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Integrated Object Detection and Blockchain Framework for Remote Safety Inspection at Construction Sites

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Abstract: Construction sites are characterized by dangerous situations and environments that cause fatal accidents. Potential risk detection needs to be improved by continuously monitoring site conditions. However, the current labor-intensive inspection practice has many limitations in monitoring dangerous conditions at construction sites. Computer vision technology that can quickly analyze and collect site conditions from images has been in the spotlight as a solution. Nonetheless, inspection results obtained via computer vision are still stored and managed in centralized systems vulnerable to tampering with information by the central node. Blockchain has been used as a reliable and efficient decentralized information management system. Despite its potential, only limited research has been conducted integrating computer vision and blockchain. Therefore, to solve the current safety management problems, the authors propose a framework for construction site inspection that integrates object detection and blockchain network, enabling efficient and reliable remote inspection. Object detection is applied to enable the automatic analysis of site safety conditions. As a result, the workload of safety managers can be reduced with inspection results stored and distributed reliably through the blockchain network. In addition, errors or forgery in the inspection process can be automatically prevented and verified through a smart contract. As site safety conditions are reliably shared with project participants, project participants can remotely inspect site conditions and make safety-related decisions in trust.

Key words: Construction safety management, Object detection, Blockchain, Remote safety inspection

1. INTRODUCTION

Construction sites are complex due to the extensive use of sophisticated plants, equipment, modern methods of construction, and multidisciplinary and multitasked aspects of the project workforce [1]. As a result, there are usually unstable and unpredictable environments at construction sites with dangerous conditions (e.g., opening floors without guardrails, fire-vulnerable activities without fire extinguishers), which are fundamental causes of fatal accidents [2]. Therefore, to reduce the occurrence of fatal accidents caused by dangerous conditions, timely decisions of safety managers based on continuous safety condition monitoring and collection of site information are first required [3]. However, the actual construction site safety monitoring is ineffective because it is labor-intensive, involving safety managers inspecting their sites on foot, the time-consuming safety inspection process, and the insufficient number of safety managers to handle the workload [4,5]. Also, inspection results are recorded in handwriting, which requires additional work to transfer inspection results into a centralized computer system [6].

To solve these problems, many researchers proposed remotely inspecting the safety conditions of construction sites through computer vision. Computer vision technology, which includes object detection, object tracking, and action recognition, extracts a large amount of data and information from images and videos and classifies them into pre-defined categories [5]. Much research shows that the application of computer vision technology at construction sites has great potential to improve their safety by enabling remote inspection of dangerous conditions in real-time, using monitoring tools such as mobile devices, drones, and CCTV.

However, even though computer vision can improve safety inspection, inspection results are still stored and managed through centralized systems, widely used for information storage and management in the construction industry [7]. Moreover, information security and management heavily rely on a central node in centralized systems, which can arbitrarily tamper with the stored information [8]. For example, inspection results, which are evaluated as project safety performance and often lead to incentives for safety managers, are often filtered and forged for personal or collective interest [9,10]. As a result, actual construction site inspection results obtained through manual inspection and computer vision-based inspection are still unreliable to be utilized in real-time; thus, project stakeholders still carry out the actual site inspection process on foot without trusting inspection result reports [11]. Hence, integrating computer vision with decentralized data storage and management systems is necessary to avoid centralized systems' problems while gaining the advantages of computer vision-based safety inspections. Such integration will enable remote inspections through computer vision, reducing safety managers' inspection workload.

Blockchain is a distributed and verifiable ledger technology. Consensus algorithms are the basis of decentralization, and cryptographic algorithms ensure blockchain security. Information can be automatically compared and verified through smart contracts, a pre-defined computer-coded consensus protocol [12]. These characteristics enable the blockchain to serve as a distributed information management system that makes information traceable and tamper-proof. Despite the blockchain potential, only a few researchers studied integrating computer vision and blockchain. Their research is limited since the blockchain was only used as a simple distributed storage system or reinforcement of computer vision performance without sufficient utilization of its information management aspect or presenting a framework to be used in the actual site.

This study proposes an integrated object detection and blockchain framework for remote safety inspection processes at construction sites with detailed inspection-related key values for the practical inspection process. Furthermore, the key values automatically verify their adequacy through the smart contract. As a result, safety condition information collected and analyzed through object detection can be safely stored and automatically verified. Consequently, it will accelerate the site safety inspection workflow and secure safety information more reliably so that the information can be utilized throughout the whole construction project's life cycle.

2. RELATED WORKS

2.1. Computer vision in the construction industry

The construction industry introduced computer vision as a solution for time-consuming and labor-intensive inspection practices at construction sites. Computer vision can provide a rich set of information about construction sites and has great potential for real-time, rapid, accurate, and comprehensive collection and management of data about complex construction processes [5]. However, as mentioned earlier, inspection results collected and analyzed using computer vision are stored in centralized systems, where its information security and management heavily rely on a central node. Thus, the information collected and analyzed using computer vision requires a decentralized system to overcome the risks posed by centralized systems, including poor quality of safety information due to errors or forgery [9,10,13]. The decentralized system can ensure the reliability and adequacy of data through specific algorithms and verification processes.

2.2. Potential of blockchain for computer vision in the construction industry

Blockchain is recognized as an effective decentralized data management system. It is a peer-to-peer distributed ledger technology that is executed, shared, authorized, and stored by participants in the form of grouping previous block hashes, transactions, and timestamps into blocks [14]. Since the blocks are grouped in chronological order, a block cannot be changed retrospectively without changing all subsequent blocks. Also, the smart contract, which is a computer-coded consensus protocol in a blockchain network, can encode any predetermined rules and execute the corresponding operations when trigger conditions are satisfied [12].

With these features, blockchain is recognized as a distributed database solution that can secure the reliability and traceability of information shared and stored in distributed ledgers. Cho et al. [15] introduced an IoT data and blockchain integrated system providing transparent data on fine dust to network participants. Sheng et al. [16] proposed construction quality information management using blockchain that ensured the information structure and authorization sequence during proposed quality management processes. Lee et al. [17] developed an integrated digital twin and blockchain for accountable project-related information sharing among stakeholders. Wang et al. [18] proposed a blockchain-based supply chain framework that achieves real-time scheduling control and information traceability in the precast supply chain. Like these studies, integrating blockchain and computer vision can create reliable and transparent distributed systems for information generated through computer vision. At the same time, it can prevent human errors or forgery of information by comparatively verifying information with pre-defined smart contracts.

However, only a few researchers conducted research integrating computer vision and blockchain. For example, Khan et al. [19] proposed the inspection data recording system with optical character recognition, allocating a hash value to inspection records through blockchain-based proof of existence service. Zhang et al. [20] proposed a blockchain-based construction site information management system, including object detection results. In addition, they proposed an image management method with third-party storage for images that are hard to be stored in blockchain. One of the limitations of the studies listed above is that blockchain was only used as a simple distributed storage system without utilizing its information management aspect or presenting a framework to be implemented at the actual construction site.

3. INTEGRATED OBJECT DETECTION AND BLOCKCHAIN FRAMEWORK FOR REMOTE INSPECTION AT A CONSTRUCTION SITE

The authors aim to develop an integrated object detection and blockchain framework that can ensure the reliability of inspection data by storing and sharing it and preventing errors or forgery through comparative verification. Object detection automatically analyzes potential risks at a construction site and transmits detection data transactions to the Hyperledger Fabric (HLF) blockchain network, an open-source consortium blockchain network platform under Linux Foundation. Transactions produced during the inspection process are recorded through the HLF blockchain network and comparatively verified through pre-defined chaincodes (refers to the smart contract in HLF) to eliminate the possibility of human errors or forgery. Through this framework, safety managers can remotely instruct site inspection work without walking around their site, and all project participants can check the shared site inspection data with trust.

3.1. Framework data structures

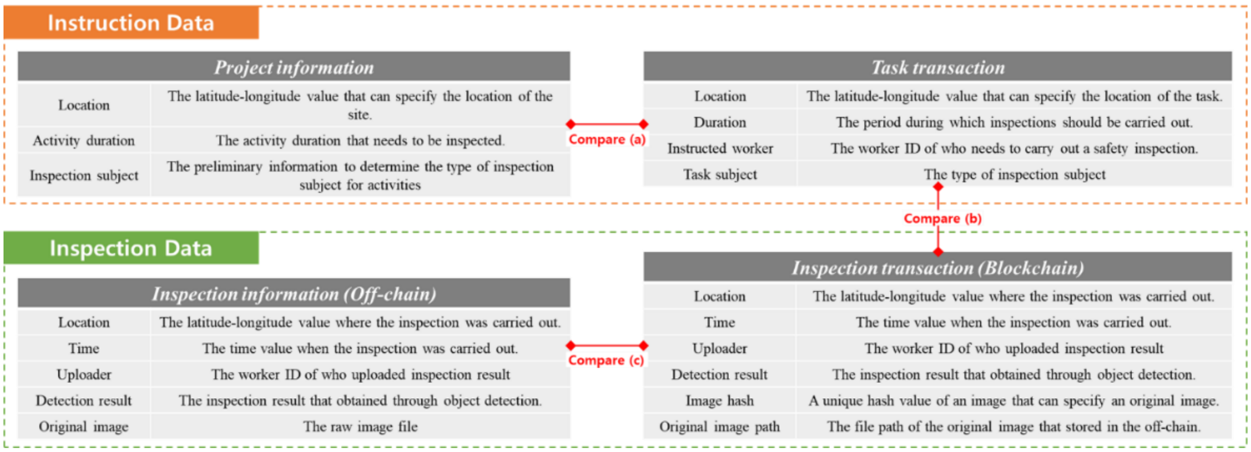

Figure 1. Types of transactions and comparative relations between the transactions

There are four types of data in the proposed framework: project information, task transaction, inspection data in the blockchain, and inspection data in the off-chain (refers to any non-transactional database that does not use the blockchain) (Figure 1). The project information is pre-defined and project-related. It is a criterion for safety managers to determine what inspection should be instructed and carried out. The task transaction is inspection instruction information created by a safety manager. It indicates to workers what inspection should be carried out. Also, another two types of inspection data indicate the same inspection results generated during the inspection by workers. One set of results is stored in the blockchain, and the other in the off-chain storage. The inspection data stored in the off-chain storage includes the original image used in the object detection process. However, the inspection data stored in the blockchain contains the image hash value and original image path instead of the original image. The framework overview section provides more details about the generation and verification of these data.

3.2. Framework overview

The integrated object detection and blockchain framework consist of seven components (Figure 2). In Figure 2, the solid lines with arrows indicate the workflow, the dashed lines with arrows indicate the transaction flow, and the thick gray arrows indicate the data processing. Figure 2 shows how inspection instructions and results are created and inputted into the blockchain network. Also, it shows the verification process through chaincodes, the sharing process of a generated block, and how original images stored in an off-chain database can maintain their integrity.

In detail, based on the project information, safety managers can instruct workers to perform site inspections by creating a task transaction, detailed in Figure 1. Based on the task transaction into the blockchain network (Figure 2(a)), workers complete the inspection as they are instructed and take pictures through a decentralized application (DApp) mounted on their edge devices, such as a smartphone or tablet PC. As the workers perform inspections with DApp, site conditions are analyzed in real-time through the YOLOv4 (You Only Look at Ones) object detection model and metadata extraction API deployed within the DApp. After the analysis of site conditions, the inspection results in the JavaScript Object Notation (JSON) format, and the transaction proposal are automatically generated (Figure 2(b)).

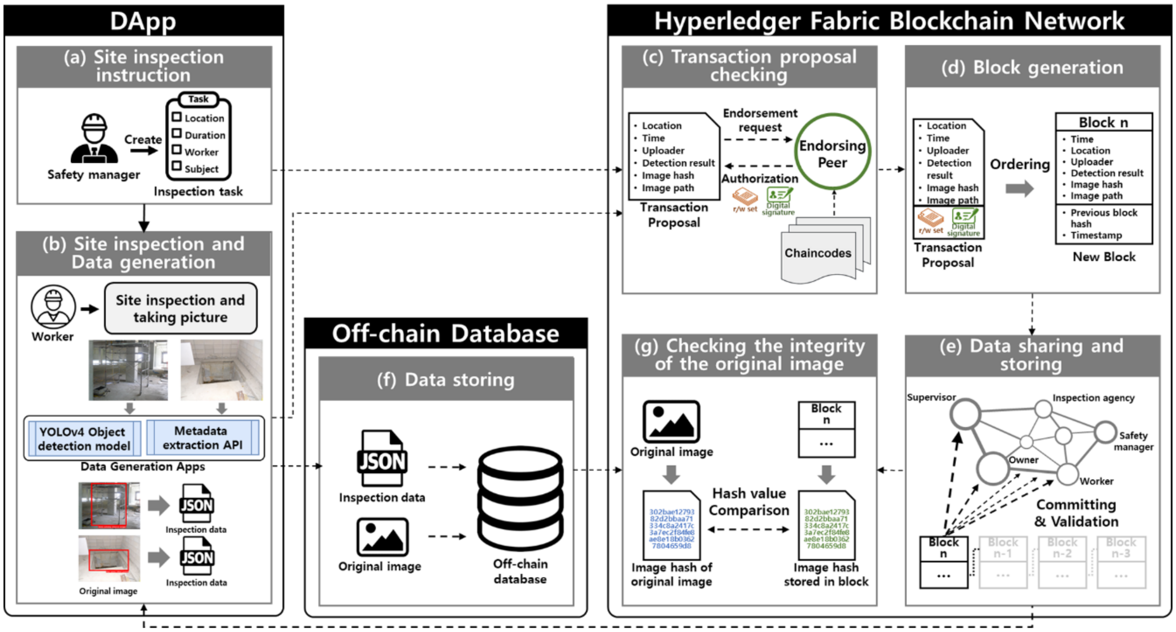

Figure 2. Integrated object detection and blockchain framework

After the transaction proposal is generated, it is submitted to endorsing peers in the blockchain network. The endorsing peers verify the transaction proposal's data adequacy through chaincodes, as detailed in Table 1. It makes it possible to reduce the manual data verifying process and prevent the generation of incorrect data. Also, during this verification process, location and duration data of transaction proposal, which are extracted from uploaded image using metadata extraction API, are compared with inspection task through a chaincode. Through this verification process, transaction proposals with wrong images (e.g., an image taken on a different day or at a different location) are ignored. After verification, a transaction proposal is received from the endorsing peers along with a read/write set—a set of original transaction and chaincode simulation results and digital signatures from the endorsing peers that authenticate the transaction proposal (Figure 2(c)). The endorsed transaction proposal is broadcasted to the orderer, and the orderer packages the transaction into a block structure through an ordering process (Figure 2(d)). The created block is shared to network participants peer-to-peer through a committing process. The network participants validate the shared block, and the shared block is newly connected to the existing blockchain in the distributed ledger owned by each network participant (Figure 2(e)). This series of transaction verification steps in the HLF is called the consensus algorithm.

Table 1. Chaincodes and their details for comparative verification process

Chaincodes	Details
checkTransactionValidity()	Verify the validity of transaction proposals that contain the data about inspection tasks or inspection results by comparing transaction proposals with the pre-defined project information and task transaction.
updateStatus()	When the uploaded inspection tasks or inspection results satisfy the specific condition, update the status of the inspection task or inspection results.

checkImageIntegrity()	Check the integrity of the original image by comparing whether the image hash in the inspection results and the hash generated from the original image stored in the off-chain database are the same.

Also, the generated inspection results and original images analyzed in Figure 2(b) are stored in the off-chain database configured in parallel with the blockchain network because the blockchain network is not suitable for storing data occupying a lot of memory space, such as images and videos (Figure 2(f)). Also, data stored in the off-chain database are relatively more vulnerable to errors or forgery than the data stored in the blockchain, especially when original images can not be stored in the blockchain. Therefore, the integrity of the original image is secured by comparing whether the hash of the original image stored in the blockchain and the hash generated from the original image stored in the off-chain database are the same through the image hash comparison chaincode (Figure 2(g); Table 1).

3.3. System architecture

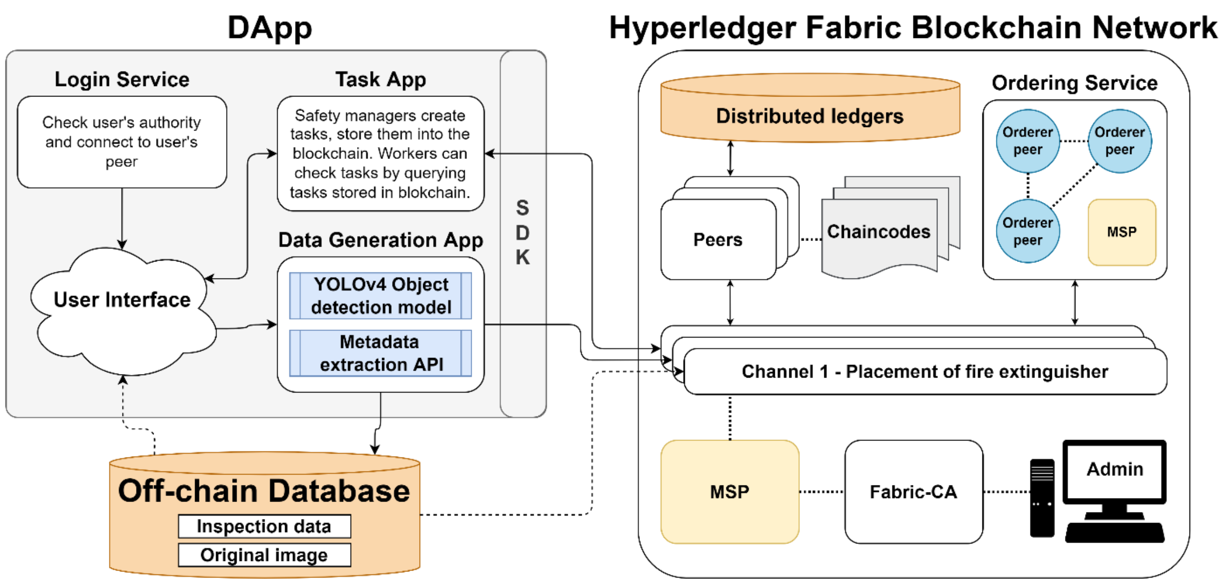

Figure 3. The system architecture of the integrated object detection and blockchain framework

The system architecture of the proposed framework with detailed flows of data transactions and the structure of utilized platforms is shown in Figure 3. In Figure 3, the solid lines with arrows indicate the workflow, the dashed lines with arrows indicate the transaction queries, and the dotted lines without any arrows indicate the network configuration of the blockchain network. The system architecture consists of the DApp, Hyperledger Fabric blockchain network, and off-chain database. In this study, the network's scalability and data security were the top priority in selecting a blockchain network platform under the assumption that multiple workers had to be able to upload data simultaneously in the proposed framework. Thus, the system was developed through the HLF, a consortium blockchain network where only pre-authorized participants can participate, with the highest throughput and lowest latency compared to other blockchain network platforms [21].

The DApp is a distributed application mounted on edge devices of network participants, providing visual and practical functions such as task creation and inspection data generation to the project participants. The pre-trained YOLOv4 object detection model and metadata extraction API are deployed within the DApp as generation apps to detect the construction sites' safety conditions and generate detection results. The YOLO network is a one-stage object detection algorithm that uses a single Convolutional Neural Network (CNN) to process images and classify objects' results and position coordinates [22]. It enables real-time object detection. Thus, it is effective in continuously inspecting the ever-changing safety conditions of construction sites. This pre-trained YOLOv4 model is deployed within the DApp through the TensorFlow Lite framework. Accordingly, workers can detect the construction sites' safety conditions without round-trip transmitting and calculating data even with no internet connection through their edge devices. Also, the metadata extraction API can extract metadata such as the date and location from source images. These two data generation apps generate inspection results in the form of JSON that can be transmitted to the blockchain and off-chain networks.

The HLF is a consortium blockchain network platform where only pre-authorized participants can participate. The network admin can grant participants the authority to participate in the network and access rights of channels within the blockchain network. It is done by creating and distributing a public key infrastructure (PKI) based membership service provider (MSP) through the Fabric-CA, a certificate authority (CA) that provides authorization information for the HLF. In this study, network participants such as owners, safety managers, and workers are configured through MSP preset while setting the configurations of peers involved in the block creation process in the network, such as the endorsing peers and the orderer peers. Network participants can query and create blocks according to their preset authority, and chaincodes are automatically executed when specific triggers are satisfied.

An off-chain database is an additional physical and logical central non-transactional storage space in addition to distributed ledgers in the blockchain network. It provides a parallel database along with the distributed ledgers, storing files that occupy a large amount of memory space (original images in this study). The off-chain database is more susceptible to errors and forgery than the blockchain. Thus, the integrity of the original image stored in the off-chain database is verified through the image hash comparison chaincode, which was described above.

4. CONCLUSION AND FUTURE RESEARCH

In this study, the authors proposed an integrated object detection and blockchain framework that automatically analyzes safety conditions through an object detection algorithm and traceably shares and immutably stores the generated information in a blockchain network. Through the framework and system, safety managers can remotely instruct workers to perform safety inspections, and workers can generate inspection results and share and store them reliably through the blockchain network. Such inspection results are compared and verified through smart contracts and can be checked when project participants need to, enabling remote safety inspection at construction sites. Thus, the site inspection workflow can be accelerated, and the workload of safety managers can be reduced. In addition, reliable sharing of inspection data allows project participants to make grounded safety-related decisions, such as eliminating dangerous site conditions. These potential values can ultimately improve construction site safety.

However, there are also limitations that asking to take pictures from workers may result in unintended miscommunication and low-quality images(e.g., low-resolution images, hazy images) from workers, which can cause the malfunction of the object detection process during an inspection from workers.

In future research, the authors aim to develop a more advanced framework and on-site safety data management system with field demonstrations of potential value by optimizing the proposed framework and system according to the characteristics of construction sites and industry.

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