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Research on Monitoring and Early Warning of the Mine Backfill System Based on Blockchain Technology

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Abstract: At present, the mine filling system is a mostly automated operation process, and it has many problems, such as centralized data storage and low safety performance. Aiming at solving the above problems, this paper proposes a mine filling overlimit warning system based on blockchain to achieve the functions of an equipment operation overlimit warning, data storage, and data retrieval. Firstly, the original data model is trained based on transfer learning to obtain the overlimit early warning model and predict the overlimit of equipment operation. Then, the interplanetary file system (IPFS) storage device is used to store the running data and overlimit data, and the corresponding file identifier CID is stored on the blockchain. At the same time, alliance chain technology is used to allow administrators and users to retrieve data based on credentials to ensure the privacy of the data retrieval process. System experiments and analysis evaluations show that the combination of blockchain and IPFS to store monitoring data can effectively save storage space and improve the efficiency of storage and retrieval. The application of an overlimit early warning model can optimize the mine filling process and prolong the operational life of system equipment.

Keywords: blockchain; alliance; mine equipment; transfer learning

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1. Introduction

In recent years, with the continuous development of science and technology, the emergence of terms such as big data, cloud computing, and blockchain, and the deepening research into artificial intelligence technology, the mine filling system has gradually developed from manual intervention control to mechanization and artificial intelligence, and mine safety monitoring and early warning technology have also developed rapidly [1–3]. At present, the filling mining method has been popularized in China's major mines, and the environmental protection of filling slurry and the visualization of slurry pipeline transportation have been studied in depth [4–6]. The monitoring technology used in the process of mine filling has made great progress [7,8], but there are still several disadvantages to this method: (1) intelligent monitoring and early warning technology of mines is still in the initial stages of developing artificial intelligence, computing, big data mining, and other technologies to initially give the mine the ability to observe and perceive through data analysis and processing in order to achieve intelligent judgment and prediction, but there is still a lack of self-adaptive mine monitoring equipment, limiting the mine's safety situational awareness, its ability to monitor information sharing systems collaboration, and other technical developments, and (2) the traditional mine monitoring database management system adopts centralized storage, and the data center is responsible for accessing and sharing data. Both data providers and data users interact with the data center and upload or obtain data according to the data interface. However, with the continuous development of intelligent monitoring technology, the mine's intelligent monitoring system tends to be complicated, and large amounts of monitoring data are generated. Due to the limitations

of the central management mode of the mine database, the security of monitoring data transmission and access cannot be safely guaranteed.

At present, most of the research on mine monitoring systems is based on the combination of software and hardware. For example, Wang Tianjun [9] proposed a server architecture based on cloud computing and adopted the AES data encryption algorithm to improve data security. Sun Changjun et al. [10] proposed a safety monitoring system based on a CAN bus, which can detect anomalies in underground intelligent nodes and send out early warning information. He Xiaowu [11] proposed a data center architecture, using different sensors to build different monitoring systems and employing an adaptive noise reduction method to monitor early warning in a mine filling system. However, these are based on the original system for different hardware references, not involving overall software-specific research.

The huge amount of data generated during the mine filling process is stored on the blockchain, which causes the blockchain to be too large. Therefore, many scholars have proposed a method of combining the IPFS with the blockchain to store data and reduce the volume of the blockchain. Miao Qi [12] proposed a blockchain storage optimization scheme based on IPFS, which limits the blockchain's capacity by reducing the size of the upper chain data. Zhu Yanxia et al. [13] used IPFS to build a storage and distribution system for the decentralized media asset platform in the media service center. The files were distributed for storage and transmission using the IPFS protocol, which achieved both secure storage of media data and CDN network optimization while reducing resource storage costs. Gao Wentao et al. [14] used the characteristics of blockchain decentralization and non-tampering combined with IPFS to jointly maintain the distributed and reliable storage of music data and built nodes in the alliance chain scenario for data verification. The Ethereum consensus mechanism avoids computational mining to reduce the consensus time of the entire network's nodes.

Recently, machine learning has been increasingly used to detect faults during system operation [15,16]. As a typical method of machine learning, transfer learning, can train existing models using small samples of data to obtain training models suitable for different scenarios. Xie Xuyang et al. [17] designed a convolutional neural network model training method based on transfer learning that can automatically extract effective fault features from vibration signals and complete fault diagnosis of electric pumps using only a small amount of sample data. Based on the idea of classification learning, Shi Bingbo [18] proposed a fault diagnosis method based on transfer learning to achieve automatic and efficient diagnosis of equipment faults on the basis of fault diagnosis knowledge representation, fault diagnosis algorithm research, and similarity calculation of fault vectors. Yuan Laohu et al. [19] proposed a rolling bearing fault diagnosis method based on AlexNet and transfer learning. The collected data were set as training samples and trained in the finely tuned, pre-trained AlexNet network. During the test, it was found that the method can still be used to diagnose the common fault types of rolling bearings when the marked fault data are scarce.

Aiming at solving the problems of fewer data samples and the low data storage safety performance of collecting equipment in a mine filling system, this paper constructs a mine filling overlimit early warning system based on blockchain and transfer learning, which mainly includes the following two models:

(1) Overlimit warning model: based on transfer learning, an overlimit warning model is established to collect the operation data generated by the equipment during the operation of the mine filling system. The convolutional neural network is used to predict the future change in the equipment operation data over a certain period of time, and all the data are detected to obtain the time of the future overlimit situation for different equipment;

(2) Data management model: data storage and retrieval are realized by combining the blockchain and the IPFS. After the overlimit data in operation are detected by the over-limit early warning model, the administrator stores the overlimit data on the IPFS and the returned file identifier on the blockchain to ensure the security performance of data storage.

At the same time, alliance chain technology is used to design the data retrieval processes of different users. The administrator can directly retrieve the required data after obtaining the access credentials given by the third-party trust institution, and the user needs to obtain the required data from the administrator after obtaining the access credentials issued by the trust institution to ensure the performance of data transmission is secure.

The rest of this article is arranged as follows. Section 1 introduces the preliminary knowledge. Section 2 describes the design goals and model framework of the mine filling overlimit warning system. Section 3 presents a system for experimental evaluation and theoretical analysis to explain the advantages of the model. Section 4 summarizes the paper.

2. Preparatory Knowledge

2.1. Transfer Learning

Transfer learning is applying the knowledge or patterns learned in a certain field or task to different but related fields or problems. It is defined as follows: given a source domain D_s and a learning task T_s and a target domain D_t and a learning task T_t, using the knowledge in D_s and T_s to improve the learning of the target prediction function $f(\cdot)$ in D_t, then $D_s \neq D_t$ or $T_s \neq T_t$. Among these values, the domain is the main body of learning, which consists of feature space and marginal probability distributions of features; the source domain refers to a domain with knowledge and a large number of labels, which is the object to be migrated; the target domain refers to the domain used to learn knowledge and apply labels; and the task is the result of learning, consisting of label space and the prediction function corresponding to the label [20,21]. Transfer learning on convolutional neural networks refers to transferring some network parameters of pre-trained convolutional neural networks from the source domain to the target domain for training. The existing models can be trained with small samples of data to obtain training models suitable for different scenarios. In actual production, the normal data in mine filling equipment operation data that can be used for network training are far greater than the overlimit data, and the network migration effect obtained by using only normal data for training is poor. It is necessary to add a small amount of overlimit data to form a dataset on the basis of a large amount of normal data and use the maximum mean difference to measure the distribution difference between the source domain and the target domain. Then, the convolutional neural network is trained according to the data set selected by the difference value, and the completed training model is used to diagnose the overlimit condition of the target domain, which can solve the problem of insufficient overlimit data for equipment operation well.

2.2. Blockchain

The blockchain is a distributed database technology with the characteristics of decentralization, tamper-resistance, openness and transparency, and traceability [22,23]. As a branch of the blockchain, the alliance blockchain is managed by multiple institutions, each of which runs one or more nodes, and the permissions between the nodes are completely equal. They can interact directly without full mutual trust (although with a certain basis of trust), and the interaction information is recorded by the peer nodes [24]. In this paper, the application of a double chain in a mine filling system is proposed to ensure good safety performance in the process of data storage and retrieval. The data chain is applied in the process of data storage, and the alliance chain is used in the process of data retrieval. The specific structure is shown in Figure 1. The main storage device in the data chain runs the CID information of the overlimit data, and the alliance chain is used to set the permissions of different users, store the user's identity information, and record the query information.

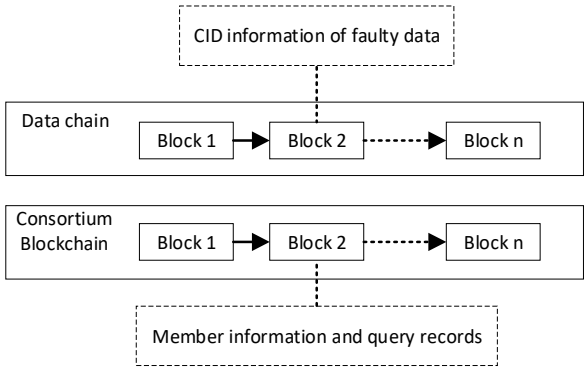


Figure 1. Data link and federation link basic structures.

3. Model Design

3.1. Overlimit Warning Model

Based on transfer learning, this paper builds an overlimit early warning model to realize the overlimit prediction of operating equipment in the mine filling system. The model is mainly composed of two parts: pre-training and parameter migration, as shown in Figure 2. The pre-training process uses the simulation data generated by the simulation system to train the neural network model, and the parameter migration process first freezes the convolutional pooling layer parameters of the pre-training model before using a small amount of actual data to fine-tune the fully connected layer parameters of the pre-training model. Due to the factors that affect the collected data in the actual environment, such as the stability of the sensor, the impact resistance, and the use time of the acquisition equipment, the overlimit warning ability of the pre-trained model may decrease, and the accuracy of the overlimit prediction needs to be improved through the transfer learning of a small amount of data.

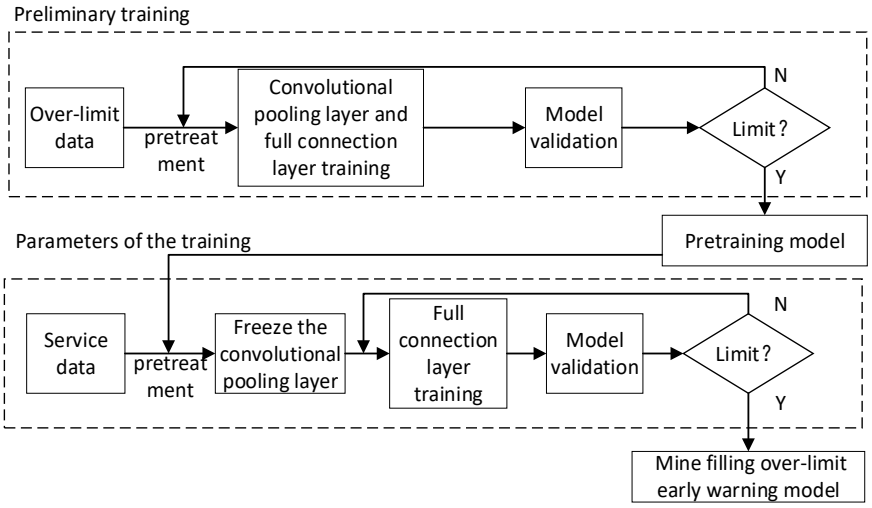


Figure 2. Flow chart of the overlimit prediction method.

3.2. Data Management Model

This paper builds a data management model of a mine filling system based on blockchain, realizes the storage and retrieval of data in the operation of the mine filling system, and ensures the safety and reliability of data transmission. The model mainly includes three stages of data upload, storage, and retrieval. The specific steps are shown in Figure 3.

The first part is the data upload and pre-preparation stage, and the main steps are as follows:

Step 1: The trust center determines the candidate for the administrator (including the dispatcher and the inspector) and stores the name, position, area of responsibility, and other relevant information of the candidate. The dispatcher is appointed to encrypt, store, and retrieve data. The inspector can detect the loyalty of the dispatcher;

Step 2: The mine filling system uploads all data during operation to the overlimit warning model for detection;

Step 3: The overlimit warning model predicts the future operation data of the mine filling system equipment, detects the overlimit data, and uploads the operation data and warning data to the dispatcher for storage.

The second part is the data storage phase, where the main steps are as follows:

Step 4: After receiving the monitoring data, the dispatcher encrypts the data with a public key and uploads it to the IPFS for storage;

Step 5: The IPFS receives the monitoring data for storage, generates the corresponding file identifier CID, and returns it to the dispatcher;

Step 6: The dispatcher stores the received CID on the blockchain;

Step 7: The inspector makes an inspection request to the dispatcher;

Step 8: The original data and encrypted hash values are sent by the dispatcher to the inspector;

Step 9: The inspector generates the hash value stored on the IPFS using the public key and the original data and compares it with the received encrypted hash value to test the credibility of the dispatcher: if the two values are consistent, the dispatcher is internally loyal; if the two values are inconsistent, it indicates that there has been a defection within the dispatcher, and the trust center needs to reappoint the dispatcher.

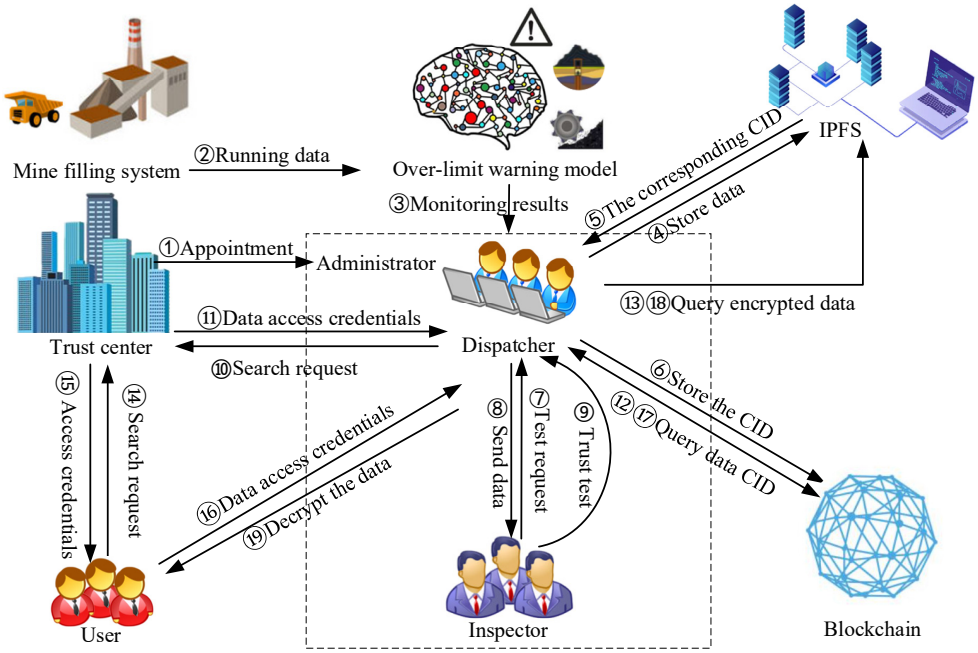


Figure 3. Data management model architecture based on blockchain.

The data from this stage are stored using a combination of the blockchain and the IPFS. The specific process is shown in Figure 4. The monitoring data generated in the overlimit warning model are stored in the IPFS, and the file identifier CID returned by the IPFS is stored in the blockchain. The administrator node initiates a data storage request and calls the smart contract to query whether the administrator node has storage rights. If so, the encrypted monitoring data of the administrator node are stored in the IPFS, and the returned CID is stored on the blockchain; if not, the data storage fails.

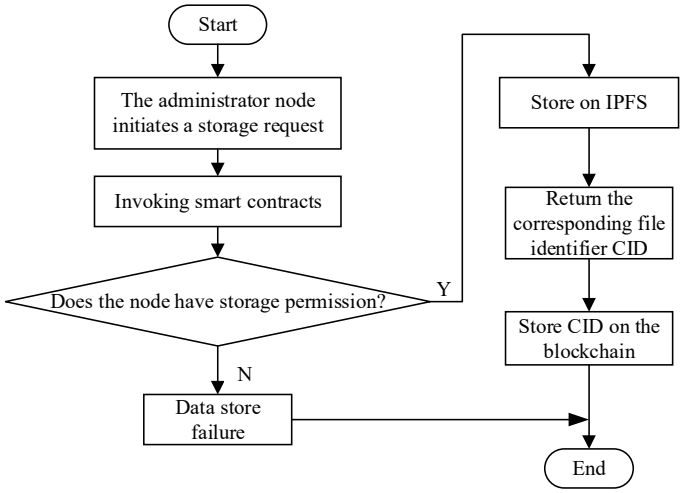


Figure 4. Data management model architecture based on the blockchain.

The third part is the data retrieval stage, which includes administrator query data and user query data.

The main steps for administrators to query data are as follows:

Step 10: The dispatcher initiates a data retrieval request to the trust center;

Step 11: The trust center delivers the data access credentials to the dispatcher;

Step 12: The dispatcher extracts the CID value of the data to be queried from the blockchain based on the access credentials;

Step 13: Using the obtained CID value, the dispatcher obtains the encrypted corresponding data from the IPFS and decrypts the original data with the private key;

The main steps of user query data are as follows;

Step 14: The user initiates a data retrieval request to the trust center;

Step 15: The trust center hands over the data access credentials to the user;

Step 16: The user hands over the data access credentials to the dispatcher;

Step 17: The dispatcher extracts the CID value of the data to be queried from the blockchain based on the access credentials;

Step 18: The dispatcher obtains the encrypted corresponding data from the IPFS by virtue of the obtained CID value and decrypts it with the private key to obtain the original data;

Step 19: The dispatcher sends the decrypted data to the user.

At this stage, the IPFS is combined with the blockchain to store the monitoring data. The monitoring data generated by the overlimit warning model are stored in the IPFS, and the CID returned by IPFS is stored on the blockchain to reduce the blockchain volume while ensuring security in the data storage process. However, after the monitoring data are stored in the IPFS, they cannot be directly queried from Fabric. It is necessary for the query node to obtain the address hash value of the query information from the blockchain and then obtain the corresponding data from IPFS according to the hash value. The query process of the administrator node is shown in Figure 5a. The administrator node initiates a data retrieval request and calls the smart contract to verify whether the administrator node has authority for the query. If the administrator node has retrieval authority, the trust center issues a data access credential to the administrator. According to the credential, the CID that is needed to query the monitoring data is returned from the blockchain, the encrypted monitoring data are retrieved from the IPFS according to the CID value, and then the original monitoring data are obtained after decryption using the private key. If the administrator node does not have retrieval rights, verification does not occur, the trust center refuses to issue data access credentials, and the administrator cannot obtain the required hash value.

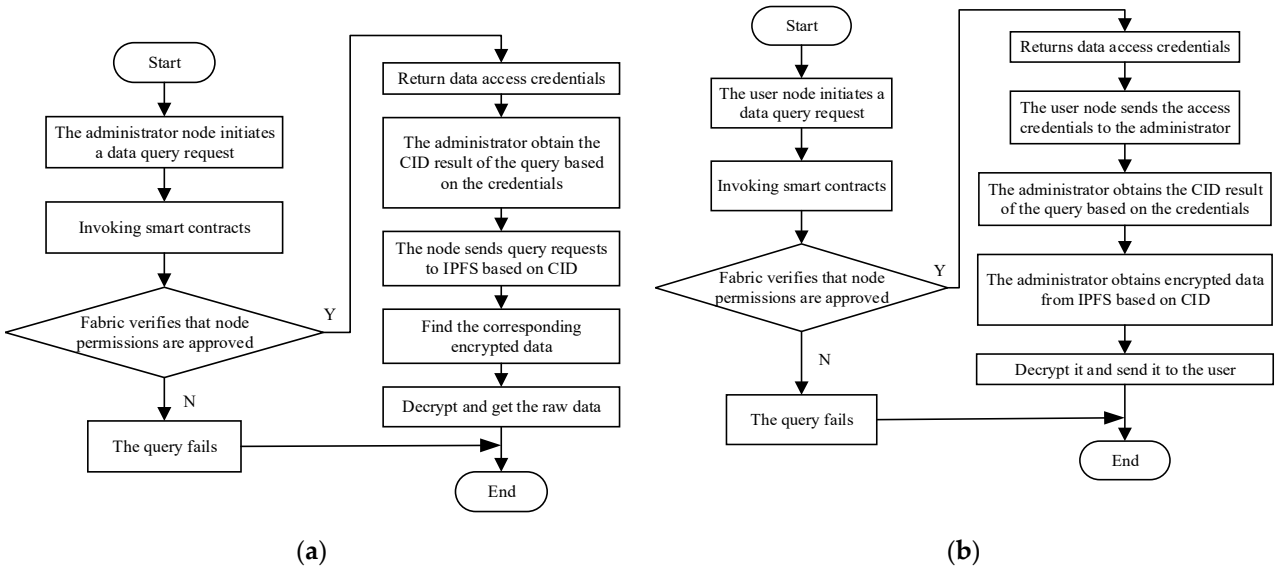


Figure 5. Data query process: (**a**) Flow chart of the administrator querying the data (**b**) Flow chart of user query data.

The user's query data needs to be sent as a data retrieval request to the trust center. After verifying its identity, the obtained data access credentials are sent to the administrator. The administrator obtains the original monitoring data based on the credentials and sends them to the user. The specific data retrieval process is shown in Figure 5b. The user node initiates a data query request and consults the smart contract to verify whether it has query authority. If the user node authentication is passed, a data access credential issued by the trust center is obtained, and the user sends the credential to the administrator. The administrator obtains the corresponding CID from the blockchain according to the credential and then requests the corresponding encrypted data from the IPFS according to the CID before using the private key to decrypt and send the original monitoring data to the user. If the user node authentication is not passed, the data query fails.

4. System Experiment and Analysis Evaluation

4.1. Storage Performance Analysis

4.1.1. Theoretical Analysis

In this paper, the original monitoring data information is stored in the IPFS system, and the file identifier generated by the IPFS is stored in the blockchain system, which greatly reduces the length of the blockchain ledger.

The calculation formula for the storage space compression ratio is shown in Equation (1).

$$\frac{H + iHash \times N}{H + \sum_{i=1}^{N} T_{X_i}} \tag{1}$$

where H represents the data volume of all block headers in the blockchain, N represents the number of all transactions in the blockchain, $iHash$ represents the size of the IPFS hash corresponding to each transaction, and T_X represents the original data volume of each transaction.

Among them, the block header takes up 80 bytes, each block contains at least 500 transactions on average, and each transaction takes up at least 250 bytes on average, but an IPFS hash value only takes up 46 bytes. It can be estimated that the optimization of the storage space of this solution is considerable [25]. It is assumed that the average size of each monitoring data point is 1 MB. As each object in the IPFS can store up to 256 kB of data, each monitoring data point needs four IPFS objects, and the hash value generated

by each data object is 46 bytes. As a result, the data on the chain are reduced to about 1/5698 of their original size. The reduction in size of blockchain ledger data can optimize the storage space, improve the storage rate of monitoring data, and reduce the access threshold of blockchain nodes. The number of nodes that meet the conditions increases, which makes it more difficult for malicious nodes to modify the ledger, improving the security performance of the system.

4.1.2. Experimental Analysis

The combined data management scheme of IPFS and blockchain storage is proposed in this paper. The blockchain layer is constructed by the Hyperledger Fabric project. The data storage performance test takes the administrator node as an example and deploys a leader node, an orderer node, and two general peer nodes. A leader node is responsible for data storage and communication with other organizational nodes. An orderer node completes the consensus of transaction sequencing. Additionally, it deploys relevant chain codes in the organization.

The comparison between the system model designed In this paper and the original blockchain model to store the same amount of data is shown in Figure 6. The blocks generated by the system are reduced by more than 72% compared with the original ordinary block, greatly reducing the capacity of the blockchain.

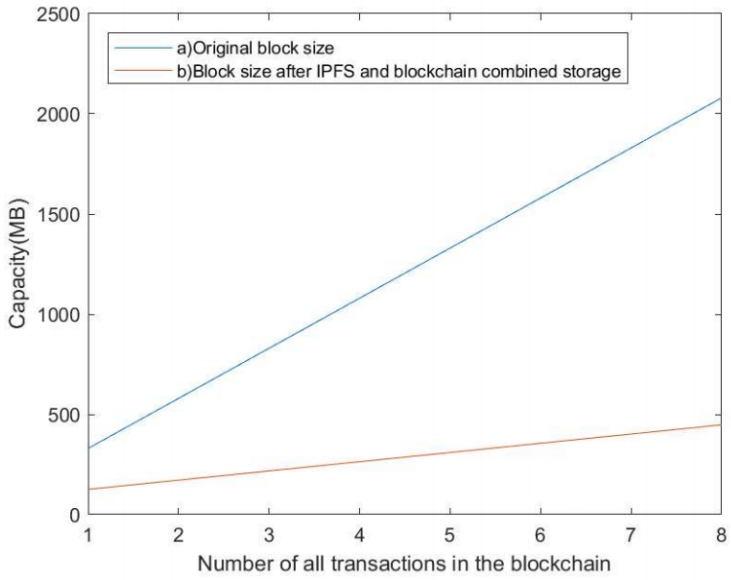


Figure 6. Blockchain capacity comparison.

4.2. Advantage Theory Analysis

The mine filling overlimit early warning system based on double chain and transfer learning that was proposed in this paper records the equipment operation data information on the blockchain, inherits the advantages of the blockchain such as having no center, transparency, distribution, and tamper-resistance, and ensures the security of the database storage and query process. At the same time, the transfer learning model is used to carry out the overlimit early warning of all the running data. According to the early warning results, overlimit equipment can be paid attention to in advance of any issues, and corresponding measures can be swiftly implemented to extend the service life of each piece of equipment:

(1) Non-centering and transparency: the data storage and access process proposed in this paper evaluates the storage and access of a smart contract on the blockchain. Only when the conditions are met is the smart contract triggered to run the node to store data or query data to realize the centralization and transparency in the data storage query process;

(2) Non-counterfeiting and security: taking advantage of the tamper-resistant characteristics of the blockchain, the CID value, user information, and query process returned

by the IPFS after storing monitoring data are recorded on the blockchain. No person or organization can forge false monitoring data to query the CID value and user information, effectively eliminating security issues such as illegal access and ensuring the reliability of data access processes. All the data were generated during the operation of the IPFS storage device, and the early warning data were generated by the transfer learning model. Each monioring data point stored on the IPFS has a unique corresponding CID value, which can ensure the security of the data storage query process and prevent the risk of data loss;

(3) Overlimit warning: in the mine filling overlimit early warning system proposed in this paper, all data can be trained by the migration model to detect the overlimit data, and the position and timing of a possible overlimit situation in the future can be predicted according to the previous position and timing of the overlimit data. The results obtained by the prediction can be used to focus on the overlimit equipment in advance and implement timely corresponding measures to ensure the safety of the system during operation.

4.3. Overlimit Warning Experiment

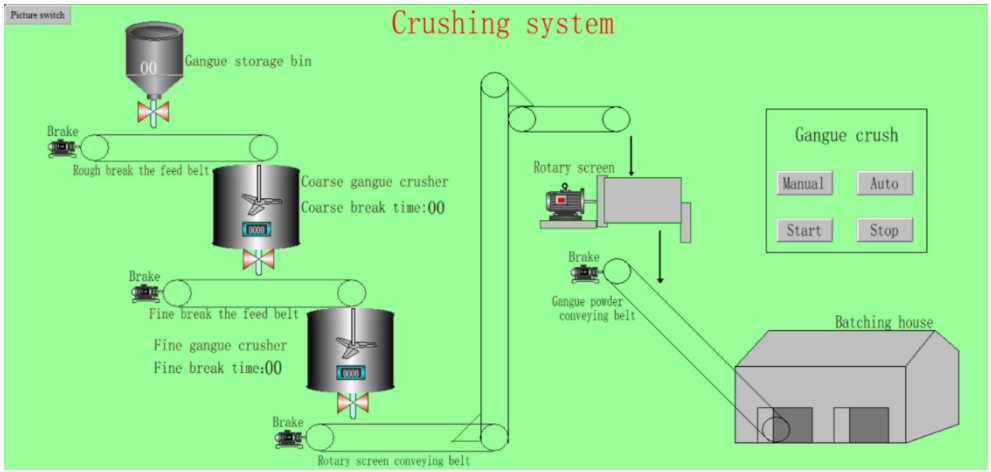
4.3.1. Experimental Environment

In order to test the accuracy of the operation results of the proposed overlimit early warning model, this paper builds a mine filling simulation system for data collection and designs an overlimit early warning model based on Tensorflow to detect and warn the overlimit data. The experimental environment of the mine filling simulation system is KingView 7.5 SP3, and the experimental environment of the overlimit early warning model is the Anaconda virtual environment based on TensorFlow 2.5, using the Python 3.9 language for programming [26–28].

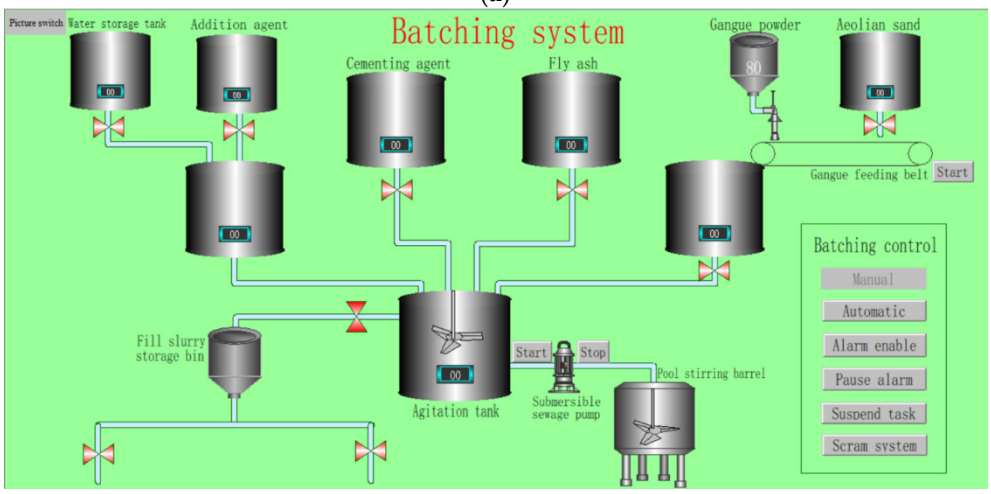
4.3.2. Experimental Results

Through KingView software, a mine filling simulation system, including a crushing system, batching system, cleaning system, and filling working face, is built to simulate the processes of gangue crushing and screening, filling slurry configuration, slurry transportation and filling, and pipeline inner wall cleaning. The specific construction situation is shown in Figure 7. The process of gangue crushing and screening is shown in Figure 7a. The process of filling slurry configuration and transportation is shown in Figure 7b. The mine filling simulation system sets the threshold values for the liquid level in water and the additive mixing bin, the material level in gangue and the gangue powder mixing tank, the slurry level in the mixing tank, and the slurry level in the filling slurry storage bin, the mixer current, and the crusher current. Then, we collected all the data generated during the operation of the mine filling system. After preprocessing, the neural network model was input to detect the overlimit data, and the non-generated overlimit situation was predicted to show the results obtained through data training.

The experimental environment of the overlimit warning model is an Anaconda virtual environment based on TensorFlow. The Python language is used for programming. The number of network layers in the model, the categories and construction order of different layers, the hidden layer parameters, and the learning rate are selected by a random search method. Each batch processes 40 items of data, with each item undergoing 10 training cycles. Among them, 80% of the samples are used as training data sets, and 20% of the samples are used as simulation verification sets to detect the prediction effect of the model. The prediction results of the model are shown in Figure 8. The comparison between the predicted data and the actual data is shown in Table 1. The calculation shows that the mean absolute error of the model is 0.023, the mean square error is 0.001, and the correlation index R2 is 0.98, indicating that the regression effect of the model is good and the predicted results are more accurate.



(**a**)



(**b**)

Figure 7. Mine filling simulation system: (**a**) Crushing system interface (**b**) Batching system interface.

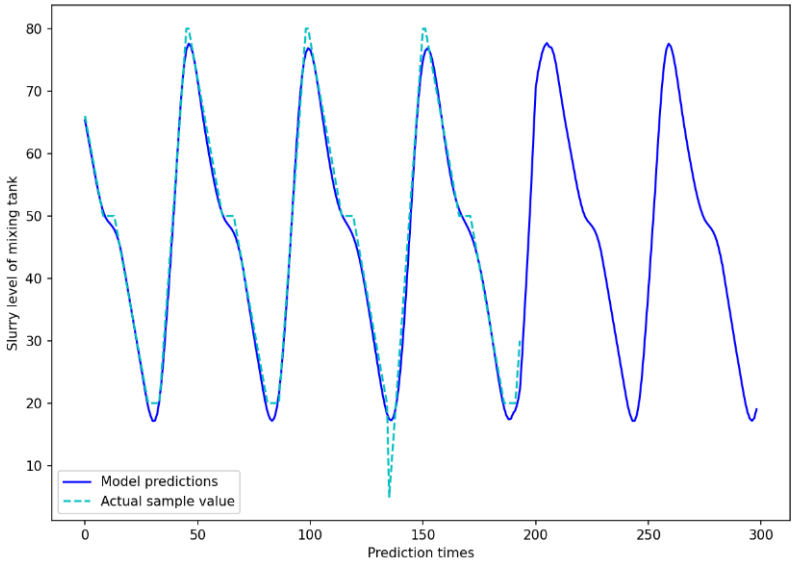


Figure 8. Model prediction result.

Table 1. Partial comparison results of actual and predicted values of slurry level in the mixing tank.

	Time	Predicted Value	Actual Value		Time	Predicted Value	Actual Value
1	11:32:55	65.32	66	11	11:33:45	49.22	50
2	11:33:00	63.35	64	12	11:33:50	48.80	50
3	11:33:05	61.44	62	13	11:33:55	48.35	50
4	11:33:10	59.44	60	14	11:34:00	47.80	50
5	11:33:15	57.40	58	15	11:34:05	46.99	48
6	11:33:20	55.43	56	16	11:34:10	45.85	46
7	11:33:25	53.64	54	17	11:34:15	44.36	44
8	11:33:30	52.09	52	18	11:34:20	42.38	42
9	11:33:35	50.76	50	19	11:34:25	40.34	40
10	11:33:40	49.82	50	20	11:34:30	38.21	38

5. Discussion

Aiming at the problems of incomplete early warning measures and low safety performance of database central management mode in the mine filling system, this paper applies blockchain technology and deep learning to the mine filling process and proposes an overlimit early warning system of mine filling equipment based on the blockchain, which achieves the functions of overlimit early warning, data storage, and retrieval of equipment operation. System experimentation and analysis evaluation show that the block generated by combining the IPFS and the blockchain to store monitoring data is reduced by more than 72% when compared to the original ordinary block, which greatly optimizes the storage space. Transfer learning is applied to the overlimit early warning model, and the correlation index of the predicted operation monitoring data reaches 0.98 in the mine filling system, which can predict the overlimit situation of different equipment more accurately and take measures to prolong the operational life of system equipment in advance.

However, there are still limitations in the current research. It is difficult to obtain the operation data of each item of equipment in the actual mine filling system. This paper only verifies the monitoring and early warning effects of the equipment in the mine filling simulation system. The environment faced by the actual filling system equipment operation is relatively harsh, and the mutation probability of the equipment operation data is large, so it cannot be proved that the proposed model is also applicable to the actual system. The performance of the blockchain and IPFS combined storage has only been verified theoretically and experimentally, without a simulation test of the whole process of storage and retrieval. It is impossible to verify the operating performance and energy consumption analysis more intuitively during storage and retrieval.

Future research will be based on the actual mine filling process, combined with the monitoring data of actual equipment operation, to optimize the overlimit early warning model and find a better method to achieve the prediction of overlimit data. The data management model will be based on the experimental test of operation performance and energy consumption analysis in the process of storage and retrieval to further demonstrate the scheme proposed in this paper. Additionally, the consensus algorithm applied in the alliance chain is optimized to improve the performance of data transmission and retrieval.

6. Conclusions

Blockchain technology and deep learning are applied to the mine filling process. The overlimit early warning system for mine filling equipment based on the blockchain proposed in this paper achieves the functions of overlimit early warning, data storage, and retrieval of equipment operation. The overlimit early warning model applies transfer learning to detect and warn of the overlimit data of the equipment during the operation of the mine filling system. The experimental results show that the accuracy of this method is high, and it can predict abnormal conditions in the operation of a mine filling system in advance. Based on the combination of the blockchain and IPFS, the monitoring data are stored, which reduces the size of the blockchain and improves the performance of

data transmission and retrieval. The alliance chain is used to standardize the functions of administrators and users. The dispatcher is responsible for storing and retrieving data. The inspector verifies the trust of the dispatcher. The user obtains the monitoring data from the dispatcher by means of data access credentials to ensure the security of the data retrieval process.

The application of the blockchain in a mine filling system gives the mine database the characteristics of being tamper-proof and decentralized, and it ensures security in the process of mine data storage and transmission. The application of deep learning models can predict the overlimit in the operation of equipment in advance and ensure safety in the operation of mining equipment. In future work, it will be further combined with the actual mine filling process, with deep research into the blockchain data management model, optimization of the consensus algorithm, and improved performance of monitoring data transmission and retrieval.

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