Digital Twin Based on 3D Visualization and Computer Image Recognition Technology in Coal Preparation Plant

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Abstract. The digital twin coal preparation plant is a potentially effective way to realize the intelligent interconnection and interactive integration of the manufacturing physical world and the information world. Aiming at the difficulty in predicting and maintaining the state of the shearer in a harsh working environment, combined with the high-fidelity behaviour simulation characteristics of the digital twin and the powerful data mining capabilities of deep learning, a coal shearer health prediction driven by the integration of the digital twin and deep learning is proposed. Method. The article builds an information management and integration platform composed of a real-time database and a comprehensive information platform, and realizes the unified management of data integration and application systems.

Keywords: 3D visualization, digital twin, coal preparation plant, visual management system

1. Introduction

With the transformation of the global energy structure, Chinese coal overcapacity problem has become prominent, coupled with the increase in environmental protection requirements, speeding up the structural reform of the coal supply side, and promoting the upgrading and transformation of coal enterprises are imminent. As the world is about to enter the era of Industry 4.0 dominated by intelligent manufacturing, coal preparation will inevitably develop in the direction of highly informative, automated, and intelligent (hereinafter referred to as "three modernizations"). The construction of "three modernizations" will be the future of coal preparation. Important means and ways for the factory to realize management innovation, efficient operation, energy saving and consumption reduction. The essence of the intelligent construction of the coal preparation plant is to use the intelligent, digital and information communication technology of industrial control, through the interconnection of production equipment, and decision support based on big data analysis to realize the real-time monitoring and intelligent management and control of the production process [1]. To realize the profound change of production management and the innovation of management mode, achieve the purpose of improving quality and efficiency, and comprehensively enhance the comprehensive competitiveness of the enterprise.
2. Reference System Architecture of Digital Twin Coal Preparation Plant

2.1. Digital Twin Architecture

In order to provide a reference for enterprises to carry out DTS practice in the future, this paper designs the DTS reference system architecture shown in Figure 1. The architecture mainly includes 5 layers: 1) Physical layer, which mainly refers to physical workshop entities such as human, machine, and material in the coal preparation plant, and the collection of corresponding production activities of the physical coal preparation plant, responsible for the realization of the physical space of product production and processing, and at the same time have the functions of self-perception, self-decision, and bottom-level data collection and transmission. 2) Model layer, mainly refers to DTS virtual coal preparation plant and its corresponding virtual production activities, including various models, rules, knowledge, etc. of the virtual coal preparation plant, responsible for the simulation, analysis, optimization, and decision-making of production activities in the virtual space. 3) The data layer refers to the twin data service platform of the coal preparation plant, which is responsible for providing data support services for the operation of the DTS's physical workshop, virtual coal preparation plant and coal preparation plant service system, and has the generation, processing and integration of the twin data of the coal preparation plant Data life cycle management and processing functions such as, fusion, etc. 4) The service layer is responsible for providing various coal preparation plant production services such as intelligent production scheduling, collaborative process planning, product quality management, production process control, equipment health management, and energy efficiency optimization analysis for workshop production. 5) The application layer mainly refers to the application requirements of intelligent manufacturing tasks such as intelligent production, precise management and control, and reliable operation and maintenance involved in the development of specific product processing and production.

![Figure 1. Digital twin coal preparation plant reference system architecture.](image)

2.1.1. Physical entity layer. The physical entity layer is the main body of the workshop, which mainly includes entities such as robots, machine tools, special processing equipment, personnel, automatic guided vehicles (AGV), conveyor belts, three-dimensional warehouses, and products/parts, as well as industrial control capable of data collection and communication Functional components such as...
computers, programmable logic controllers (PLC), sensors, and radio frequency identification (RFID) readers. They are organically combined to realize production activities such as product processing, assembly, transportation, and storage.

2.1.2. Twin model layer. The twin model layer is the core of the digital twin technology. The twin model is composed of twin data and a digital model. The digital model is the mapping of the workshop object entity, which is a true portrayal of physical characteristics such as the geometry of the workshop entity. The twin data is generated by the workshop entity, and the twin data and the digital model are organically combined to form the twin model [2]. The twin model is a digital reconstruction of the production site, aiming to map the production activities of the physical space in the virtual digital space, including the physical shape, position, movement, and their interrelationships. The twin model layer mainly realizes the virtual reproduction, analysis, optimization, and decision-making functions of workshop production activities in the digital space.

2.2. Main functions of the system

2.2.1. Personnel positioning. As people’s demand for location information continues to increase, the traditional global positioning system GPS can only perform better in outdoor positioning. For indoor positioning, it cannot meet people’s needs due to signal shielding and other reasons. Therefore, it is urgent to find an accurate indoor positioning system. Personnel positioning technology. By comparing several common indoor positioning technologies, considering that there are many mechanical equipment and steel structures in the production plant, the signal shielding phenomenon is serious, the number of base stations is limited, and the distance between the staff carrying the tags is relatively long, and the base station and the tag are required [3]. The working frequency is in the microwave range, while considering compatibility with the mobile communication system, the RFID microwave frequency band with long read and write distance and fast speed is finally selected.

2.2.2. Visual scheduling. The traditional dispatch system is mainly composed of telephones, walkie-talkies, and video surveillance systems. With the development of modern information technology, the real-time visual command and dispatch system has been widely used. From video conferences to command and dispatch, information reporting and push, an intuitive and reliable visual dispatch system has become an indispensable tool for large modern enterprises. This system aims to establish a four-in-one visual dispatch system of "intercom + positioning + video + dispatch". With the help of smart handheld terminals, with powerful image, voice, video, and data transmission functions, it can conduct two-way or multi-directional command and dispatch [4]. The person holding the handheld terminal can perform voice intercom, video sharing, etc. with someone or group of people in the area at any time. However, in areas such as under the coal pit, traditional walkie-talkies cannot be used, and only fixed telephones can be used. At present, by arranging wireless APs under the coal pit and outputting signals through the network, you can communicate with relevant personnel.

2.2.3. Online temperature monitoring. The coal preparation plant has many electromechanical equipment, and the operating temperature is the most intuitive reflection of whether the equipment is operating normally. Therefore, real-time monitoring of the temperature of electromechanical equipment is very important. The temperature monitoring system in this system is a hierarchical distributed network structure, composed of the equipment layer, the wireless network transmission layer, and the monitoring layer. The equipment layer is mainly composed of temperature sensors, RFID tags, and smart handheld terminals; the wireless network transmission layer is mainly composed of RFID tags and smart handheld terminals; the monitoring layer is composed of servers, monitoring software, and smart handheld terminal alarm modules. Figure 2 shows the working principle of the temperature sensor.
3. The prediction method of the shearer health status driven by the fusion of digital twins and deep learning

3.1. Data acquisition based on edge-cloud collaboration

The shearer perception data includes two parts: data transmission and data storage, as shown in Figure 3. Data storage uses a combination of distributed edge storage and centralized cloud storage. In order to overcome the shortcomings of cloud storage, such as high latency, low bandwidth, and low security, edge computing is introduced, and data used for real-time analysis is transmitted over the network to the nearest computing device close to the data source for processing and analysis, and local storage is realized, reducing equipment The pressure on the network throughput of the end and the cloud can alleviate the data analysis load of cloud centre equipment, and improve the efficiency of data analysis response and data storage security. Delay-insensitive data and data that need to be processed centrally are transmitted to the cloud centre through a dedicated line, and the cloud centre can access edge computing data at any time.

![Figure 3. Data acquisition of shearer based on edge-cloud collaboration.](image-url)
3.2. Digital twin construction based on dynamic interaction of virtual and real space

As shown in Figure 4, according to the shearer's physical space geometric parameters, material properties and other physical parameters, its high-fidelity model is constructed based on UG parameterization technology and saved as 3DMax identifiable. Still format. Use offline data such as environmental parameters and location parameters to construct a hyper-realistic simulation environment in Unity3D software [5]. Convert the high-fidelity model to Unity3D identifiable in 3DMax. The fbx format is imported into Unity3D software to realize the integration of high-fidelity model and super-realistic simulation environment. The digital virtual space model and environment are updated in real time through online data such as operating data and dynamic parameters, driving the high-fidelity model to perform high-fidelity behavior simulation in a hyper-realistic simulation environment, and mirroring the real-time state of the shearer's physical space to the virtual space to realize mining Online visualization of the real-time status of the coal mining machine provides decision-making guidance for the predictive maintenance of the physical space coal mining machine.

![Figure 4. Construction of the digital twin of the shearer.](image)

3.3. The remaining life prediction process based on GRU network

For model training based on the training set, we use the BPTT algorithm to reversely adjust the parameters, optimize the weight W and the bias b, and take the cross entropy as the objective function, namely.

$$f_{MSE} = \frac{1}{N} \sum_{i=1}^{N} (y_i - \hat{y}_i)^2$$  \hspace{1cm} (1)
In the formula, $y_i$ is the actual value; $\hat{y}_i$ is the predicted value; N is the number of test sets. Based on the test set, the model evaluation index is used as the objective function. By adjusting the depth of the network layer, the number of hidden layer neurons, and the number of training times, the evaluation index value of the model reaches a predetermined value, that is, the prediction performance of the model reaches the best [6]. Finally, real-time data is used as the input of the prediction model to predict the remaining life online. The coefficient of determination $R^2$ is the criterion for evaluating the good fit of the regression model. Its value varies between (0, 1). The closer the function value is to 1, the better the model fitting effect. The expression of $R^2$ is

$$R^2 = 1 - \frac{\sum_{i=1}^{N}(\hat{y}_i - y_i)^2}{\sum_{i=1}^{N}(y_i - \bar{y})^2}$$ (2)

4. System Test
As a key component of the shearer, the rocker arm carries the main tasks of drum power transmission and position control, and is also a vulnerable part of the shearer. The wearing parts of the rocker arm are mainly three-axis and planetary gear mechanism. The bearing is the main support and wearing part, and its health status can reflect the working status of the rocker arm. Therefore, the MG1000/2500-WD shearer rocker is selected [7]. The arm is used as an example object. According to online monitoring data (position and speed, etc.), the real-time state of the shearer's physical space is mirrored to the virtual space by dynamically updating the corresponding parameters of the virtual space in real time to realize the visualization of the real-time state of the shearer. The 1000th running time point is selected for research, and the position, pose, and trajectory of the shearer are used as the qualitative analysis standard. At this moment, the simulation result of overwriting is shown in Figure 5.

Figure 5. Super-realistic simulation of shearer.
5. Conclusion
This paper uses digital twin technology to construct a high-fidelity model of the shearer to realize the visualization of the real-time state of the shearer. This provides a qualitative analysis basis for the prediction of the health status of the shearer. Using online monitoring data, the deep learning model of driven gate loop neural network realizes the quantitative analysis of the remaining life prediction of the shearer. The comprehensive qualitative and quantitative analysis results provide comprehensive and multi-angle decision-making guidance for the predictive maintenance of the shearer.

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