Intelligent Foundation Pit based on Digital Twin Technology Safety Monitoring and Prediction

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Abstract. With the increasing scale of foundation pit engineering, construction constraints are becoming more and more complex, under this background, it is urgent to carry out automatic monitoring and safety control of foundation pit Taking Tagang Village foundation pit project in Zengcheng District of Guangzhou as an example, a new automatic safety monitoring, prediction and early warning technology for the whole life of foundation pit is proposed, which provides a new idea for the stability evaluation of foundation pit. This technology combines tilt photography technology, BIM and deep learning to develop a digital twin integrated platform for foundation pit construction and maintenance stage management, which successfully realizes comprehensive, accurate and real-time monitoring and prediction of foundation pit, and provides more reliable and detailed data support for evaluating the stability of foundation pit. This not only improves the safety and reliability of foundation pit engineering, but also shows significant application value in the engineering field.

Keywords: Foundation pit; Deformation monitoring; BIM; Deep learning

1 INTRODUCTION

The stability of foundation pit is the premise to ensure the development and construction of various underground Spaces and high-density buildings[1]. The traditional evaluation method of foundation pit stability, on the one hand, the method of physical modeling evaluation is highly dependent on human expertise, large-scale evaluation of foundation pit stability is inefficient and subjective; On the other hand, due to the development of cities, deep foundation pits are getting deeper and deeper, and more and more factors affecting the stability of foundation pits need to be considered[2]. The geological information collected by establishing physical modeling is not accurate, which can no longer meet the basic requirements of deep foundation pit deformation prediction[3]. Moreover, with the characteristics of long pit monitoring period, many personnel, scattered equipment and materials, and trivial management process, the traditional manual inspection and manual paper media recording can no longer meet the requirements of construction control[4]. In order to solve the above problems, ensure the safety

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of the foundation pit construction process, and meet the urgent needs of the digitization, modernization, lean management and information construction of the project, this paper presents a new automatic safety monitoring, prediction and early warning technology for the whole stage of foundation pit, which provides a new way to evaluate the stability of foundation pit[5].

2 FOUNDATION PIT INTELLIGENT MONITORING PLATFORM BASED ON DEEP LEARNING AND BIM

In recent years, with the development of urban construction, large-scale buildings have been continuously constructed, and the number of foundation pits has increased accordingly[6]. Excavation engineering is a complex system engineering, and accidents such as collapse of pit walls, landslides inside the pit, and soil infiltration damage are prone to occur during excavation construction. Traditional foundation pit monitoring includes surface settlement monitoring, groundwater level monitoring, soil stress monitoring, support structure deformation monitoring, etc. Although traditional foundation pit monitoring methods are classic, they also have some shortcomings in practical applications, such as limited real-time and accuracy of data, which cannot meet the high standard requirements for foundation pit monitoring in modern construction. Therefore, traditional methods for evaluating the stability of foundation pits, on the one hand, rely heavily on human professional knowledge in physical model evaluation methods, resulting in low efficiency and strong subjectivity in large-scale foundation pit stability evaluation; On the other hand, due to the development of cities, deep foundation pits are becoming increasingly deep, and more and more factors that affect the stability of foundation pits need to be considered[7]. The geological information collected through the establishment of physical models is inaccurate and can no longer meet the basic requirements for predicting deformation in deep foundation pits. Due to the long monitoring cycle, large number of personnel, scattered equipment and materials, and cumbersome management processes in foundation pit monitoring, traditional manual inspection and manual paper media recording can no longer meet the requirements of construction control.

In order to solve the above problems, ensure the safety of the foundation pit construction process, and meet the urgent needs of engineering digitization, modernization, lean management, and information construction, taking the foundation pit project in Tagang Village, Zengcheng District, Guangzhou City as an example, using the combination of foundation pit monitoring and engineering management, using oblique photogrammetry technology to obtain foundation pit data, and implementing intelligent monitoring and prediction of foundation pits through BIM and deep learning technology[8]. A new automatic monitoring, prediction, and early warning technology for the safety of foundation pits throughout the entire stage has been proposed, providing a new method for evaluating the stability of foundation pits.

2.1 Deformation prediction model of foundation pit

Temporal and spatial characteristics are important characteristics of monitoring point displacement prediction. As a result, a spatio-temporal feature matrix of multiple orders is created to expand the features from similar time domains to all time domains and from adjacent monitoring points to all monitoring points[9]. The autocorrelation function is employed to compute the correlation of order for the temporal features at monitoring point B., as shown in equation (1), and the spatial features as shown in equation (2).

$$p_n = \frac{1}{P-n}\sum_{i=1}^{P-n}\frac{h_i h_{i+n}}{H*H}, (n = 1,2, \dots, m) \tag{1}$$

Where, P is the length of the collected foundation pit time series data, h_i represents the time domain characteristics of the i time monitoring, H represents the sum of all time data, and m represents the order of the correlation coefficient.

$$q_n = \frac{1}{Q-n}\sum_{j=1}^{Q-n}\frac{s_j s_{j+n}}{S*S}, (n = 1,2, \dots, m) \tag{2}$$

Where: Q represents the total number of monitoring points for foundation pits, s_i denotes the characteristics of the i th monitoring point, and S is the aggregate sum of characteristic data from all monitoring points.

Taking the deformation monitoring data of the last 5 days as input features, the time domain prediction model is established to predict the future horizontal displacement of monitoring point B. The model is trained using a sliding window that maps 5 time domain feature samples to one day's values, with 85% of the data used for training and 15% for prediction. In addition, using the displacement data of the next day after 10 adjacent monitoring points at point B as input features, a spatial domain prediction model was established to predict the displacement of point B on the next day, in which 85% of the data was used for training and 15% for prediction.

A predictive model is developed by integrating time and space domains. Deformation monitoring data from monitoring point B and its neighboring 10 points are utilized. The past 5 days' time domain features of monitoring point B and the displacement of the 10 adjacent points one day later serve as spatial domain feature inputs for predicting the future displacement of monitoring point B. Sliding Windows are used to map five samples of time domain features to 1-day values successively. The first 85% of the data is employed for training, while the remaining 15% is used for prediction.

The comparison is made between the simulated and actual monitoring values of the BPNN model and GA-optimized BPNN model in terms of time domain, spatial domain, and spatiotemporal domain. The root mean square error (RMSE) and consistency index (IA) are calculated for the prediction models in the time domain, spatial domain, and spatiotemporal domain.

The evaluation of test results utilized RMSE, IA, and training time as assessment criteria. Due to limited observations in actual measurements, only the best value is used to replace the true value. RMSE serves as an indicator for measuring the deviation between observed and true values, reflecting observation quality to some extent. A smaller root-mean-square error indicates better observation quality[10]. IA was employed to assess the model's fitting effect, with a larger value indicating better model fitting. Additionally, under conditions of guaranteed prediction accuracy, a shorter model training time leads to faster convergence rate.

2.2 Intelligent monitoring platform for foundation pit based on BIM

The platform allows for multiple edits and modifications of BIM models, as well as the addition and removal of monitoring equipment models. Real-time synchronization facilitates the monitoring and management of BIM models at different stages, while reusing a single model enhances its practical value. The platform offers an open cloud computing framework that supports third-party algorithm loading for online data analysis from various monitoring devices to predict future trends with ease. Additionally, it provides an algorithm backtest function to compare predicted values with measured ones, assessing accuracy and selecting the most suitable algorithm based on data type[11]. Figure 1 illustrates the platform summary.

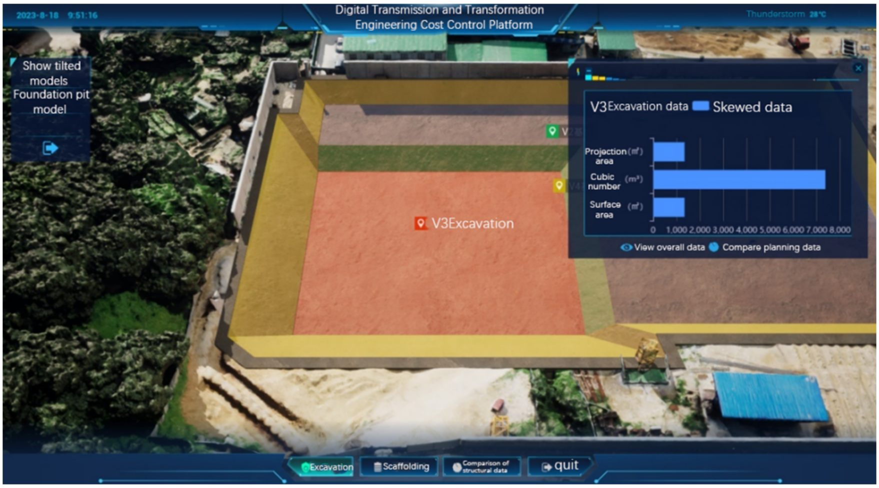

Fig. 1. Platform summary display

2.3 Foundation pit construction and digital twin integration

Currently, the platform has been applied in the intelligent foundation pit construction management project in Tagang Village, Zengcheng District, Guangzhou, demonstrating its potential and value in practical engineering. In order to promote this advanced technological solution to more engineering projects, the key is to customize the import of relevant data information based on the specific characteristics and requirements of each project. This means that key information such as environmental conditions, geological features, and construction plans of the new project will be integrated into the platform system to achieve precise monitoring and management.

However, in order to better serve diverse engineering needs, the compatibility of the platform urgently needs to be improved. This involves optimizing software architecture to seamlessly interface with various types of hardware devices and data interfaces, while also ensuring system stability and scalability to adapt to future technological developments and changes.

The predicted results listed in Table 1 are a concrete manifestation of the practical application effects of these functions, demonstrating the significant achievements of the platform in improving construction efficiency, reducing costs, and ensuring worker safety. With the continuous improvement of technology and the accumulation of application cases, this platform is expected to become an important force in promoting the intelligent transformation of the construction industry.

Table 1. Statistics on the maximum changes of measurement points

monitoring program	Building settlement monitoring around	
	Maximum rate of chang(mm/d)	Maximum cumulative change(mm)
numerical value	-1.15	-13
dit	JZ3	
monitoring program	Foundation pit roof settlement	
	Maximum rate of chang(mm/d)	Maximum cumulative change(mm)
numerical value	0.57	-12.62
dit	WY8	

3 CONCLUSION

A novel concept for combining intelligent monitoring and management of foundation pit was introduced in this research. A digital twin integrated platform was developed to oversee the construction and maintenance stages of foundation pit using tilt photography technology, BIM technology, and deep learning[12]. This platform was utilized to predict foundation pit deformation in the Tagang Village project in Zengcheng District, Guangzhou. By incorporating time domain and space domain as input features, the accuracy and efficiency of the monitoring and prediction model for foundation pit deformation can be enhanced. As a result, the foundation pit deformation prediction model based on BP neural network and genetic algorithm presented in this paper demonstrates strong predictive capabilities and is suitable for similar projects. The findings of this study hold significant theoretical importance and practical value for monitoring foundation pit deformation in geotechnical engineering. However, there is a need to enhance the accuracy of the prediction model. The safety of production is crucial to the overall project, ensuring the safety of the foundation pit is extremely important and cannot be neglected. Therefore, the accuracy of predictions still needs to be improved in the future; The generalization ability of the prediction model is that the current foundation pit monitoring model performs well in specific scenarios, but its generalization ability needs to be improved in new or different environments. This means that the model may not be able to adapt to all situations and requires more data and algorithm optimization to improve generalization performance. In the future, we can move towards multimodal fusion: combining the data of different sensors (such as cameras, laser radars, sensors, etc.) with the information of BIM model, we can conduct multimodal data fusion to improve the comprehensive performance and accuracy of the monitoring platform; Strengthen intelligent optimization and management, further integrate artificial intelligence technologies such as deep learning and optimization algorithms, develop intelligent foundation pit management systems, achieve automation and intelligent management of the foundation pit construction process, and improve construction efficiency and quality.

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