

Novel Design of Blockchain based IIoT Framework for Smart Factory

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Abstract— A smart factory is an advanced manufacturing system that utilizes various cutting-edge technologies such as IIoT (Industrial Internet of Things), big data, AI(Artificial Intelligence), blockchain to automate and optimize production processes. While there is a growing demand for smart factories in recent times, the adoption and proliferation of these facilities have been delayed due to concerns about security, the reliability of collected information, and challenges in management and control. Moreover, traditional centralized smart factory systems pose a risk of operational downtime in the event of failures or attacks since a central server controls the entire system. Therefore, we propose the design of a secure, transparent, and reliable blockchain-based IIoT framework for smart factories. The framework consists of three layers: the blockchain core layer, the blockchain operation layer, and the IIoT service layer. The IIoT service layer plays a crucial role in providing various services essential for the advancement of smart factories, utilizing blockchain technology. Our proposed framework combines IIoT and blockchain technologies to leverage the advantages of decentralization, trust, security, transparency, data management, and traceability.

Keywords— Blockchain, Industrial Internet of Things(IIoT), Smart Factory, Framework, Decentralization

I. INTRODUCTION

With the advancement of various technologies and innovative ideas such as IIoT, big data, AI, edge and cloud computing, and blockchain, the modern industry is evolving to a new level [1]. Smart factories represent an advanced manufacturing system that harnesses these latest technologies to automate and optimize production processes. Smart factories are a core concept driving the digital transformation of manufacturing industries, enhancing productivity, improving quality, and conserving resources and time.

Despite the growing demand for smart factories driven by the development of IIoT technology and intelligent information technology, their construction and proliferation have been delayed due to security concerns, reliability issues of collected information, and challenges in management and control. In the existing centralized smart factory system, a central server controls the entire system, so there is a risk of operation interruption due to failures and attacks. In particular, recent studies have shown that IIoT cloud platforms for smart factories are semi-trusted third parties, and there is a security

risk in managing smart factory information [2, 3]. Therefore, to promote the activation of the smart factory industry, a trusted platform is needed to ensure the management of IIoT devices and the reliability of collected information.

Blockchain is a distributed ledger management technology that stores data in a chain-like structure of blocks connected in a peer-to-peer-based distributed data storage environment. Blockchain technology has the potential to provide innovative solutions in various industrial sectors, including reliable data exchange, smart contracts, security, and logistics management in a decentralized environment [4]. The combination of IIoT and blockchain technology in the smart factory domain can enhance safety, efficiency, and transparency, bringing innovation to various processes such as manufacturing process optimization, quality management, and distribution management.

In this paper, we design the architecture of a blockchain-based IIoT framework for smart factories. The proposed framework consists of three layers: the blockchain core layer, the blockchain operation layer, and the IIoT service layer. The blockchain core layer and blockchain operation layer provide essential technologies for the operation of the blockchain system and functionalities required for blockchain system operation in the IIoT environment. The IIoT service layer, a critical component, utilizes blockchain to offer various services necessary for the advancement of smart factories, including IIoT device management, smart data management, and automated control services.

Firstly, the IIoT device management service, based on blockchain, provides efficient and reliable authentication of IIoT devices, verification and management of the status information of IIoT devices, firmware updates, and history management. Secondly, the smart data management service shares data in a decentralized manner, without the need for a central DB server, leveraging blockchain technology. The irreversibility of blockchain ensures data integrity collected from IIoT devices and transparency in the data processing process. Additionally, we facilitate smart factory advancement by offering data through open APIs for machine learning and big data analysis of the collected data. Lastly, the automated control service utilizes smart contracts to automate manufacturing processes within the smart factory, inspect the

manufacturing status, and provide control over the manufacturing process.

The rest of this paper is organized as follows. In Section II, we provide a brief overview of blockchain and IIoT, and review relevant research on blockchain based smart factories. Section III offers a detailed explanation of our proposed blockchain-based IIoT Framework. In Section IV, we discuss the challenges that arise when practically applying IIoT and blockchain technology to smart factories. Finally, Section V concludes the paper.

II. RELATED WORK

A. Blockchain & IIoT & Smart factory

IIoT refers to Internet of Things (IoT) technology used in industrial environments [5]. IIoT connects various devices and sensors in manufacturing, production, and industrial sectors to collect data, which can be transmitted to central servers or the cloud. This enables real-time monitoring, remote operation, and maintenance in industrial environments, leading to increased production efficiency and improved product quality. The IIoT architecture is composed of three layers: the physical layer, communication layer, and application layer [6]. The physical layer consists of physical devices such as sensors, manufacturing equipment, and data centers. The communication layer uses network technologies like wireless sensor networks, 5G, and others to integrate various devices from the physical layer. These two layers together form cyber-physical systems (CPS) to support the development of applications like smart factories [7].

Blockchain is a distributed ledger management technology where data in block form is connected in a chain within a peer-to-peer based distributed data storage environment. This technology ensures data safety and integrity and utilizes peer-to-peer networks for data sharing and verification [8]. In blockchain, anyone can read the data, but tampering with it is difficult, ensuring the reliability of the data. This is a crucial characteristic of distributed ledger management, which guarantees the trustworthiness of data. Nodes participating in the blockchain store and share the same records, and any changes to the data require consensus among the nodes. Therefore, as the number of participating nodes increases, blockchain management becomes more complex, but decentralization is reinforced. Decentralization is one of the core features of blockchain, enabling the provision of services in entirely different forms compared to traditional centralized services.

Blockchain technology has the potential to offer innovative solutions in various industries, such as reliable data exchange, smart contracts, security, and logistics management, within this decentralized environment [4]. Leveraging these core features of blockchain, it is possible to implement innovative technologies and services, such as data management, enhanced security, real-time tracking, and automation, in smart factories and manufacturing environments.

B. Blockchain based Smart Factory

[3] proposes a solution that combines Blockchain technology with IIoT architecture for smart factories. The proposed architecture consists of five layers: the sensing layer, the management hub layer, the storage layer, the firmware layer, and the application layer. The Sensing layer includes various types of sensors and at least one microcomputer, which collect information from various devices and preprocess the collected data. The Management Hub layer integrates and coordinates various devices and responds to user requirements in real time. The Storage layer functions as a data center, specifically designed for storing data using a private blockchain. Additionally, the proposed architecture enhances data security and privacy by employing a whitelist mechanism and asymmetric encryption mechanism.

According to [2], while there are many mature IIoT cloud platforms for smart factories, securely storing and sharing smart factory data on these platforms remains a challenge. To address this issue, [2] proposes a blockchain-based security access scheme for IIoT in smart factories that supports traceability and revocability. In this proposed scheme, the blockchain performs unified identity authentication and stores all public keys, user attribute sets, and revocation lists.

[9] presents a blockchain system that considers both security and efficiency for power-constrained IIoT devices in smart factories. The proposed credit-based consensus mechanism can reduce the power consumption of honest devices. Additionally, the proposed data authority management method protects data privacy without affecting system performance.

III. BLOCKCHAIN BASED IIOT FRAMEWORK

The combination of IIoT and blockchain technology enhances safety, efficiency, and transparency in the field of smart factories, bringing innovation to various application areas such as manufacturing process optimization, quality management, and supply chain management. A more detailed explanation of the key advantages resulting from the combination of IIoT and blockchain technology is as follows:

- **Decentralization:** Blockchain utilizes a distributed network instead of centralized systems. This means that data and processes within smart factories are not controlled from a central authority but are distributed and managed among multiple nodes. This enables the storage and management of reliable, distributed data and enhances resilience to device failures or faults. Important decisions and transactions can be executed without the need for central intermediaries, thereby strengthening trust.
- **Trust and Security:** Blockchain technology enhances data integrity and security. It provides assurance that data blocks on the blockchain are not altered or tampered with, ensuring the trustworthiness of the data. Storing data related to manufacturing processes and product information on the blockchain within a smart factory helps prevent tampering or fraudulent activities,

ensuring product safety. Additionally, encryption techniques can further enhance data security.

- **Transparency:** Blockchain provides transparency of data, allowing all relevant parties to access and track transactions. Recording all data related to the manufacturing process within a smart factory on the blockchain offers transparency regarding production stages, product origins, quality control, and distribution. This fosters greater trust between producers and consumers and provides information about product safety and quality.
- **Data Management and Traceability:** Blockchain facilitates data tracking and management across all stages, from raw materials to the final product. This enables capabilities such as tracking defective products, recall management, and optimizing production processes. Manufacturers can monitor the production and distribution processes of their products in real-time and take prompt action in case of issues.

In this paper, we design the architecture of a blockchain-based IIoT service framework for smart factories. As shown in Figure 1, the proposed framework operates on top of a communication layer where IIoT devices are interconnected and aims to provide services that support the operation, control, and data analysis of the higher-level smart factory. This framework is internally composed of three main layers:

- **Blockchain Core Layer:** This layer provides the core technologies required for the operation of the blockchain system. It consists of 1) cryptographic algorithms including hash functions, elliptic curve cryptosystems, and ECDSA electronic signatures, 2) consensus algorithms suitable for IIoT environments, 3) transaction management for the structure, storage, and verification of transactions, and 4) ledger management components including technologies such as ledger storage and merkle tree.

- **Blockchain Operation Layer:** This layer offers functionalities necessary for operating the blockchain system within the IIoT environment. It encompasses smart contracts, which are programs executed on the blockchain, governance mechanisms that determine policies and rules for blockchain operation, and components responsible for authenticating and controlling access to participating nodes in the blockchain.
- **IIoT Service Layer:** This layer provides blockchain based IIoT services for smart factories. It includes services for managing IIoT devices that comprise the smart factory, a smart data management service for processing data collected from IIoT devices, and an automated control service for controlling the manufacturing process of the smart factory.

In particular, the IIoT Service Layer is a crucial layer for delivering various services essential for advancing smart factories using blockchain. Here are detailed descriptions of the IIoT services provided in this layer:

IIoT Device Management

- **Device authentication service:** In a smart factory environment, due to the participation of a large number of IIoT devices, authentication is essential to verify the legitimacy of devices and defend against the infiltration of malicious devices by attackers. It is difficult to apply traditional authentication methods to heterogeneous IIoT devices with different hardware, communication methods, and security policies. Authentication services based on blockchain can provide efficient and highly reliable authentication for IIoT devices.
- **Firmware update service:** The firmware of IIoT devices needs to be updated frequently, and there is a high probability that an attacker's malware will be secretly propagated and infiltrated into the device during this process. To prevent such attacks, it is

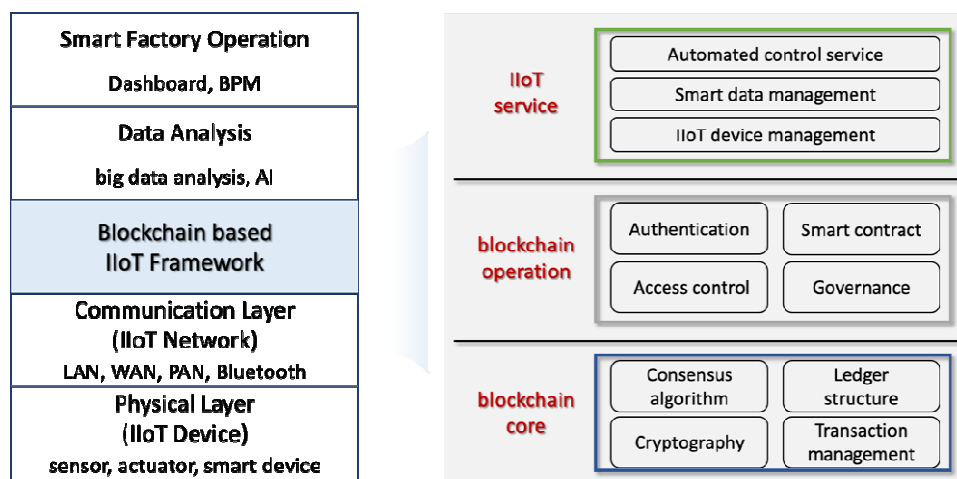


Figure 1 Proposed Blockchain based IIoT Framework for Smart Factory

necessary to ensure the safety of the update process and firmware, and existing methods have difficulty securing centralized update servers. Blockchain based firmware update services have the advantage of providing firmware integrity and reliability, and transparently tracking and verifying update history.

- **Device status managing service:** Smart factories require management technology that can efficiently maintain a large number of IIoT devices of various types. In particular, management technology that can collect and analyze the overall life cycle status information from device installation to operation status check, location movement, malfunction detection, and removal is required. The blockchain-based device status managing service secures the reliability of device management and enables efficient device status information sharing.

Smart Data Management

- **Data sharing service:** Various types of data, such as sensing information from IIoT devices and information about the progress of manufacturing processes, are generated during manufacturing processes. Depending on the nature of the information, it needs to be shared between factory managers and devices. Data sharing service, based on blockchain, enables decentralized data sharing without the need for a central database server. Furthermore, it facilitates information sharing and collaboration between multiple smart factory hubs.
- **Data validation service:** Data collected through IIoT devices is susceptible to errors at each stage of collection, transmission, and storage, and there is a high risk of malicious manipulation to disrupt manufacturing processes. To prevent these issues, it is essential to ensure the integrity of collected data and the transparency of data processing. The data validation service, based on the irreversibility of blockchain, verifies data to guarantee its reliability.
- **Open data service:** Collected data needs to be supplied to external entities to assist in making policy decisions regarding smart factory operations while ensuring that sensitive manufacturing information is not leaked. The open data service provides the functionality to supply collected data to the external world through open APIs. In particular, it supports the enhancement of smart factories by providing clean data to upper layers such as machine learning and big data analysis.

Automated Control Service

- **Automated manufacturing process service:** This service provides automation of manufacturing processes within the smart factory using smart contracts. It supports the definition, creation, deployment, and execution of smart contracts tailored to the manufacturing processes defined through analysis of the smart factory's manufacturing environment and

requirements. It ensures that predefined processes are automatically executed when specific conditions are met. Additionally, it leverages blockchain technology to enable fault-tolerant progress of manufacturing processes even in the presence of certain failures.

- **Manufacturing control service:** This service offers functionalities to inspect the manufacturing status within the smart factory and control the manufacturing processes. It verifies the environmental information of the smart factory and the information related to manufacturing processes. It facilitates easy process control for administrators and provides access control and security policy management to prevent the leakage of confidential information in the manufacturing process. Furthermore, when integrated with financial services, this service can serve as a foundation for the end-to-end integration of processes, from product contracts and orders to production, distribution, and payments.

IV. DISCUSSION

Despite the various advantages of combining IIoT and blockchain technology, there are challenges when it comes to practical implementation in smart factories.

- **Data Privacy:** There can be conflicts between the transparency of blockchain and data privacy. Blockchain's nature of publicly sharing data may make it challenging to protect sensitive production data and personal information in smart factories. Finding a way to manage data access rights while maintaining data integrity is necessary. Additionally, while transactions in blockchain are processed anonymously, in some cases, specific data can be linked to certain companies or devices, posing privacy concerns. Striking a balance between anonymity and identifiability is essential.
- **Energy Efficiency:** Blockchain can consume a significant amount of energy due to its complex encryption and consensus processes. On the other hand, IIoT devices often operate in low-power environments, necessitating the minimization of power consumption. Therefore, implementing blockchain in smart factories should consider energy efficiency.
- **Throughput Restrictions:** Most blockchains have limitations on transaction processing speed, making it challenging to handle large-scale real time data processing in smart factories. Especially in large-scale smart factory environments, scalability issues in the blockchain network may arise. Therefore, effective strategies are required to manage numerous IIoT devices and large datasets.
- **Security:** Some blockchain networks face risks of malicious activities like 51% attacks, which can impact the security of smart factory data. Additionally, smart contracts may be exposed to threats due to code bugs or security vulnerabilities, which need to be considered.

Taking these challenges into account, we have designed and proposed a secure and practical blockchain-based IIoT framework in Section III. As future tasks, we aim to conduct research on technologies that can realistically implement the proposed framework and develop a blockchain-based IIoT system for smart factories. The combination of blockchain and IIoT is a crucial factor driving innovation in the smart factory sector, and by overcoming these challenges, we can establish a safe and efficient production environment.

V. CONCLUSIONS

In this paper, we designed the architecture of a secure, transparent, and reliable blockchain-based IIoT framework for smart factories. The proposed framework consists of three layers: the blockchain core layer, the blockchain operation layer, and the IIoT service layer. The blockchain core layer and blockchain operation layer provide essential technologies for the operation of the blockchain system and functionalities required for blockchain system operation within the IIoT environment. The IIoT service layer is a crucial layer that leverages blockchain to offer various services necessary for the enhancement of smart factories, including the authentication of trustworthy IIoT devices, verification and management of the status information of IIoT devices, transparent and secure sharing and verification of information collected through IIoT devices, and automated control services for manufacturing processes within smart factories. The combination of IIoT and blockchain technology offers a variety of advantages, including decentralization, trust, security, transparency, data management, and traceability.

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