

Survey of Recent Literature on Advanced Technologies in Digital Agriculture: Internet of Things and Blockchain

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Abstract: Agriculture represents a major turning point in economic development, and many modern technologies, such as the Internet of Things (IoT) and blockchain technology, are playing an effective role in making farming practices simpler and smarter. IoT is a common model of information technology, and its use in agriculture has become widespread, with integrated applications for recording and updating various activities. Sensors make it easier for farmers to gather basic information and details in the field, for example by monitoring soil and crops. However, with the growing sophistication of IoT attacks, the threat vectors are increasing. This is where blockchain technology comes in to address the security and privacy challenges associated with IoT use. Blockchain can extend the scope of IoT applications. This article aims to present a comprehensive review of existing and recent research concerning blockchain and IoT technologies, as well as future research directions in the field of intelligent agricultural systems.

Keywords: Intelligent agricultural systems, IoT, Blockchain

1 Introduction

The most modern machines were introduced and taken over for production. However, pre-harvest and post-harvest processing still follows traditional methods of tracking, storing and publishing agricultural data. For this reason, it has become necessary to use emerging technologies in the application of precision agriculture through information technology and access to the use of intelligent applications to obtain precise data and to invest that data to steer agriculture in a specific direction.

Some of the old farming methods are still available, affecting the profitability of production. Due to the fact that the majority of farmers do not have an intelligent information system developed to manage their data, the use of digital technologies and innovative devices such as big data, cloud computing, robotics, the Internet of Things, blockchain and artificial intelligence has been supported and promoted. The aim is to apply these intelligent applications to obtain accurate data and invest this data to steer agriculture in a specific direction.

Sensors are designed to detect the range of soil pH, soil moisture, UV, temperature and water level sensors. With the rapid increase of important IoT applications in digital agriculture, this field is facing many security and privacy challenges. Due to the problems faced by IoT applications, blockchain solutions have been created to help overcome these difficulties [1]. It consists of a kind of large database supported by many new computer technologies and protocols. Blockchain technology stores and protects data on servers, which generally consist of huge networks of computers with the storage and computing power needed to enable multiple users to access a database simultaneously.

The terms Internet of Things (IoT), big data and artificial intelligence (AI) may be buzzwords in the technology industry, but they have only recently begun to make a significant impact. Indeed, search history data on Google Trends shows that IoT and big data have generated considerable interest among Internet users over the past five to six years, while AI has remained a topic of interest for over a decade.

With the multiplication of communication devices, the volume of data generated continues to grow, and AI continues to integrate effectively into the lives of a large proportion of the world's population, in various forms.

Unlike AI, however, IoT is primarily an industrial technology, attracting little interest from the general public. For food scientists and engineers, one of the natural topics of interest is maximizing the impact of these emerging technologies to sustainably feed the planet.

Blockchain was first proposed by Chaum [2] in 1979. In 1992, Bayer et al [3] improved this concept by incorporating Merkle trees into block design. The structure is an ever-growing list of cryptographically connected blocks: each block contains the cryptographic hash of the previous block, the timestamp and the underlying data, also known as transaction data. Thanks to this design, blockchain is highly resistant to data modification. Blockchain began to make inroads in 2008, as envisaged in Nakamoto's studies. The aim of blockchain in all its applications is to provide data to parties with integrity.

The blockchain in the agriculture market was valued at USD 133.06 million in 2020 and is projected to reach USD 1387.71 million by 2026, at a CAGR of 47.81%. The market in the Asia Pacific region is expected to grow at a high CAGR between 2013 and 2026 [4]. The key players in the blockchain agriculture market are IBM (US), Microsoft (US), SAP-SE (Germany), Ambrosus (Switzerland), Arc net (Ireland), Original Trail (Slovenia), and Ripe.io (US), among others.

The significant contributions of this article are:

- To present the most important work related to the development of agriculture using Internet of Things applications and Blockchain technologies and their effective role specifically in solving problems in this field.
- To bring more artificial intelligence-based solutions to advanced devices from scratch to discover proposed difficulties in real time and rapid corrective actions, making more open and customizable solutions available to farmers and integrating cyber-security measures.
- We show among these previous works that innovations in blockchain technology and their deployment in IoT applications are current topics in current research communities.
- An in-depth discussion of future trends, to enhance the impact of these technologies in the agricultural sector.

2 Related Work

A comprehensive review of current research literature and the latest developments in the field of smart agricultural systems has been published. It presents a set of proposed solutions for Blockchain applications and IoT systems.

This section briefly summarizes relevant work from recent years [2019-2023].

We mention some of the important contributions made by researchers in this field [5]. They have contributed to the preparation of a detailed educational program on the developments available in SAS through IoT technologies and artificial intelligence, followed by a comprehensive review of these two available technologies and the large-scale challenges.

The authors [6] establish a model based on IoT systems that ensure a widely available smart farming infrastructure. The Fog platform integrates the appropriate processing of data generated by IoT tools used in connected agriculture by storing data as close as possible to the edge of the network.

The model proposed by the authors [7] is an intelligent irrigation system that predicts crop water requirements using a machine learning algorithm. This system is based on a temperature and humidity sensor distributed in agriculture. It sends data via a microprocessor and develops an IoT device with the cloud using a learning algorithm application. Efficient automation based on data discovered in the field leads to effectively predicting results.

The authors propose an implementation of IoT systems using collaborative synchronization control in a cloud fog environment. Enhanced partial authentication protocols have been implemented to perform IoT transactions, which are validated for security in the cloud. Traditional blacklisting methods for detecting intrusions into IoT devices are no longer effective due to the emergence of new hostile attacks [8].

The authors [9] investigated the importance of integrating Internet of Things (IoT) and blockchain technologies in the development of intelligent systems and applications in precision agriculture, as this technological integration has shown that the application of blockchain can offer new solutions to chronic security and performance challenges in Internet of Things-based precision agriculture systems.

Others [10] explained and discussed the most important blockchain platforms implemented for IoT applications, such as the Hyperledger Fabric and Ethereum platforms, and then focused on the role of blockchain technology in scaling IoT applications.

Other researchers [11] have proposed a new Agri-SCM-IoT architecture based on blockchain technology to solve the storage and security problem, in addition to some other challenges of the agricultural supply chain. The authors [12] discuss current privacy challenges when applying blockchain in different fields. On this basis, they present two layers of classification for privacy-preserving blockchain applications by examining some major developments in different areas of this application. Most importantly, they proposed a new smart farming framework that would preserve blockchain privacy and continue to explore the potential of this technology in smart agriculture.

Other researchers [13] argue that any open innovation structure in the agri-food sector must be continually reconfigured to meet the needs of farmers and the market. The ecosystem that supports the Internet of Things can only be sustainable if there is continuous interaction and consultation between the various stakeholders in the food system. Given the emergence of Internet of Things (IoT)-based smart farming, which faces big challenges such as data storage, control and transmission due to its distributed nature and large scale, the framework of the smart farming approach consists of four layers: Smart Farming, Smart Contracts, Interplanetary File System (IPFS) and Farming Participants (remote users) [14].

This research [15], presented a robust and fair decentralized platform called DeepChain based on blockchain technology to secure collaborative deep learning. They set up incentives to achieve three security goals, which are confidentiality, verifiability and fairness.

3 Research Methodology

3.1 Internet of Things (IoT)

Thanks to new technologies, especially the Internet of Things (IoT), farmers have the opportunity to determine the best harvest season and protect the large-scale production of food. The Internet of Things (IoT) refers to the interconnection between physical objects that have electronics embedded in their architecture to communicate with each other or with the external environment and capture interactions. It's a revolution in the agricultural industry, helping farmers face many of the challenges associated with water scarcity and land control, controlling costs, and increasing consumption. Based on the data provided, the IoT is used to collect real-time data from sensors that are sent to the application via cloud storage. As IoT develops, more standards for data use and sharing should be developed.

The Internet of Things (IoT) is playing a key role in the agricultural revolution. The proliferation of affordable smart devices connected to the Internet is transforming the efficiency of agriculture at the field level. IoT-enabled smart farming systems enable the collection of vast quantities of agricultural data stored in the cloud.

- **Real-time farm monitoring:** IoT uses robots, drones, remote sensors, and computer images. These technologies are combined with constantly evolving machine learning and analysis tools.
- The aim is to monitor crops, map fields, and provide farmers with data for rational farm management.
- Time and money savings for farmers.

Many researchers around the world are exploring technologies and solutions to increase agricultural productivity by using IoT technology to complement existing services (see Table 1).

Figure 1 below presents a graphical representation of the details by year of the articles studied.

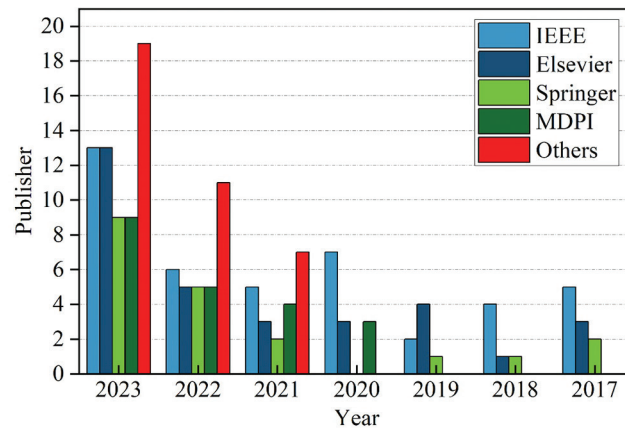


Figure 1. Publisher and year-wise details of surveyed articles on IoT

Table 1. Progressive technology used in agriculture based on IoT

Technology	Descriptions
Location monitoring tools	The use of satellites to determine the amount of water in the ground and various other measurements. Data collected by connected GPS satellites are widely used by crop insurance companies, scientists and commodity organizations
Sensors	By installing monitoring sensors to track the condition of livestock in real time. Perceive a chain of parameters such as biomolecular, chemical, optical, thermal, electrical and biological to get a 360 degree view of crop health
Connectivity protocols	• ZigBee is the long ranges that are most beneficial for the agricultural sector. • LoRaWAN, LPWAN and cellular connection are the most used connectivity protocols for smart agriculture.

a) IoT architecture

IoT systems consist of sensors and devices that are requested by the cloud via some form of connectivity. If data has been accessed in the cloud, the software will handle it and will then prefer to take action. For example, sending alerts or reinforcing sensors/devices automatically with no user input required.

If the user does need to intervene or simply wants to log in to this system, they can do this via the user interface. Any adjustment or user action will then be fed by this system in the opposite direction of the user interface, back to the cloud, and again back to the sensor/device to make changes. IoT Systems can detect real-time weather conditions like temperature, humidity, rainfall, and winds very precisely.

Generally, an IoT solution consists of the following components shown in Figure 2:

- Object (Sensor-module)
- Sensors, Actuators
- Gateway
- Cloud (Cloud Computing)

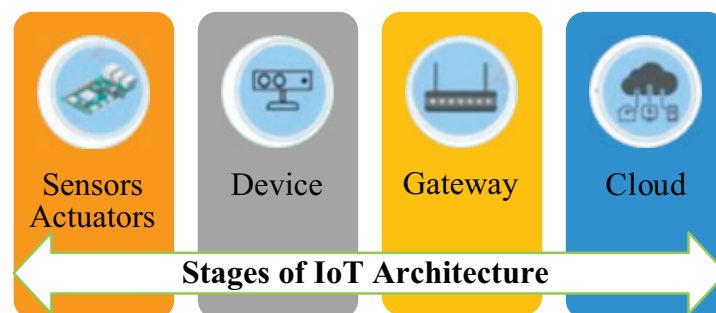


Figure 2. Stages of IoT architecture

For farmers, we have created a flexible application based on IoT (see Figure 3). IoT-based smart farming systems can monitor soil moisture, irrigation, temperature, and weather conditions to grow and produce high-quality crops.



Figure 3. IoT-based smart farming

b) Application Areas of IoT-Based Agriculture

IoT applications are also used in precision agriculture. Livestock monitoring, vehicle tracking, field observation, and inventory monitoring allow farmers to analyze information and make informed, rapid decisions. Farmers can also analyze soil moisture and nutrient status to improve farming effectiveness and efficiency.

IoT has advanced farming techniques where it has provided smart alternatives to solve long-known farming challenges and problems. With the current speed of advancement in IoT technology, we can be sure of its favorable effect on the agricultural industry in the future.

The various application areas of **IoT-based agriculture**:

- **Smart Monitoring:** Utilizing sensors and IoT devices to **monitor** various parameters such as soil moisture, temperature, humidity, and light levels. Helps farmers make informed decisions about irrigation, fertilization, and pest control.
- **Smart Water Management:** Efficiently managing water resources by using IoT-enabled systems. Real-time monitoring of water levels in tanks, reservoirs, and irrigation channels. Automated irrigation based on soil moisture data.
- **Agrochemical Applications:** Precise application of fertilizers, pesticides, and herbicides. IoT helps optimize the timing and dosage of agrochemicals, reducing waste and environmental impact.
- **Disease Management:** Early detection of plant diseases using IoT sensors. Monitoring plant health and identifying anomalies. Timely intervention to prevent disease spread.
- **Smart Harvesting:** Using IoT devices to determine the optimal time for harvesting crops. Monitoring crop maturity, yield estimation, and quality assessment.
- **Supply Chain Management:** Tracking and managing the movement of agricultural products from farm to market. Ensuring freshness, reducing spoilage, and improving logistics.
- **Smart Agricultural Practices:** Implementing precision farming techniques, combining data from sensors, drones, and satellite imagery to optimize crop production and enhancing overall efficiency and sustainability.

These IoT applications empower farmers by providing meaningful data, enabling better decision-making, and ultimately increasing agricultural productivity and sustainability.

We can consider the main existing applications of smart agriculture (see Figure 4) based on IoT to ensure better revolution in the agricultural sector. IoT field applications are designed to report various conditions such as soil fertility, temperature, humidity, gas, pressure and monitor plant diseases in the home. By using multiple sensors, many animal diseases, temperature, watering and humidity can be monitored.

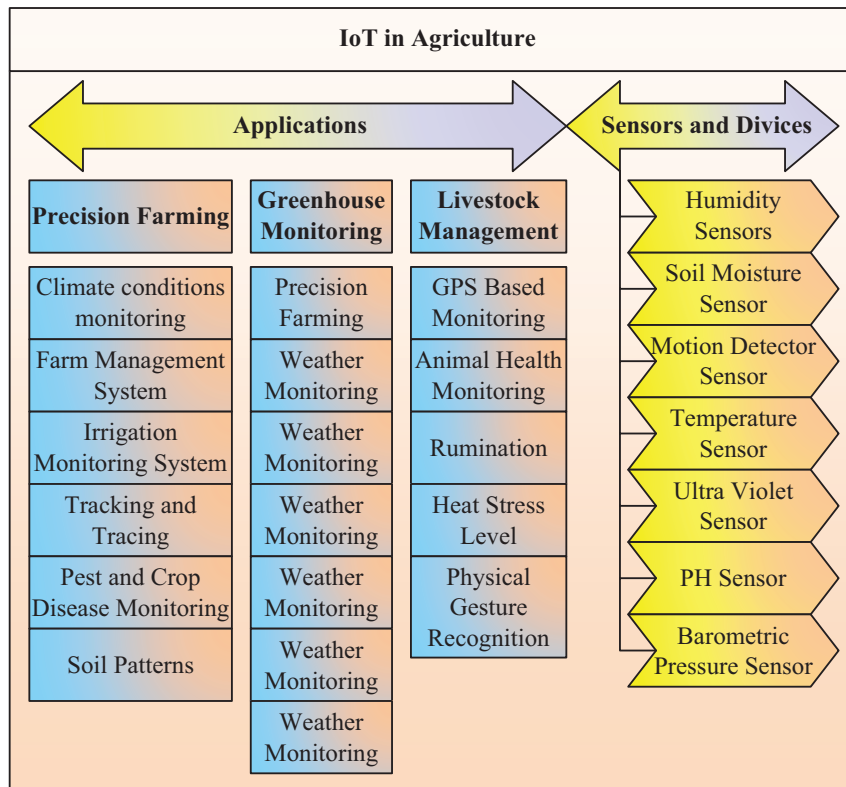


Figure 4. Representation of IoT applications for smart agriculture

c) IoT challenges in Agriculture

The agricultural sector still faces several major challenges, including (see Table 2):

- **Connectivity:** Unfortunately, IoT connectivity in general remains an obstacle because the systems use different methods and protocols for data transfer. The development of the Internet could soon solve this problem, providing fast and secure Internet access to any space, regardless of its dimensions and characteristics.
- **Design and robustness:** An IoT system for agriculture must not only be able to handle connections. It must also be able to deal with conditions in the external space: drones and wearable sensors. IoT for smart grids and weather monitoring stations must be designed functionally and simply, with a level of sustainability that matches the reality of the farm.

Table 2. Related existing IoT challenges in agriculture

IOT CHALLENGES	
Authorization and security	Communications take place over edge, cloud, and machine-to-machine networks. It must be ensured that the message is sent from an authority
Regulation and Compliance	Intersection of multiple areas of regulation including wireless communication, data privacy, drones ...etc
Standards and Implementation	The edge devices are from multiple vendors following different communication protocols makes implementation a challenge
Connectivity and Infrastructure	Connectivity at the farm level is always a challenge. IoT is based on basic premise of communication hence infrastructure is vital
Data Variety and Velocity	Structured, Semi Structured and Un Structured Data on Real-time Basis
Hardware and software	Harsh Environmental Conditions for the Hardware as well as lots of compromise including battery life, features on board, ...etc

For more explanation of fundamental design considerations and major functional layers characteristic of the IoT ecosystem, we have introduced a global IoT architecture that is practically categorized in Figure 5.

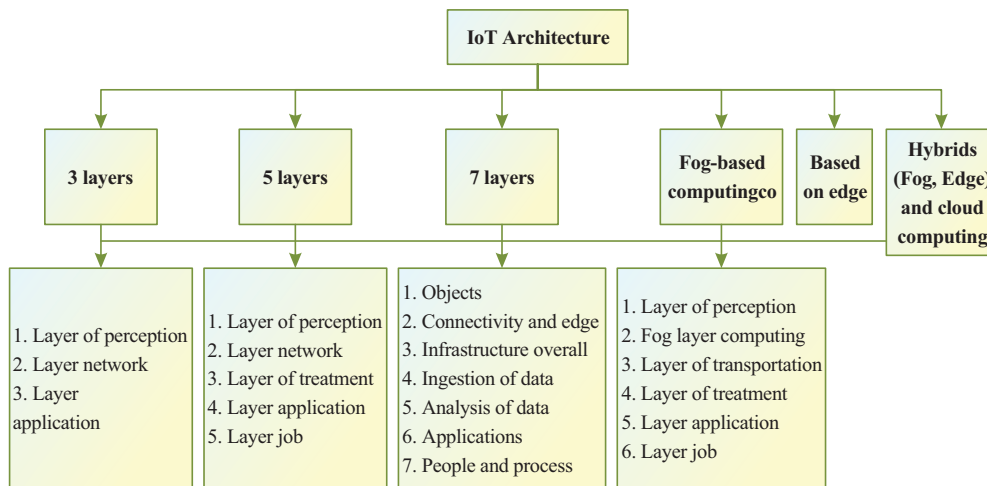


Figure 5. IoT architecture

3.2 Blockchain Technology

Simply put, a blockchain is a long string (or chain) of digital information (or blocks). It sounds like it might not be different from any other data source so far. What's special about a blockchain is that the list is public, stored on many computers around the world, and each new block builds on all previous blocks. The last part is crucial. This means that each block is a permanent record that is difficult to change: if one block changes, all subsequent blocks must also change.

A blockchain stores data in the form of cryptographically linked blocks.

- Each block contains information, like a cell in a spreadsheet.
- Blocks are chained together to form a continuous sequence.

The blockchain is distributed, meaning that multiple copies are stored on numerous computers (nodes).

- All these copies must match for the blockchain to be valid.
- Transactions are verified by miners (network participants) to guarantee their integrity.

When a new transaction is initiated, it enters the blockchain network.

- Transaction information is encrypted using public and private keys.
- Once the block is full, the information is processed by an encryption algorithm, creating a hexadecimal number called a hash.
- This hash is then added to the header of the next block and encrypted with the rest of the block's information.

In this way, a series of blocks is formed and chained together.

Blockchain works (see Figure 6) where each record is called a block; each block contains a section of data and a "hash" generated from the data in each block using cryptography. Blocks are linked to each other by referring to the hash of the previous block.

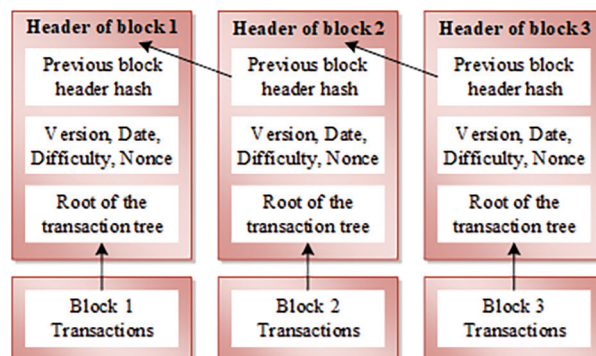


Figure 6. Blockchain works

a) Blockchain architecture

Blockchain architecture is a key concept in blockchain technology. It refers to the structure and manner in which blocks of data are organized and interconnected. Here are some important points about blockchain architecture (see Table 3):

- **Blockchain structure:** The blockchain is made up of a series of interconnected blocks. Each block contains specific transactions or data. When a new block is created, it is linked to the previous one, forming a continuous chain.
- **Decentralization:** Unlike centralized systems, blockchain is decentralized. It is distributed across a network of computers (nodes) that validate and store transactions. This decentralization guarantees the system's security and resilience.
- **Consensus:** To add a new block to the chain, nodes must reach a consensus. Different consensus algorithms, such as proof-of-work (PoW) or proof-of-stake (PoS), are used to verify transactions and guarantee their integrity.
- **Cryptography:** Blockchain security is based on cryptographic techniques. Each block is encrypted and linked to the previous block using a hash function. This makes data modification virtually impossible.
- **Smart Contracts:** Using blockchain technology, all kinds of monitoring data can be stored securely, provided smart contracts are used to automate processes, trigger events and define the necessary terms and conditions for implementation by all parties. Smart contracts are computer protocols stored on the blockchain that are used to digitally facilitate, verify, or enforce the negotiation or performance of a contract. A smart contract is a set of organizational conditions that also govern trust. The key point is that smart contracts are coded using a programming language. Rules, terms and conditions are implemented through controlled coding and reflect the exact agreement approved by all parties. Some blockchains, such as Ethereum, support smart contracts. These are autonomous programs that run automatically when certain conditions are met. They enable advanced functionalities beyond simple transactions.

Table 3. Characteristics of Blockchain-based Smart Contracts

Features	Description
Elimination of centralized authority	Since the blockchain works decentrally with every node in the network, smart contracts can execute autonomously according to predefined rules. Therefore, the decentralization of the system ensures uninterrupted service availability by eliminating single points of failure, reducing data usage and latency, and ensuring accountability.
Forge Resistance	Smart contracts maintain the integrity of the distributed ledger and verify computing logic through digital signatures. Once a smart contract is implemented, it cannot be changed even by its owner.
Transparency	Authenticated users can access transaction data and smart contract logic at any time.
Accuracy	Since conditions are programmed to be immutable and verified multiple times before being deployed to blockchain nodes, execution is automated and guaranteed to be accurate and error-free at execution time. This feature eliminates biased operations and maintains trust between entities through transparent execution.

i. Ethereum is a platform specifically designed to create smart contacts.

You no longer need a trusted third party. Smart contracts are also immutable and distributed. You will need to configure:

- Custom Genesis File
- Custom Data Directory
- Custom Network ID: Disable/Enable Node Discovery

ii. **Solidity:** is an object-oriented programming language for writing smart contracts. It was developed to enable the writing of smart contracts on blockchain platforms like Ethereum.

iii. **Hashing:** Hashing involves generating an encrypted value from a text string using a mathematical function. These functions are called “one-way hash functions” because there is no way to preserve the encryption.

iv. **Ledger:** Can be described as the database that records all transactions in blockchain since day0. It is implemented as chain of blocks linked together back to genesis block. It can be centralized/ decentralized ledger. It can be public/private ledger.

- v. **Nonce:** is a small piece of data in a block that can be randomly and repeatedly changed at any time, allowing miners to continue hashing the entire block's data. Miners keep guessing nonces until they find a nonce that, along with the rest of the block data, generates an output (signature) that matches the block's conditions.

b) Blockchain Resolving IoT Challenges

Blockchain technology is seen as a promising approach to overcoming the challenges posed by the Internet of Things (IoT). Experts and researchers are advocating a more decentralized and distributed IoT architecture to solve these problems. However, integrating blockchain with IoT presents challenges such as scalability, latency, data size and storage, energy efficiency, interoperability, security, cost and regulatory compliance. Cost remains a major obstacle for large-scale IoT deployments. The use of blockchain in the IoT can eliminate the single point of failure and provide a secure mechanism for storing and processing IoT data to help solve some of the challenges facing the IoT.

c) Technical Review of Innovative Agricultural Blockchains

Recently, blockchain technologies have been integrated with many other advances, such as the Internet of Things (IoT), cloud computing and cloud storage, to deliver better services in agriculture. The convergence of blockchain and IoT, defined as the Blockchain of Things (BCoT), has become one of the most useful frameworks in blockchain applications. In many data-intensive applications, such as tracking and recording continuous signals from IoT devices, achieving optimized performance is a challenge. This is due to various theoretical limitations and bottlenecks in blockchain. For example, conventional blockchain systems have reduced on-chain speed due to their decentralized nature and consensus schemes. When the volume of data captured in real-time exceeds transaction capacity, low throughput hampers the use of blockchain technology.

Thus, many innovative agricultural blockchain systems with technical innovations are proposed to ensure better integration to improve data throughput (see Figure 7), security and rapid retrieval of shared data in the agricultural sector, while retaining the main characteristics of blockchain, namely traceability, immutability and data integrity.

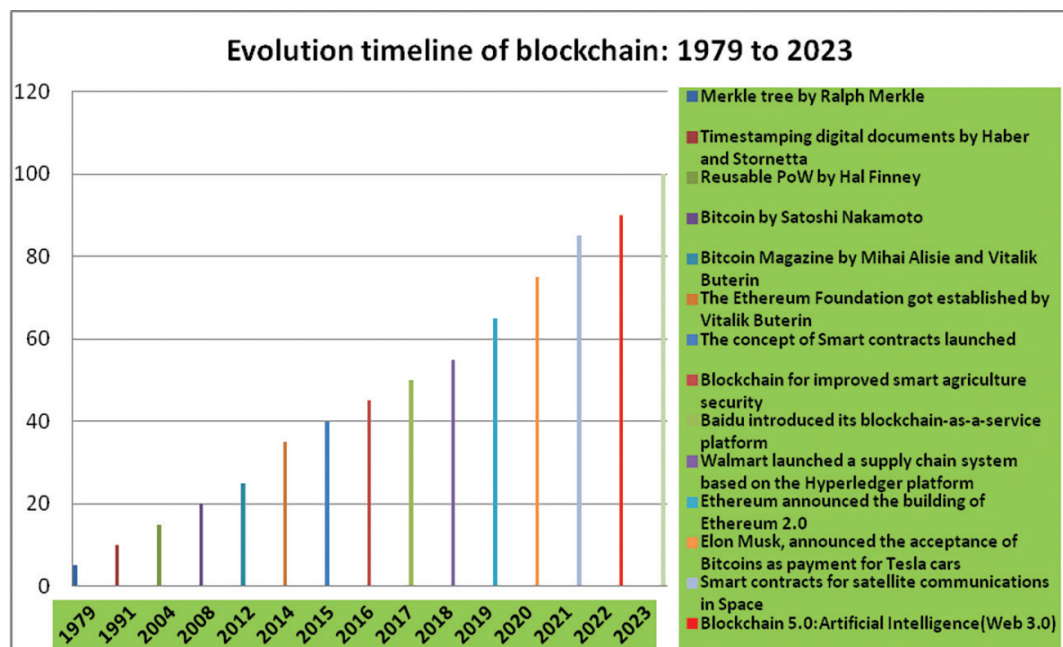


Figure 7. Blockchain Evolution

Public blockchains promote decentralization, transparency, and trustless transactions but face challenges like scalability, energy consumption, and privacy concerns. Private blockchains enhance privacy, control, and efficiency but may face issues of centralization, limited transparency, and security risks.

Table 4 presents the comparison between private blockchain and public blockchain.

Table 4. Private Blockchain vs. Public Blockchain

Criterion	Private Blockchain	Public Blockchain
Access Control	Restricted: Only authorized participants can join the blockchain.	Open: Accessible to everyone without restrictions.
Permission	Requires prior permission to join.	No permission required.
Confidentiality	High: Data is visible only to authorized participants.	Low: All transactions are public and visible to everyone.
Speed	Fast: Fewer nodes to validate, resulting in quicker processing.	Variable: Depends on the number of nodes and network congestion.
Security	Higher: Strict control over participants and permissions.	Lower: Security relies on decentralization.
Examples	Hyperledger Fabric, Corda, Quorum.	Bitcoin, Ethereum, Litecoin.

3.3 System overview

Smart farming refers to agricultural fields equipped with IoT sensors such as humidity, light and water level sensors, as well as actuators.

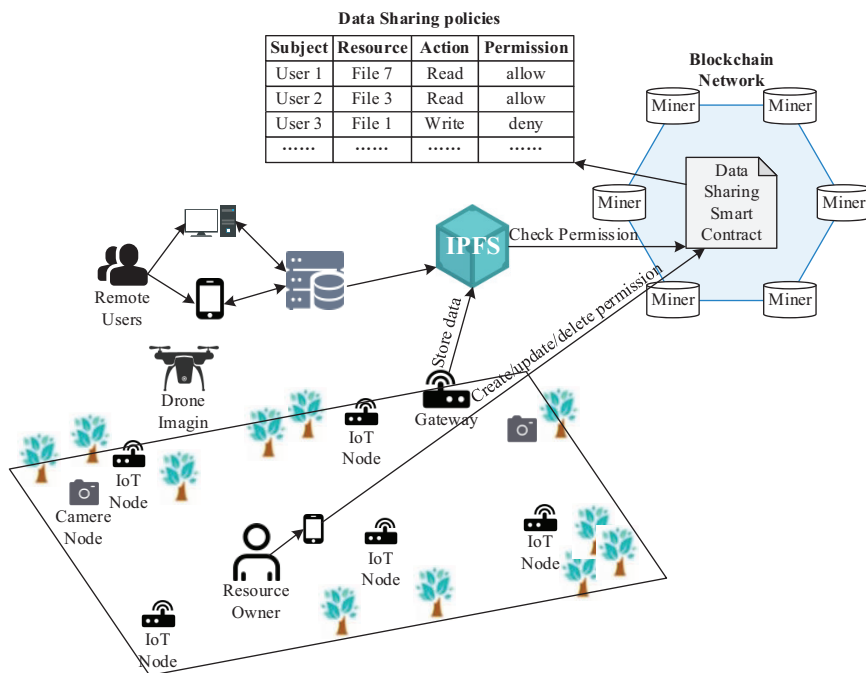
Each agricultural field is managed by its owner via a mobile device or computer.

The owner decides who can access the data generated in the farm field.

- **Interplanetary File System (IPFS):** IPFS is a peer-to-peer distributed file system considered to be the “skeleton of Web.3”. Files stored in IPFS are uniquely identified by their hashes.

These fingerprints are used to create data-sharing policies in the blockchain. When an IoT device generates data in smart farming, it encrypts it and sends it to the IPFS for storage. The resource owner sends a transaction to the smart data-sharing contract to share the data using its hash. This system enables agricultural data to be shared securely using blockchain and IPFS while guaranteeing precise and reliable access control.

Blockchain architecture-based data exchange system that integrates access control for smart farming. It consists of storage devices (IPFS), a large number of servers, IoT gateways, smart contracts, authorized EOS blockchain, resource owners and remote users (see Figure 8). For simplicity, we will implement and test a single smart contract for data exchange. However, in practice, multiple smart contracts must be deployed for each resource owner to share data securely. The resource owner uses the remote user’s public key to create, update, or delete data-sharing policies. In order to access the resource owner’s data, each remote user sends a request to access the data stored in IPFS using a client application. A smart data-sharing contract returns an authorization or denial decision based on the authorization field in the data-sharing policy [14].

**Figure 8.** Overall system overview [33]

We propose the use of IoT-enabled smart actors to enable better data flow mechanisms required by the system. IoT devices will be used to monitor the quality and status of products stored in department stores. They will also monitor and submit data on the prices of agricultural products and services during the pre-harvest and post-harvest periods. IoT devices will also provide information during the cultivation process. IoT systems need to be immunized against unauthorized access to private IoT networks and data. With state-of-the-art blockchain systems and advances in the development of non-traditional smart contracts and distributed ledgers, blockchain is expected to provide magical solutions to many IoT cybersecurity challenges and meet requested security requirements.

a) IoT Architecture for Smart Agriculture

The general architecture of an IoT device consists of sensors to collect information from the environment, actuators based on wired or wireless connections, and a system with a processor, memory, communication modules, input-output interfaces and battery power. There are several typical sensors applied in the smart farming sector, these sensors are used to gather information such as air temperature, soil temperature, air humidity, soil moisture, leaf moisture, precipitation, wind speed, wind direction, solar radiation and barometric pressure.

IoT and blockchain technologies can be used to collect, store and analyze this data, providing farmers with valuable information for optimizing yields, crop management and data-driven agricultural decision-making.

Therefore, the development of future IoT communication systems must meet the following security requirements: IoT devices must operate securely and be authenticated. Data integrity must be guaranteed against falsification, alteration and unauthorized access. IoT device code must be secure and cannot be tampered with.

All IoT devices must be authenticated in the IoT system before being installed on the network. IoT networks must be tamper-resistant in terms of both software and hardware tampering. IoT systems must ensure user security, such as management of credentials, registration, authentication, authorization, and non-repudiation.

IoT systems need to be immunized against unauthorized access to private IoT networks and data. With state-of-the-art blockchain systems and advances in the development of non-traditional smart contracts and distributed ledgers, blockchain is expected to provide magical solutions to many IoT cybersecurity challenges and meet requested security requirements.

b) System Design

i. Data collection layer: The data collection layer, also known as the Data Layer, can come from various data sources in the food supply chain, usually in the form of a platform. In this case, we're using our agricultural IoT platform, which collects environmental data from farms using various sensors and a LoRaWAN connection. This platform acts as the data source.

The Data Layer in this context represents the data collection layer that aggregates information from IoT sensors on farms. This data can then be accessed via our platform's API, enabling improved data management and analysis for intelligent agriculture.

ii. Sensors and IoT devices: Sensors are used to collect various agricultural data in real-time, such as weather conditions, soil moisture, air quality, etc. These sensors are connected to IoT devices that transmit the collected information to a centralized platform for further processing.

iii. Central platform: A centralized platform is used to receive, store and process the data collected by IoT sensors. This platform can include cloud servers, databases, data management software, etc.

iv. Real-time data analysis: Deep learning techniques are used to analyze agricultural data in real-time and make rapid decisions. Deep learning models can be trained for plant disease detection, pest identification, yield prediction, etc....

v. Blockchain: Blockchain technology can be used to secure and immobilize collected agricultural data. It helps establish trust and transparency in agriculture-related transactions by recording information on product provenance, smart contract management, certification tracking and more.

vi. Visualization of results and Automated control: We develop a user-friendly interface to display the results of data analysis.

- We can use interactive dashboards to enable users to monitor crop status, resource utilization and forecasts.

- Use the results of data analysis to automate certain farming tasks such as irrigation, fertilization or the activation of pest control systems.
- You can also integrate alert mechanisms to warn farmers of any detected problems.

Table 5 briefly summarizes the relevant surveys and provides a comparison that also includes the content of this article.

Table 5. Survey reviews

Work / Application	Applications of Deep Learning	UAVs in Smart Agriculture	Edge AI applications	Big Data Applications	Security and Privacy Aspects	Water-saving Irrigation Technologies	Block-chain	IoT	IoT and Block-chain technologies	Challenges and Future Trends
2019	[15]	[16]	[17]		[18]	[19]	[15]	[20]	[18]	
2020		[21]			[22]		[23]	[7]	[24]	
2021				[25]		[26]	[27]	[28]	[16]	
2022	[29]	[30]		[29]			[31]	[29]	[10]	
2023							[32]	[6]	[5]	
Our Work	✓						✓	✓	✓	✓

Research has focused on the integration of IoT and blockchain as abstract technologies, but this study is one of the first research attempts that have investigated how this integration of IoT and blockchain can be implemented in the field of precision agriculture [33].

4 Future work

Based on all these literature articles related to the application of IoT and blockchain technology in agriculture, we need to strengthen the impetus of technological innovation because we need more research for comparative studies and future development directions of the agricultural field in the world. The Internet of Things is more connected than ever, as multiple models are able to communicate with each other, allowing algorithms to reach greater consensus. This will lead to a proliferation of IoT ecosystems actively using consensus algorithms and blockchain. Therefore, there is a need to ensure the confidentiality of systems and devices, data and entities. Security technologies and protocols are also expected to flourish, offering more diverse ways to ensure confidentiality.

Future privacy trends in blockchain are also discussed, as we anticipate that advancements in blockchain and privacy will create new opportunities for smart agriculture and smart contract applications in the near future. Agriculture has evolved from old decision support systems (with pre-defined scheduling functions in most cases) to new age cropping systems incorporating various innovative technologies such as IoT, drones, artificial intelligence, machine learning, etc.

5 Conclusion

Applying the Internet of Things (IoT) to agriculture makes it more efficient, effective and sustainable, ensuring that humanity's growing food needs are always met.

IoT-based smart farming improves the entire agricultural system by monitoring fields in real-time. Thanks to sensors and connectivity, IoT in agriculture not only saves farmers time but also reduces the wastage of resources such as water and electricity. In this way, IoT-based agricultural applications enable breeders and farmers to collect meaningful data. Whether large landowners or smallholders, all need to understand the potential of the agricultural IoT market by installing smart technologies to improve the competitiveness and sustainability of their production. This research also identifies future directions for some open and complex questions that should guide research. In addition, this survey will help researchers identify and solve problems related to the design and integration of blockchain-based technologies for IoT applications.

References

- [1] Wang, X., Zha, X., Ni, W., Liu, R.P., Guo, Y.J., Niu, X., Zheng, K. (2019). 'Survey on block-chain for Internet of Things.' *Comput. Commun.*, 136, 10–29.
- [2] Chaum, D.L. (1979). 'Computer Systems Established, Maintained and Trusted by Mutually Suspicious Groups.' *Electronics Research Laboratory*, Univ. California, California, USA.
- [3] Bayer, D., Haber, S., Stornetta, W.S. (1993). 'Improving the efficiency and reliability of digital time-stamping.' In *Sequences II*. Berlin, Germany: Springer, pp. 329–334.
- [4] Global Blockchain in Agriculture Market. <https://www.globalmarketestimates.com/market-report/global-blockchain-in-agriculture-market>
- [5] Surya, M., Manohar, S., et al. (2023). 'An Interpretation of the Challenges and Solutions for Agriculture-based Supply Chain Management using Blockchain and IoT.' In *2023 7th International Conference on Computing Methodologies and Communication (ICCMC)*. IEEE DOI: 10.1109/ICCMC56507.2023.10083747
- [6] Singh, G., Singh, J. (2023). 'A Cost Effective IoT-Assisted Framework Coupled with Fog Computing for Smart Agriculture.' In *2023 IEEE 8th International Conference for Convergence in Technology (I2CT)*. DOI: 10.1109/I2CT57861.2023.10126231
- [7] Reddy, K.S.P., Roopa, Y.M., L.N., K.R., Nandan, N.S. (2020). 'IoT based Smart Agriculture using Machine Learning.' In *2020 Second International Conference on Inventive Research in Computing Applications (ICIRCA)*. DOI: 10.1109/ICIRCA48905.2020.9183373
- [8] Stergiou, C.L., Psannis, K.E., Gupta, B.B. (2021). 'IoT-based Big data secure management in the fog over a 6G wireless network.' *IEEE Internet Things J*, 8 (7), 5164e5171. DOI: 10.1109/jiot.2020.3033131
- [9] Torky, M., Hassanein, A.E. (2020). 'Integrating blockchain and the internet of things in precision agriculture: Analysis, opportunities, and challenges.' *Computers and Electronics in Agriculture*, Volume 178, November 2020.
- [10] Abdelmaboud, A., Ahmed, A.I.A., Abaker, M., Eisa, T.A.E., Albasheer, H., Ghorashi, S.A., Karim, F.K. (2022). 'Blockchain for IoT Applications: Taxonomy, Platforms, Recent Advances, Challenges and Future Research Directions.' *Electronics*, 11, 630. DOI: 10.3390/electronics11040630
- [11] Bhat, S.A., et al. (2021). 'Agriculture-Food Supply Chain Management Based on Blockchain and IoT: A Narrative on Enterprise Blockchain Interoperability.'
- [12] Tran, Q.N., et al. (2021). 'A Survey on Privacy-Preserving Blockchain Systems (PPBS) and a Novel PPBS-Based Framework for Smart Agriculture.' *Digital Object Identifier*, 10.1109/OJCS.2021.3053032
- [13] Mahdad, M., Hasanov, M., Isakhanyan, G., Dolfisma, W. (2022). 'A smart web of firms, farms and internet of things (IOT): enabling collaboration-based business models in the agri-food industry.' *British Food Journal*, Vol. 124 No. 6, pp. 1857-1874.
- [14] Rahman, M.U., et al. (2020). 'Blockchain Smart Contract for Scalable Data Sharing in IoT: A Case Study of Smart Agriculture.' In *2020 IEEE Global Conference on Artificial Intelligence and Internet of Things (GCAIoT)*.
- [15] Weng, J., Weng, J., Zhang, J., Li, M., Zhang, Y., Luo, W. (2019). 'DeepChain: Auditable and Privacy-Preserving Deep Learning with Blockchain-based Incentive.' *IEEE*, DOI: 10.1109/TDSC.2019.2952332.
- [16] Pranto et al. (2021). 'Blockchain and smart contract for IoT enabled smart agriculture.' *PeerJ Comput. Sci.*, DOI: 10.7717/peerj-cs.407/ 2021.
- [17] Gia, T.N., Qingqing, L., Queralta, J.P., Zou, Z., Tenhunen, H., Westerlund, T. (2019). "Edge AI in smart farming IoT: CNNs at the edge and fog computing with LoRa", *Proc. IEEE AFRICON*, pp. 1-6, Sep. 2019.
- [18] Wu, H.-T., Tsai, C.-W. 'An Intelligent Agriculture Network Security System Based on Private Blockchains.' *Creative Commons Attribution-NonCommercial (CC BY-NC)*.
- [19] Takeuchi, Y. '3D printable hydroponics: A digital fabrication pipeline for soilless plant cultivation.' *IEEE Access*, vol. 7, pp. 35863-35873, 2019.

- [20] Lambrinos, L. 'Internet of Things in Agriculture: A Decision Support System for Precision Farming.' In *2019 IEEE Intl Conf on Dependable, Autonomic and Secure Computing, Intl Conf on Pervasive Intelligence and Computing, Intl Conf on Cloud and Big Data Computing, Intl Conf on Cyber Science and Technology Congress (DASC/PiCom/CBDCCom/CyberSciTech)*.
- [21] Boursianis, A.D., Papadopoulou, M.S., Diamantoulakis, P., Liopa-Tsakalidi, A., Barouchas, P., Salahas, G., et al. (2020). 'Internet of Things (IoT) and agricultural unmanned aerial vehicles (UAVs) in smart farming: A comprehensive review.' *Internet Things*, Mar. 2020.
- [22] Dhar, P. 'Cybersecurity report: 'Smart farms' are hackable farms.' *IEEE Spectr.*, Mar. 2021.
- [23] Yang, X., et al. (2021). "Trusted Blockchain-Based Traceability System for Fruit and Vegetable Agricultural Products", *Digital Object Identifier*. DOI: 10.1109/ACCESS.2021.3062845
- [24] Vangala, A., Das, A.K., et al. (2020). "Smart Secure Sensing for IoT-Based Agriculture: Blockchain Perspective", *IEEE Sensors Journal*. DOI: 10.1109/JSEN.2020.3012294
- [25] Maddikunta, P.K.R., Hakak, S., Alazab, M., Bhattacharya, S., Gadekallu, T.R., Khan, W.Z., et al. (2021). "Unmanned aerial vehicles in smart agriculture: Applications requirements and challenges", *IEEE Sensors J.*, vol. 21, no. 16, pp. 17608-17619, Aug. 2021.
- [26] Benyezza, H., Bouhedda, M., Rebouh, S. 'Zoning irrigation smart system based on fuzzy control technology and IoT for water and energy saving.' *J. Cleaner Prod.*, vol. 302, Jun. 2021.
- [27] Shahid, A., et al. (2020). "Blockchain-Based Agri-Food Supply Chain: Complete Solution", *Digital Object Identifier*. DOI: 10.1109/ACCESS.2020.2986257
- [28] Vunnava, S.L., Yendluri, S.C., Dhuli, S. (2021). "IoT based novel hydration system for smart agriculture applications", *Proc. 10th IEEE Int. Conf. Commun. Syst. Netw. Technol. (CSNT)*, pp. 505-509, Jun. 2021.
- [29] Qazi, S., Khawaja, B.A., Farooq, Q., et al. (2022). "IoT-Equipped and AI-Enabled Next Generation Smart Agriculture: A Critical Review", Current Challenges and Future Trends. *IEEE*, 2022.
- [30] Ubina, N.A., Cheng, S.-C. 'A review of unmanned system technologies with its application to aquaculture farm monitoring and management.' *Drones*, vol. 6, no. 1, pp. 12, Jan. 2022.
- [31] Agrawal, K., Aggarwal, M., Tanwar, S., et al. (2022). 'An Extensive Blockchain Based Applications Survey: Tools, Frameworks, Opportunities, Challenges and Solutions.' *IEEE*, DOI: 10.1109/ACCESS.2022.3219160.
- [32] Raza, Z., Haq, I.U., Muneeb, M., et al. (2023). 'Agri-4-All: A Framework for Blockchain Based Agricultural Food Supply Chains in the Era of Fourth Industrial Revolution.' *IEEE Access*, DOI: 10.1109/ACCESS.2023.3259962.
- [33] Marzougui, F., Elleuch, M., Kherallah, M. (2023). "Literature Survey of Emerging Technologies IoT and Blockchain in Digital Agriculture", In *Hybrid Intelligent Systems: 23th International Conference on Hybrid Intelligent Systems (HIS 2023)*, December 12–14, 2023. Springer Nature. In press.