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Intelligent Analysis of Construction Safety of Large Underground Space Based on Digital Twin

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Abstract: With the rapid development of underground space, the issue of safety in construction processes is becoming more and more significant. The purpose of this paper is to solve the problem of the existing underground space monitoring technology not being centralized and unified. In view of the problems related to large underground spaces in the process of constructing complex structures, with the introduction of Internet of Things technology and digital twins, we put forward an application of an intelligent safety-monitoring digital twin system in the construction of a large underground space structure, and at the same time, explore the Internet and digital integration mechanism of the twin system. The twin system uses BIM technology to establish the corresponding physical construction model, and collects multi-source heterogeneous monitoring data in real time through Internet of Things technology to achieve the exchange of information between the virtual construction model and the physical construction model. The twin system uses the multi-source heterogeneous data for real-time security analysis, and obtains the security status of the structure and feeds it back to the application service layer. The effectiveness and practicability of the twin system in large underground spaces are verified by an example project. Aiming at the safe performance of the orthogonal arch, the mapping relationship of various parameter indexes is obtained, and reasonable control measures are given. This study provides a new solution for improving the safety of construction projects and risk prevention and control, and has important theoretical and practical value for the safety management of underground space construction processes.

Keywords: large underground space; digital twin; internet of things technology; safety monitoring; parameter analysis

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1. Introduction

With the acceleration of modern urbanization, the demand for large-scale buildings and underground space projects is increasing, which also promotes the continuous growth of the number and scale of large-scale foundation pit projects. However, the foundation pit is usually underground, the construction period is long, the construction is difficult, and the influencing factors are complex and changeable; therefore, the risk associated with foundation pit construction is relatively high [1,2]. Therefore, the safety monitoring of foundation pits is one of the most important means of ensuring the safety of foundation pit construction and the stability of the foundation pit structure.

In traditional foundation pit monitoring, measurements are performed manually on a regular basis through instruments, which not only is associated with a large workload, but also is easily affected by external factors such as the weather and the site itself. In the construction process of very large underground space structures, due to the large scale of the space, there are many problems, such as its complex structure, strong disturbances, the changeable geological environment, and multiple risk factors and difficult risk prevention and control, which cannot meet the requirements of high-precision and real-time safety analysis [3]. With the continuous development of electronic technology and computer technology, more and more new technologies are applied to the monitoring of foundation pits [4–6]. The application of these technologies can enable the measurement and monitoring of parameters such as the surrounding environment, soil deformation and displacement, and the water level of the foundation pit, so as to achieve the comprehensive monitoring of foundation pit construction safety.

Xu et al. [7] designed an automatic monitoring system for foundation pits based on vibrating wire sensors, which can monitor the whole process of deep foundation pit construction and provide early warnings of structural safety in real time. Zhang et al. [8] developed a foundation pit monitoring system based on the Internet of Things and WebGIS. The wireless monitoring system is composed of sensors, data collectors, data transmission equipment, and an information management module, which can achieve the on-line monitoring and early warning of indicators such as the horizontal displacement and settlement of the foundation pit. Hashash et al. [9] captured the horizontal displacement, settlement, and other parameters of a foundation pit through sensors during the excavation of an urban underground space, and achieved the real-time monitoring of ground deformation during construction. In addition, monitoring technologies based on microwaves, lasers, and drones have also been gradually applied to the field of foundation pit monitoring. Through the three-dimensional scanning and high-precision measurement of the soil around the foundation pit, the deformation of the foundation pit can be more accurately reflected. Han et al. [10] introduced a method of using BIM and 3D laser scanning technology to monitor the deformation of a foundation pit, and took a large foundation pit as an example to verify that the method can monitor the three-dimensional overall deformation of foundation pits efficiently and accurately. In the prediction of surface subsidence caused by mining, Lee et al. [11] proposed two models based on a long short-term memory network to capture the characteristics of surface subsidence caused by mining and predict subsidence. The proposed deep learning model can accurately predict the subsidence of the training set and the test set. Li et al. [12] introduced an improved support vector machine algorithm based on multi-point measurement technology to monitor and predict the deformation of deep foundation pits. These studies provide effective technical support for the monitoring and prediction of ground deformation caused by excavation engineering.

Many researchers have studied the monitoring of foundation pits from different angles and different perspectives, with the important aim of providing a guarantee of the safety of foundation pit construction. However, at present, current research is unable to integrate various types of monitoring data into a centralized and unified system. Therefore, this paper proposes a twin system for the safety monitoring of super-large foundation pits based on the Internet of Things, addressing the above issues, which innovatively achieves the centralized processing of multi-dimensional multi-source data and the twin synchronization of underground space construction. The application layer provides decision makers with the safety status of the foundation pit, so that they can take corresponding measures in real-time according to this information to ensure the safety of personnel during the construction of the foundation pit.

2. Establishment of Digital Twin System Framework

Digital twin systems can play an important role in solving structural safety problems during construction and can reduce construction safety risks. For example, Wang et al. [13] proposed a digital twin-driven structural safety control method for a cable network considering spatio-temporal variations, which was able to compare and analyze the geometric information of the construction site with the real-time finite element simulation results to ensure the structural safety during construction. Liu et al. [14] carried out an intelligent safety assessment of the steel structure based on digital twins, and achieved the analysis of the safety performance of the structure by constructing a digital twin framework for multidimensional spatial and temporal information fusion. In view of the complex characteristics of the construction of super-large underground space structures, the concept of digital twins is introduced, combined with Internet of Things technology, and a twin system architecture that can meet the actual needs of the project is proposed to improve the level of intelligent structural construction safety monitoring and ensure that the underground space structure is in a safe state during construction.

2.1. Construction Safety Risk of Large Underground Spaces

Construction safety risk data are the basis of driving the digital twin framework. Therefore, the construction risk index system of large underground spaces is first constructed through a literature research and expert interviews. The construction risk of urban underground large space engineering is mainly divided into [15–18] retaining structure instability, support system instability, pit bottom deformation and failure, soil collapse, surface subsidence, building (structure) damage, road and bridge damage, and underground pipeline damage, etc., as shown in Figure 1.

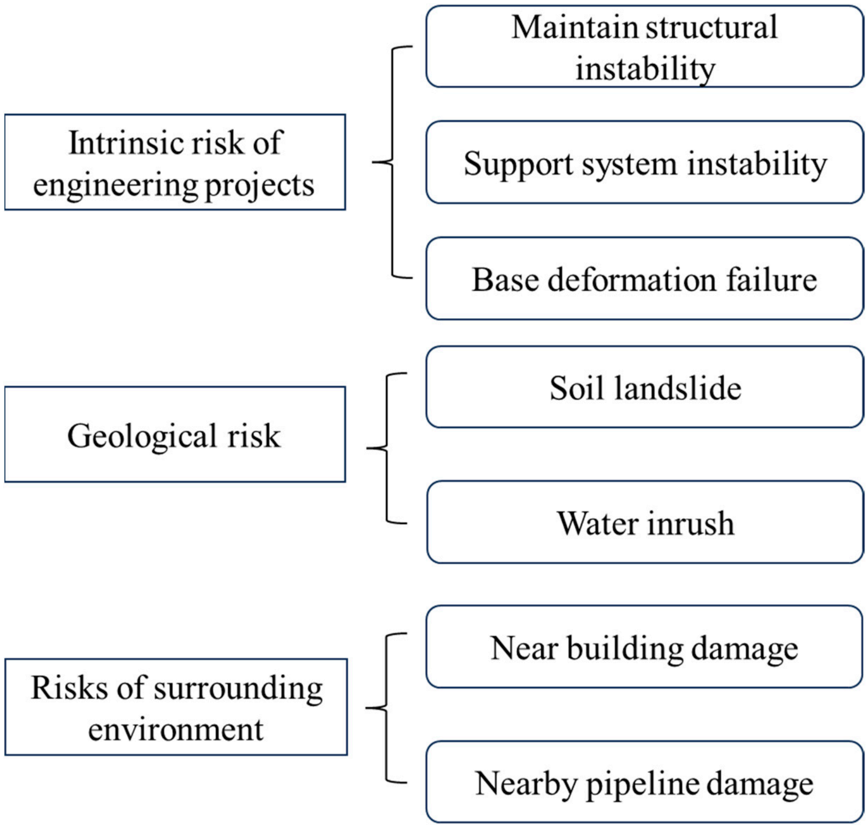


Figure 1. Construction risk sources of large-scale underground space projects.

2.2. Digital Twin System Framework

In order to meet the requirements of the high-precision and real-time construction safety monitoring of large underground spaces, considering the factors of time and space in multiple dimensions, the concept of digital twins is integrated into the construction safety monitoring system of underground structure engineering. Digital twin technology can achieve real-time information interactions between the physical space and virtual space, and map the behavior changes of entities in the real environment in the virtual space [19,20].

In the construction process of underground space structures, a large amount of measured data will be generated, which will interact with the data of the virtual simulation to form the twin data. Through the information mining of twin data, the dynamic prediction of the construction process is realized. The first and most important aim in the safety monitoring of large underground space construction is to capture the data of key safety risk factors. Through the analysis of the safety risk of large underground space construction, it can be seen that the information that needs to be captured in the construction process is mainly divided into the project's own risk, O; geological risk, G; surrounding environment risk, E; and construction personnel management, Pi. The established twin model framework can truly reflect the safety state of construction.

In the process of large underground space construction, there are many causes of safety problems. Combining the effects of various influencing factors, focusing on the risk of the project itself; the retaining structure, E; the support system, S1; the bottom deformation, F; the geological risk soil slump, S2; the mud inrush water inrush, W; the surrounding environmental risk of the adjacent building damage, A; the adjacent road and railway damage, R; the adjacent bridge damage, B; and the adjacent pipeline damage, P, they are closely related to the construction safety of the underground space structure. According to the information that needs to be captured in the construction safety analysis, the twin information is divided into three categories, which are represented by Formulas (1)–(3), respectively.

$$O = \{E, S_1, F\} \tag{1}$$

$$G = \{S_2, W\} \tag{2}$$

$$E = \{A, R, B, P\} \tag{3}$$

For each construction risk factor, the finite element model and BIM model corresponding to the entity are established, respectively, and the virtual model is uploaded to the twin system platform. According to the specification requirements and engineering experience, the management standards are set up for each key risk factor, and the intelligent auxiliary decision module of the twin system is established to ensure the scientificity of safety monitoring throughout the entire process of construction. According to the information required for the safety risk management of underground space structure construction, combined with the concept of digital twins, a twin system framework is proposed, as shown in Figure 2.

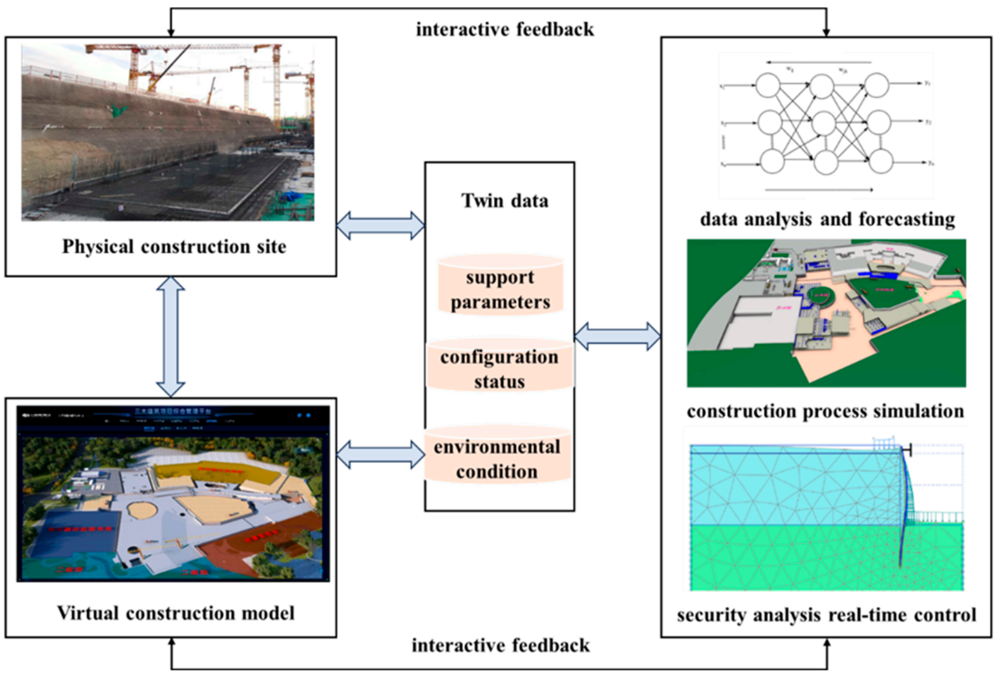


Figure 2. Twin system framework of underground space safety monitoring.

In this framework, the physical construction entity and the virtual simulation model achieve virtual and real-world interaction through the Internet of Things technology. With the help of real-time multi-factor data acquisition, they are transmitted to the cloud platform for cloud computing. Through the analysis, mining, and prediction of historical accumulated data by an intelligent algorithm, the safety state of the structure is obtained, and the information is fed back in the application layer to achieve the automatic decision-making and self-scheduling of the construction process.

3. Integration of the Internet of Things

The twin system framework of safety monitoring in the underground space construction process provides the basis of the theoretical framework for safety management in construction processes. In order to achieve the automatic decision-making and self-scheduling of the construction process of underground space structures, the most important thing is data collection. Internet of Things technology, as the supposed eye of data, can collect a large amount of monitoring data needed by twins in real time. The fusion mechanism of Internet of Things technology and twin systems is studied, and a twin system for large underground space safety monitoring based on Internet of Things technology is obtained.

3.1. The Fusion Mechanism of Internet of Things and Digital Twin Systems

The Internet of Things (IoT) refers to the use of sensing devices, such as radio frequency identification technology (RFID), global positioning systems, and other information sensing devices, on the basis of Internet technology, to connect the material itself with virtual information data to achieve the intelligent identification, positioning, and tracking of items, and to achieve information technology and remote monitoring and management [21,22].

The Internet of Things has the characteristics of convenient configuration, high security and stability, and has a simple and easy operation interface. However, the construction process of the structure is a complex task. On the one hand, the structure itself will change over time; on the other hand, the construction environment is often complex and changeable. In order to solve these specific problems, Internet of Things technology is used to transmit the construction monitoring data of the structure more appropriately and effectively, so as to monitor the state change of the structure during the construction period and for use as the control information of the construction procedure to ensure its safety.

The principle of digital twin technology is to realize the simulation, monitoring, and optimization of physical entities through the interaction of key steps such as data acquisition, virtual modeling, real-time monitoring and feedback, simulation and optimization, control and decision-making, and state diagnosis and maintenance. The data of the physical entity are collected by sensors and monitoring equipment and synchronized with the digital twin model to ensure that the model is consistent with the state of the actual entity. Based on the collected data, a virtual model of the physical entity is constructed, including detailed information such as structure, attributes, and behavior rules. By synchronizing with real-time data, the state, performance, and behavior of physical entities are monitored in real time, and real-time feedback signals are provided to control and adjust the operation of entities. The digital twin model is used for simulation and optimization analysis to predict the state and performance of the structure, and provide optimization suggestions and decision support. Through the linkage of the digital twin model and real-time data, the remote control and operation of physical entities are achieved, and intelligent decision support is provided for decision makers. Finally, based on the digital twin model and real-time data, the state diagnosis is carried out, the causes of structural safety risks are identified, and corresponding maintenance suggestions and strategies are provided.

From the summary of the principles of Internet of Things technology and the twin system, the commonality of the two can be obtained. Therefore, on the basis of the twin system framework, the Internet of Things technology is integrated to explore the following five fusion mechanisms, and the mechanism fusion framework is given, as shown in Figure 3.

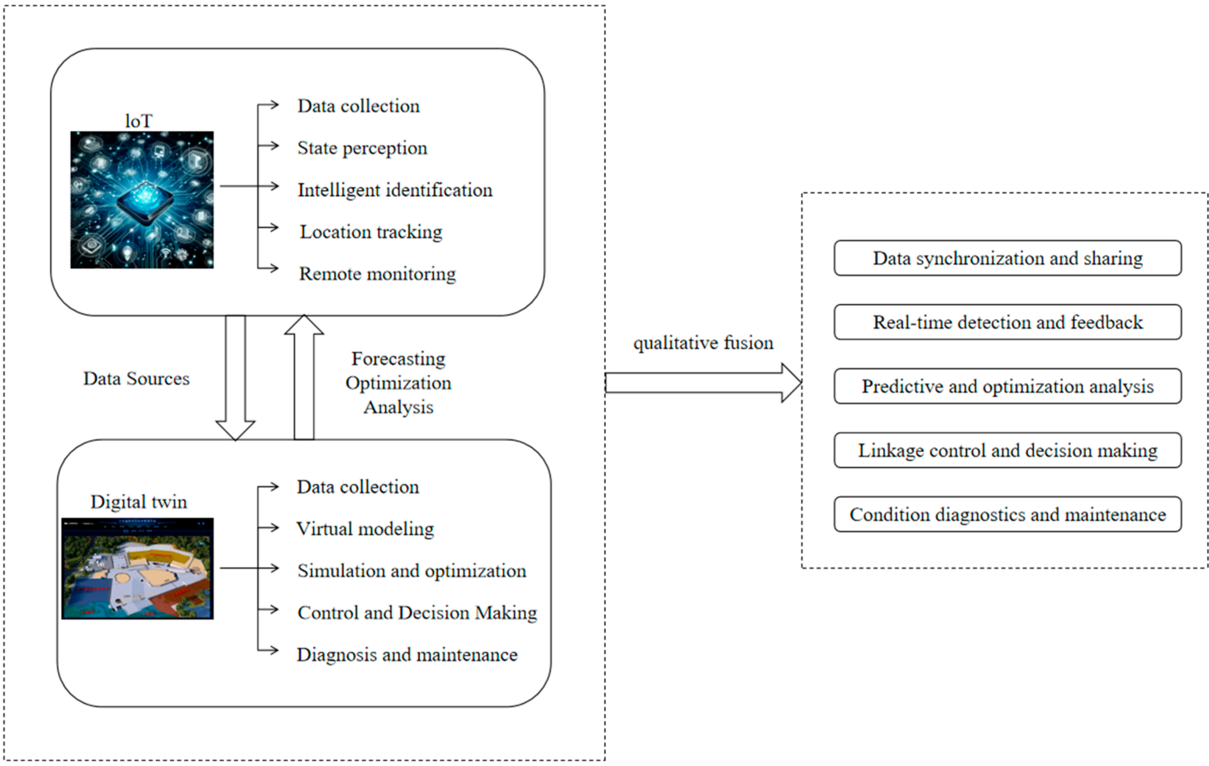


Figure 3. Fusion mechanism of IoT and digital twin.

(1) Internet of Things technology achieves real-time data acquisition and sharing by connecting and transmitting data between devices and sensors. These data can be used to update and maintain the model of the twin system and keep the model in sync with the actual physical world. Internet of Things technology provides data sources and real-time, high-quality data input for the twin system.

(2) Internet of Things technology can monitor various parameters and states in the physical world in real time, including equipment operating status, environmental conditions, energy consumption, and so on. Through combination with the twin system, the real-time monitoring data of the Internet of Things technology can be compared and analyzed with the twin model to find anomalies and provide real-time feedback. This real-time monitoring and feedback mechanism helps users to accurately understand the operating status of the physical system and perform timely adjustments and optimizations.

(3) A large amount of data generated by Internet of Things technology can be used for the prediction and optimization analysis of twin systems. By analyzing the historical records and real-time monitoring data of the Internet of Things data, the twin system can predict the future behavior and performance of the physical system and make optimization suggestions. This prediction and optimization analysis can be used for equipment maintenance, resource utilization optimization, energy efficiency improvement, etc., to achieve more efficient and sustainable operations.

(4) The integration of IoT technology and a Siamese system can enable the realization of linkage control and intelligent decision support. Through the real-time data collected by Internet of Things technology, the twin system can generate a virtual model that matches the physical system, and perform simulation and analysis. Based on the analysis results of the twin model, the remote control and operation of the physical system can be realized, and intelligent decision support can be provided for decision makers to optimize operation and management.

(5) The combination of the real-time monitoring of IoT technology and modeling analysis of a Siamese system can enable the state diagnosis and maintenance support of

physical system. Through monitoring data and model analysis, the safety status of the structure can be accurately identified, and corresponding maintenance suggestions and schemes can be provided. This helps to improve the reliability and maintenance efficiency of the structure and reduce the impact of accidents on construction.

3.2. Establishment of Mathematical Model of Fusion Mechanism

Through the analysis of the basic principles of Internet of Things technology, combined with the characteristics of digital twin technology, the fusion mechanism of Internet of Things technology and the twin system is explored. Because the safety monitoring of the underground space construction process is guided by the time dimension, multi-dimensional and multi-source data are integrated into the cloud platform for calculation and analysis. Taking the fusion mechanism as the core, a mathematical model is established to provide a reference for the development and application of the subsequent twin system.

In the mathematical model, M represents the model of the twin system. D (t) represents the real-time data collected by the Internet of Things technology, where t represents time. S (t) denotes the state of the physical system at time t.

(1) Data sharing and synchronization:

$$M(t) = f(D(t)) \tag{4}$$

The real-time data D (t) collected by the Internet of Things technology is mapped to the twin system model M (t) by function f to ensure the synchronization between the model and the actual physical system.

(2) Real-time monitoring and feedback:

$$M(t) \approx S(t) \tag{5}$$

Through the synchronization of real-time monitoring data, the twin system model M (t) is approximated to the physical system state S (t).

Feedback mechanism: According to the difference between M (t) and S (t), a feedback signal is generated to control and adjust the behavior of the physical system.

(3) Prediction and optimization analysis:

$$P(t) = g(M(t)) \tag{6}$$

The twin system model M (t) is predicted and optimized by the function g, and the prediction result P (t) is obtained.

Optimization decision: According to the prediction result P (t), the optimization decision is made, and the operating state and parameters of the physical system are adjusted.

(4) Linkage control and decision-making:

Control mechanism: According to the twin system model M (t) and real-time data D (t), the control instruction C (t) is generated to control the behavior of the physical system.

Decision support: Based on model analysis and real-time data, decision support is provided, such as intelligent decision-making based on M (t) and D (t).

(5) Status diagnosis and maintenance:

State diagnosis: According to the twin system model M (t) and real-time data D (t), the state simulation analysis is carried out to identify the causes of risk in the physical system.

Maintenance support: Provide maintenance support based on status diagnosis results, including maintenance recommendations and strategies.

According to the fusion mechanism, the following key points can be summarized. Firstly, the real-time data D (t) are mapped to the twin system model M (t) by function f to ensure the synchronization between the model and the actual physical system. Secondly, through the synchronization of real-time monitoring data, the twin system model M (t) is approximated to the physical system state S (t), so as to realize real-time monitoring and feedback. The behavior of the physical system is controlled and adjusted by generating feedback signals. In addition, the function g is used to predict and optimize the twin system model M (t), and the prediction result P (t) is obtained. According to the prediction result P (t), the optimization decision is made to adjust the operating state and parameters of the physical system. At the same time, according to the twin system model M (t) and the real-time data D (t), the control instruction C (t) is generated to control the behavior of the physical system. Based on model analysis and real-time data, decision support can be provided, such as intelligent decision-making based on M (t) and D (t). Finally, the twin system model M (t) and real-time data D (t) are used to diagnose the state to identify the causes of risk in the physical system.

In summary, the integration mechanism of Internet of Things technology and the digital twin system provides a powerful tool and decision support for the safety monitoring of the underground space construction process. Through real-time data acquisition, model analysis, and prediction optimization, the physical system can be monitored, controlled, and maintained to ensure the safety and efficiency of the construction process.

4. Case Verification

4.1. Project Case

The effectiveness of this research method is verified by taking the foundation pit construction of three major buildings' shared facilities in the urban sub-center as an example. The shared support facilities of the project are mainly located on the first and second floors of the underground, covering an area of about 154,000 square meters, with a total construction scale of about 255,000 square meters. The main functions are comprehensive support for parking, parking for three major buildings, and comprehensive support for service facilities. A plane schematic diagram of the foundation pit project for three major buildings' shared support facilities is shown in Figure 4.

Figure 4. Plane schematic diagram of foundation pit project of three major buildings' shared support facilities.

The project is based on the largest commercial underground center in China. The project has a huge volume, many work surfaces, a complex structural system, high construction accuracy requirements, many professional interfaces, and great difficulty in professional integration and coordination. Near the North Canal, the groundwater level is high; at the same time, there are two canal sites in the project that need to be supported separately.

The targets being monitored in the project mainly include horizontal displacement monitoring, settlement monitoring, deep horizontal displacement monitoring, groundwater level monitoring, anchor cable internal force monitoring, concrete support axial force monitoring, etc. The data of the foundation pit are collected in real time by arranged sensors and monitoring equipment at the monitoring points, and synchronized with the twin model to ensure that the twin model is consistent with the state of the underground space.

4.2. Construction Safety Monitoring on Twin System Platform

BIM technology is used to establish the geometric and physical models corresponding to the foundation pit, and the virtual model is uploaded to the twin system platform. At the same time, considering the dynamics of the construction process, the 4D construction simulation of the BIM technology is used to visually simulate the construction sequence and the overall construction period plan. Collection of risk indicator data is carried out by installing corresponding sensors at the construction site. The targets of safety monitoring in the foundation pit mainly include horizontal displacement, settlement, groundwater level, anchor cable internal force, etc. The data from the foundation pit are collected in real time by installing sensors and monitoring equipment at the monitoring points. The specific monitoring types and sensor models are shown in Table 1. The sensor monitoring layout requirements include the following: (1) The layout of the foundation pit engineering sensors should be able to reflect the actual state of the monitored object and its changes, such as the layout of the internal force and deformation key feature points, and should meet the monitoring needs. (2) The layout of the sensors in the foundation pit should not hinder the normal work of the monitored targets, should reduce adverse impacts on construction operations, and mark the location of the layout to help remind construction personnel and monitoring personnel how to find the sensor. (3) A regular inspection and calibration plan should be established to ensure the normal operation of the sensor, and regular maintenance measures should be taken if the sensor equipment fails or functions abnormally.

Table 1. Foundation pit safety monitoring type and sensor name.

Serial Number	Monitoring Type	Sensor Name	Sensor Type
1	Concrete supporting stress	Embedded concrete strain gauge	YB-MR01
2	Anchor cable axial force	Anchor cable axial force meter	YB-MS300
3	Deep horizontal displacement	Automatic inclinometer	LRK-CX06
4	Settlement around foundation pit	Static level	LRK-J112
5	Settlement and horizontal displacement around foundation pit	Two-dimensional laser displacement meter	LRK-DL630
6	Groundwater table monitoring	Wireless water level gauge	RYY-SW01
7	Incline monitoring of surrounding buildings	Wireless high-precision biaxial inclinometer	LRK-RG911

Through the comprehensive utilization of different transmission methods, a variety of on-site monitoring instruments, detection equipment, and wireless sensors are connected through Internet of Things technology, and data are transmitted to the twin platform through Zigbee or the 4G network, so as to realize the automatic collection and real-time transmission of monitoring data, ensure the authenticity, integrity, and real-time performance of data, and ensure that the twin model of foundation pit safety monitoring can reflect the underground space entity in physical space accurately and in real time. The twin model of the underground space of the three major buildings' shared support facilities is shown in Figure 5.

Figure 5. Twin model of underground space of three major buildings' shared support facilities.

Through the integration of the above twin model and monitoring equipment, a twin system platform for foundation pit safety monitoring is constructed, as shown in Figure 6. The system can process the original monitoring data in real time, and use mathematical models and mathematical methods such as regression analysis and difference analysis to digitally model and analyze all kinds of collected data to form various change curves, graphs, and charts. Through various forms of real-time alarm functions, the hidden dangers of engineering and the surrounding buildings and pipelines can be found in time.

Figure 6. Twin platform for foundation pit safety monitoring.

The twin platform for pit safety monitoring, under the digital construction site board in the information control platform of the three major public buildings project, is able to display in real time whether the monitoring points have exceeded the alarm value, and to count the number of safe points and the number of points exceeding the alarm value. At the same time, the system platform can count the proportion of the monitoring types; display the monitoring data of the groundwater level, deep horizontal displacement, settlement around the foundation pit, and horizontal displacement in real time; and count the number of alarm situations occurring over a period of 30 days. Through the integration of Internet of Things technology and digital twin system, the real-time monitoring of foundation pit data can be realized, and the change in the safety state of foundation pit in the whole construction period can be measured. Through the analysis of monitoring data, alarms, and the real-time reflection of the state of foundation pit engineering, the occurrence of major accidents is avoided.

4.3. Parametric Analysis of Construction Safety

During the construction process, the displacement of the orthogonal arch is an important monitoring index. The orthogonal arches of the project are longitudinally primary arches, transversely connected beams, and flanked by secondary arches. The structure of the orthogonal arch is shown in Figure 7. Based on the twin platform, the parameter analysis between the section size and vertical displacement of the main arch, secondary arch, and coupling beam is carried out. On the basis of the parameter analysis, the control measures to ensure the structural safety are obtained, which provides an important reference for the construction safety of the underground space.

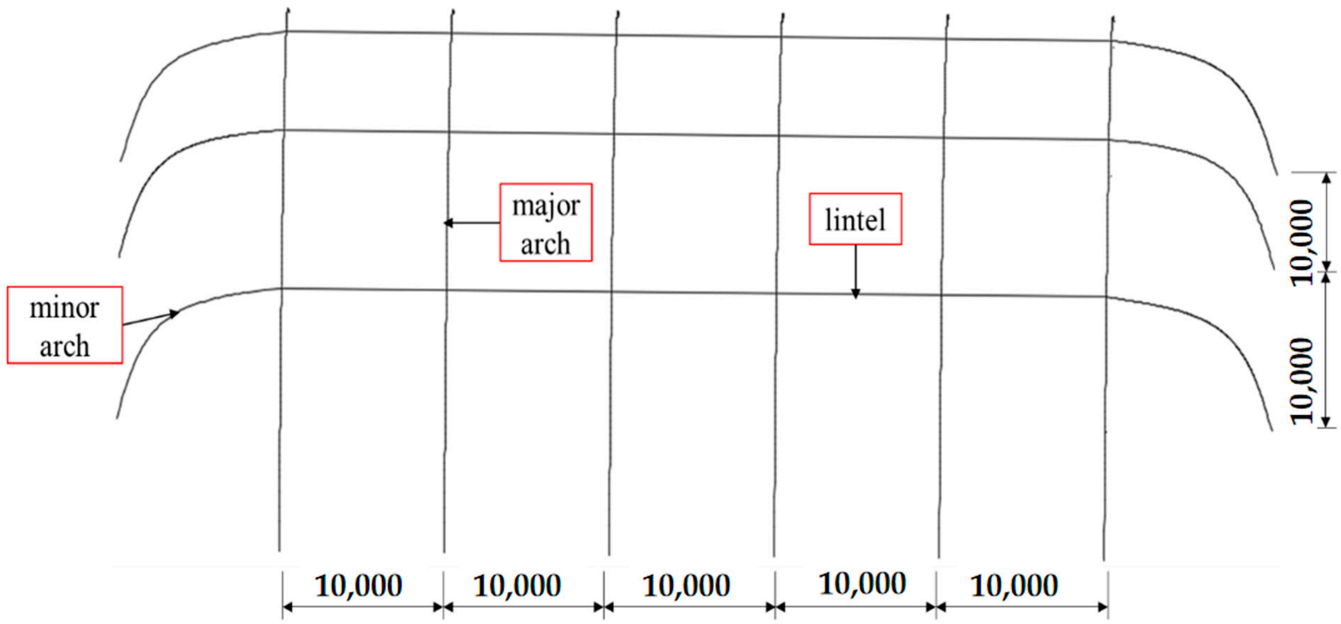
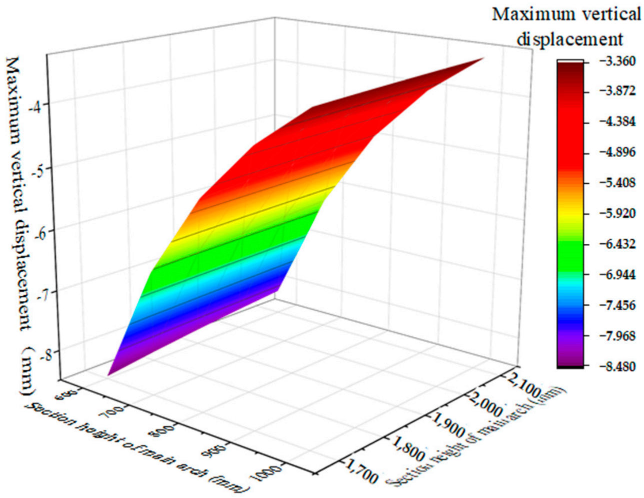
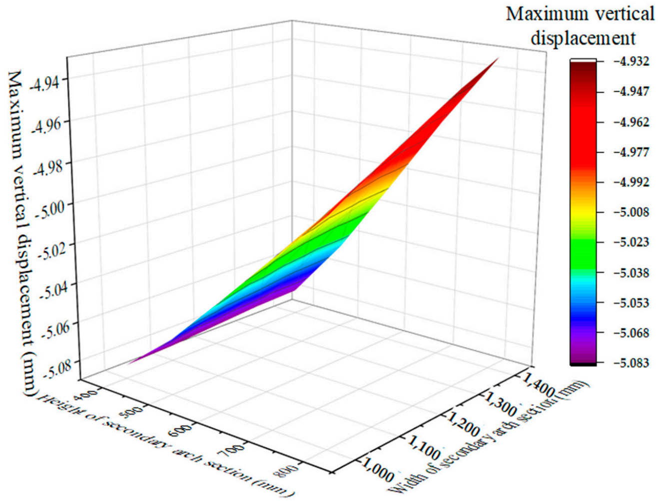


Figure 7. Construction of orthogonal arch.

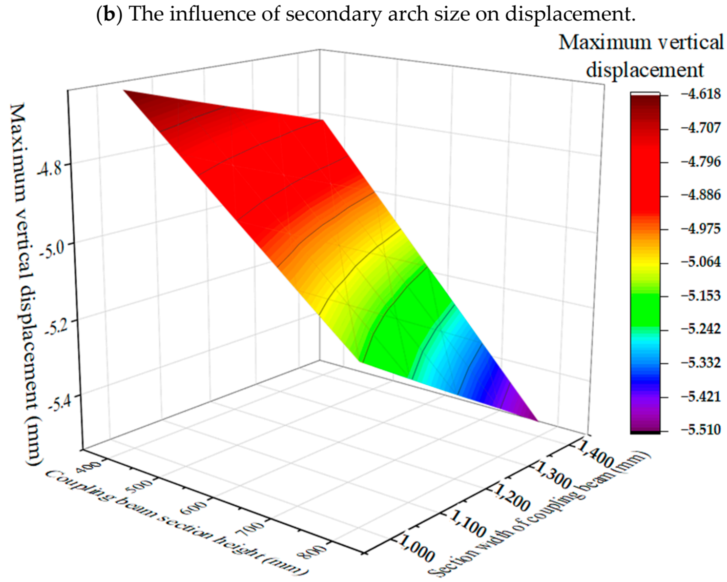
In the twin platform, the cross-sectional dimensions of the three types of components are modified, respectively. The maximum vertical displacement of the structure corresponding to different types of cross-sectional dimensions is shown in Figure 8. The section size of the main arch has the greatest influence on the structural displacement, and the section size of the secondary arch has the least influence on the structural displacement.



(**a**) The influence of main arch size on displacement.



(**b**) The influence of secondary arch size on displacement.



(**c**) The influence of coupling beam size on displacement.

Figure 8. The influence of different types of section size on the maximum vertical displacement of the structure.

According to Figure 8, the vertical displacement of the structure decreases with the increase in the section size of the main arch and the secondary arch. With the increase in the section size of the coupling beam, the vertical displacement of the structure increases. The section height of the main arch has the most significant effect on the vertical displacement. Therefore, the best measure to ensure the safety of the structure is to increase the section height of the main arch.

4.4. Discussion of Results

(1) Effectiveness

The pit safety monitoring twin platform achieves the expected effects of synchronization between the model mentioned in the theoretical research and the actual physical system, real-time monitoring and feedback, the control and adjustment of the behavior of the physical system, prediction and optimization analysis, the optimization of decision-making, state diagnosis, etc. It meets the requirements of high-precision and real-time safety analysis for the construction of the structure of a super-large underground space, and it has been verified by application case studies to more effectively solve structural safety problems during the construction process.

(2) Limitations

The scope of applications and application case studies for the fusion mechanism of Internet of Things technology and a digital twin proposed in this paper includes the construction process of large underground space structures. In the section discussing the parametric analysis of construction safety, the displacement of the orthogonal arch is analyzed only as an example, which means this theoretical research has certain limitations despite accurately solving the construction safety risk problem of a large underground space.

(3) Prospects

At present, the world is in an era of informationization, and Internet of Things technology and digital twin technology, as representatives of information technology, have a huge scope of possible applications, and can be more widely used in engineering construction. The fusion mechanism of IoT and digital twins and the digital twin system framework proposed in this paper provide a model for similar projects in the future and can be further developed to solve other problems in the construction process.

5. Conclusions

Aiming at the complex challenges faced in the construction of super-large underground space structures, an intelligent monitoring system architecture suitable for the construction of super-large underground space structures is proposed by introducing the concept of digital twins and Internet of Things technology, and the fusion mechanism of Internet of Things technology and digital twins is explored. The system can collect a large amount of monitoring data in real time, and carry out real-time safety analysis with the help of twin technology. The effectiveness and practicability of the twin system in the construction of super-large foundation pits are proven by the example project.

(1) Aiming at the complex characteristics of the construction of super-large underground space structures, the concept of digital twins is introduced. Combined with Internet of Things technology, a twin system architecture that can meet the actual needs of the project is proposed to improve the level of intelligent structural construction safety monitoring and ensure that the underground space structure is in a safe state during construction.
(2) The fusion mechanism of Internet of Things technology and the twin system is studied, and a twin system for large underground space safety monitoring based on Internet of Things technology is obtained.
(3) For construction in practical engineering, a twin system platform is developed. Based on the twin platform, a parametric analysis of construction safety is carried out, and

the mapping relationship between the section size and structural displacement is obtained. The parametric analysis effectively assists the formulation of structural safety control decisions.

This study provides a new solution for improving the construction safety level and risk prevention and control, and has important theoretical and practical value for the safety management of underground space construction processes. The safety monitoring of foundation pit construction is the core function of the twin system. The construction of the twin system for safety monitoring needs to integrate various elements such as the safety monitoring, topography, geology, and soil quality of the foundation pit, and needs to integrate multidisciplinary knowledge and industry experience to enable accurate analyses and build a decision-making knowledge base.

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