any time.
- A smart contract removes the intermediate processor. In agriculture, there are so many intermediate person/factors which increases the market price drastically. However, a smart contract monitors all the prices and the flow of product from one level to another.
- Every date, times, and product id are stored in the blockchain. So, authentic, traceable data ensures the consumer's right to know about the product's origin.
- Central monitoring organizations can use this to control market prices and also to estimate supply-demand.
- The processes are automated and robust.
- There is no third-party support needed. Only the system alone can handle all the operations without any human interaction.

B. Challenges

- If, in any step, someone does something by mistake, chang[illegible]ng data in the blockchain is impossible. Immutability indeed is one[illegible]trengths of blockchain, but unlike the traditional database syst[illegible]ain, due to its reliable security schemes, does not allow us to twerk the data of a verified transaction.

tweek or modify

- Smart contracts are deployed to take control of the system and automate the steps. Once deployed inside the blockchain, it can never be changed.
- The initial settings of the blockchain environment take a reasonable amount of money.
- IoT devices are vulnerable to security issues.
- Data acquisition is dependent on IoT devices. If devices get damaged, data collection or check is not possible.

C. Cost Estimations The table below (Table 2) show the gas costs of different operations within our system.

it will be good to add a column on which actor will bear the gas cost for each task

Task	Transaction cost	Execution cost
addSeed()	168402	144314
temperatureSelfCheck()	50681	29217
hummiditySelfCheck()	50812	29348
lightExpoSelfCheck()	35503	14039
violationTrigger()	48625	26969
initiateDistribution()	132122	108610
startDistribution()	106442	84786
startWholesale()	91530	69874
retailSell()	91464	69808

Table 2. Gas costs of different operations.

CONCLUSION

The objective of this work was to demonstrate the capability of blockchain in agricultural process development. How the usage of blockchain can ensure data availability, ensure security, apply immutability so that there can be no manipulation of data, and ensure trust among producers and consumers. Consumers can, without any doubt, know the origin and distribution history of products. Farmers can know the history of seed storage, and the governing bodies can control the market based on these data. The whole system is bought under IoT surveillance, where blockchain provides absolute security of them. All codes related to the system have been made public in GitHub (`https://github.com/Tahmid1406/Blockchain-Based-Agriculture`) so that other enthusiasts can learn from it and use it for their purpose. The implementation is quite generalized and generic. The same implementation can be applied to trace, develop, and enhance any process. We also presented the gas costs for a better understanding of the costings to run the system. Our future goal is to deploy the system in our own blockchain. We also intend to build a web application that meets our purpose.

REFERENCES

Abdel-Basset, M., Manogaran, G., and Mohamed, M. (2018). Internet of Things (IoT) and its impact on supply chain: A framework for building smart, secure and efficient systems. *Future Generation Computer Systems*, 86:614–628.

Andy, S., Rahardjo, B., and Hanindhito, B. (2017). Attack scenarios and security analysis of mqtt communication protocol in iot system. In *2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, pages 1–6.

Bader, L., Burger, J. C., Matzutt, R., and Wehrle, K. (2019). Smart Contract-Based Car Insurance Policies. *2018 IEEE Globecom Workshops, GC Wkshps 2018 - Proceedings*.

Baranwal, T., Nitika, and Pateriya, P. K. (2016). Development of IoT based smart security and monitoring devices for agriculture. *Proceedings of the 2016 6th International*

Conference - Cloud System and Big Data Engineering, Confluence 2016, pages 597–602.
Ben-Daya, M., Hassini, E., and Bahroun, Z. (2019). Internet of things and supply chain management: a literature review. *International Journal of Production Research*, 57(15-16):4719–4742.
Biswas, S., Sharif, K., Li, F., Nour, B., and Wang, Y. (2019). A scalable blockchain framework for secure transactions in IoT. *IEEE Internet of Things Journal*, 6(3):4650–4659.
Bumblauskas, D., Mann, A., Dugan, B., and Rittmer, J. (2020). A blockchain use case in food distribution: Do you know where your food has been? *International Journal of Information Management*, 52:102008.
Caro, M. P., Ali, M. S., Vecchio, M., and Giaffreda, R. (2018). Blockchain-based traceability in Agri-Food supply chain management: A practical implementation. *2018 IoT Vertical and Topical Summit on Agriculture - Tuscany, IOT Tuscany 2018*, pages 1–4.
Casino, F., Dasaklis, T. K., and Patsakis, C. (2019). A systematic literature review of blockchain-based applications: Current status, classification and open issues. *Telematics and Informatics*, 36(November 2018):55–81.
Chang, S. E., Chen, Y. C., and Lu, M. F. (2019). Supply chain re-engineering using blockchain technology: A case of smart contract based tracking process. *Technological Forecasting and Social Change*, 144(March 2018):1–11.
Chen, S., Shi, R., Ren, Z., Yan, J., Shi, Y., and Zhang, J. (2017). A Blockchain-Based Supply Chain Quality Management Framework. *Proceedings - 14th IEEE International Conference on E-Business Engineering, ICEBE 2017 - Including 13th Workshop on Service-Oriented Applications, Integration and Collaboration, SOAIC 207*, pages 172–176.
Chen, Y., Ding, S., Xu, Z., Zheng, H., and Yang, S. (2018). Blockchain-Based Medical Records Secure Storage and Medical Service Framework. *Journal of Medical Systems*, 43(1).
Crosby, M., Pattanayak, P., Verma, S., Kalyanaraman, V., et al. (2016). Blockchain technology: Beyond bitcoin. *Applied Innovation*, 2(6-10):71.
Devi, M. S., Suguna, R., Joshi, A. S., and Bagate, R. A. (2019). Design of iot blockchain based smart agriculture for enlightening safety and security. *Emerging Technologies in Computer Engineering: Microservices in Big Data Analytics Communications in Computer and Information Science*, page 7–19.
Eyal, I. (2017). Blockchain Technology : Cryptocurrency Dreams to Finance and Banking. *Computer- IEE Computer Society*, pages 38–49.
Galvez, J. F., Mejuto, J. C., and Simal-Gandara, J. (2018). Future challenges on the use of blockchain for food traceability analysis. *TrAC - Trends in Analytical Chemistry*, 107:222–232.
Hagen, B. N., Albright, A., Sargeant, J., Winder, C. B., Harper, S. L., O'Sullivan, T. L., and Jones-Bitton, A. (2019). Research trends in farmers' mental health: A scoping review of mental health outcomes and interventions among farming populations worldwide. *PLoS ONE*, 14(12):1–20.
Hasan, H. R., Salah, K., Jayaraman, R., Ahmad, R. W., Yaqoob, I., and Omar, M. (2020). Blockchain-Based Solution for the Traceability of Spare Parts in Manufacturing. *IEEE*

Access, 8(May):100308–100322.
Hiromoto, R. E., Haney, M., and Vakanski, A. (2017). A secure architecture for IoT with supply chain risk management. *Proceedings of the 2017 IEEE 9th International Conference on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, IDAACS 2017*, 1:431–435.
Hoepman, J. H. (2010). Distributed double spending prevention. *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 5964 LNCS:152–165.
Humayun, M., Jhanjhi, N. Z., Hamid, B., and Ahmed, G. (2020). Emerging Smart Logistics and Transportation Using IoT and Blockchain. (June):58–62.
Hunkeler, U., Truong, H. L., and Stanford-Clark, A. (2008). Mqtt-s — a publish/subscribe protocol for wireless sensor networks. *2008 3rd International Conference on Communication Systems Software and Middleware and Workshops (COMSWARE 08)*.
Kamble, S. S., Gunasekaran, A., and Sharma, R. (2020). Modeling the blockchain enabled traceability in agriculture supply chain. *International Journal of Information Management*, 52:101967.
Kamilaris, A., Fonts, A., and Prenafeta-Boldv, F. X. (2019). The rise of blockchain technology in agriculture and food supply chains. *Trends in Food Science and Technology*, 91(July):640–652.
Kim, M., Hilton, B., Burks, Z., and Reyes, J. (2018). Integrating Blockchain, Smart Contract-Tokens, and IoT to Design a Food Traceability Solution. *2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference (IEMCON)*, (Figure 1):335–340.
Kim, M., Hilton, B., Burks, Z., and Reyes, J. (2019). Integrating Blockchain, Smart Contract-Tokens, and IoT to Design a Food Traceability Solution. *2018 IEEE 9th Annual Information Technology, Electronics and Mobile Communication Conference, IEMCON 2018*, (Figure 1):335–340.
Kumar, D. and Kalita, P. (2017). Reducing Postharvest Losses during Storage of Grain Crops to Strengthen Food Security in Developing Countries. *Foods*, 6(1):8.
Lamberti, F., Gatteschi, V., Demartini, C., Pelissier, M., Gomez, A., and Santamaria, V. (2018). Blockchains Can Work for Car Insurance: Using Smart Contracts and Sensors to Provide On-Demand Coverage. *IEEE Consumer Electronics Magazine*, 7(4):72–81.
Lezoche, M., Panetto, H., Kacprzyk, J., Hernandez, J. E., and Alemany Díaz, M. M. E. (2020). Agri-food 4.0: A survey of the Supply Chains and Technologies for the Future Agriculture. *Computers in Industry*, 117.
Li, J., Wu, J., and Chen, L. (2018). Block-secure: Blockchain based scheme for secure P2P cloud storage. *Information Sciences*, 465:219–231.
Lin, J., Zhang, A., Shen, Z., and Chai, Y. (2018). Blockchain and IoT based food traceability for smart agriculture. *ACM International Conference Proceeding Series*, pages 1–6.
Lin, W., Huang, X., Fang, H., Wang, V., Hua, Y., Wang, J., Yin, H., Yi, D., and Yau, L. (2020). Blockchain Technology in Current Agricultural Systems: From Techniques to Applications. *IEEE Access*, 8:143920–143937.
Lucena, P., Binotto, A. P. D., Momo, F. d. S., and Kim, H. (2018). A Case Study for

Grain Quality Assurance Tracking based on a Blockchain Business Network.

Macrinici, D., Cartofeanu, C., and Gao, S. (2018). Smart contract applications within blockchain technology: A systematic mapping study. *Telematics and Informatics*, 35(8):2337–2354.

Manupati, V. K., Schoenherr, T., Ramkumar, M., Wagner, S. M., Pabba, S. K., and Inder Raj Singh, R. (2020). A blockchain-based approach for a multi-echelon sustainable supply chain. *International Journal of Production Research*, 58(7):2222–2241.

Miloslavskaya, N. and Tolstoy, A. (2019). Internet of Things: information security challenges and solutions. *Cluster Computing*, 22(1):103–119.

Mohanty, S. N., Ramya, K. C., Rani, S. S., Gupta, D., Shankar, K., Lakshmanaprabu, S. K., and Khanna, A. (2020). An efficient Lightweight integrated Blockchain (ELIB) model for IoT security and privacy. *Future Generation Computer Systems*, 102:1027–1037.

Nakamoto, S. (2008). Bitcoin whitepaper. *URL: https://www.bitcoin.com/get-started/bitcoin-white-paper-beginner-guide/*.

Nakamoto, S. (2019). Bitcoin: A peer-to-peer electronic cash system. Technical report, Manubot.

Nguyen, D. C., Pathirana, P. N., Ding, M., and Seneviratne, A. (2019). Blockchain for Secure EHRs Sharing of Mobile Cloud Based E-Health Systems. *IEEE Access*, 7:66792–66806.

Nicole, S., Christoph, J., Matthias, B., Matthias, E., and Marcel, Z. (2020). Time trend of suicide in Swiss male farmers and comparison with other men: A cohort study. *Swiss Medical Weekly*, 150(21-22):1–10.

Nofer, M., Gomber, P., Hinz, O., and Schiereck, D. (2017). Blockchain. *Business and Information Systems Engineering*, 59(3):183–187.

Opara, L. U. (2003). Traceability in agriculture and food supply chain: a review of basic concepts, technological implications, and future prospects.

Pavithra, D. and Balakrishnan, R. (2015). Iot based monitoring and control system for home automation. In *2015 global conference on communication technologies (GCCT)*, pages 169–173. IEEE.

Peters, G. W. and Panayi, E. (2016). *Understanding modern banking ledgers through blockchain technologies: Future of transaction processing and smart contracts on the internet of money*.

Pradhan, B. K. and Badola, H. K. (2012). Effect of storage conditions and storage periods on seed germination in eleven populations of Swertia chirayita: A critically endangered medicinal herb in Himalaya. *The Scientific World Journal*, 2012.

Raikwar, M., Mazumdar, S., Ruj, S., Sen Gupta, S., Chattopadhyay, A., and Lam, K. Y. (2018). A Blockchain Framework for Insurance Processes. *2018 9th IFIP International Conference on New Technologies, Mobility and Security, NTMS 2018 - Proceedings*, 2018-January:1–4.

Salah, K., Nizamuddin, N., Jayaraman, R., and Omar, M. (2019). Blockchain-based soybean traceability in agricultural supply chain. *IEEE Access*, 7:73295–73305.

Shahid, A., Almogren, A., Javaid, N., Al-Zahrani, F. A., Zuair, M., and Alam, M. (2020). Blockchain-based agri-food supply chain: A complete solution. *IEEE Access*, 8:69230–69243.

Szabo, N. (1996). Smart contracts: building blocks for digital markets. *EXTROPY: The*

Journal of Transhumanist Thought,(16), 18(2).
Szabo, N. (1997). Formalizing and securing relationships on public networks. *First Monday*.
Tan, A., Gligor, D., and Ngah, A. (2020). Applying Blockchain for Halal food traceability. *International Journal of Logistics Research and Applications*, 0(0):1–18.
Tapashetti, A., Vegiraju, D., and Ogunfunmi, T. (2016). IoT-Enabled Air Quality Monitoring Device. *IEEE 2016 Global Humanitarian Technology Conference*, pages 0–3.
Tian, F. (2017). A supply chain traceability system for food safety based on HACCP, blockchain & Internet of things. *14th International Conference on Services Systems and Services Management, ICSSSM 2017 - Proceedings*.
Umamaheswari, S., Sreeram, S., Kritika, N., and Prasanth, D. R. J. (2019). Biot: Blockchain based iot for agriculture. *2019 11th International Conference on Advanced Computing (ICoAC)*.
Vashi, S., Ram, J., Modi, J., Verma, S., and Prakash, C. (2017). Internet of things (iot): A vision, architectural elements, and security issues. In *2017 international conference on I-SMAC (IoT in Social, Mobile, Analytics and Cloud)(I-SMAC)*, pages 492–496. IEEE.
Wang, S., Li, D., Zhang, Y., and Chen, J. (2019). Smart Contract-Based Product Traceability System in the Supply Chain Scenario. *IEEE Access*, 7:115122–115133.
Wang, Z., Wang, T., Hu, H., Gong, J., Ren, X., and Xiao, Q. (2020). Blockchain-based framework for improving supply chain traceability and information sharing in precast construction. *Automation in Construction*, 111(April 2019):103063.
Westerkamp, M., Victor, F., and Kupper, A. (2018). Blockchain-based supply chain traceability: Token recipes model manufacturing processes. *Proceedings - IEEE 2018 International Congress on Cybermatics: 2018 IEEE Conferences on Internet of Things, Green Computing and Communications, Cyber, Physical and Social Computing, Smart Data, Blockchain, Computer and Information Technology, iThings/GreenCom/CPSCom/SmartData/Blockchain/CIT 2018*, pages 1595–1602.
Zhang, Y., Deng, R. H., Liu, X., and Zheng, D. (2018). Blockchain based efficient and robust fair payment for outsourcing services in cloud computing. *Information Sciences*, 462:262–277.
Zhao, S. and O'Mahony, D. (2018). BMCprotector: A blockchain and smart contract based application for music copyright protection. *ACM International Conference Proceeding Series*, pages 1–5.
Zheng, Z., Xie, S., Dai, H.-N., Chen, X., and Wang, H. (2017). Blockchain Challenges and Opportunities : A Survey Shaoan Xie Hong-Ning Dai Huaimin Wang. *International Journal of Web and Grid Services*, 14(4):1–24.
Zheng, Z., Xie, S., Dai, H.-N., Chen, X., and Wang, H. (2018). Blockchain challenges and opportunities: A survey. *International Journal of Web and Grid Services*, 14(4):352–375.