Design and Research of Integrated Safety Early Warning System of Super Tall Building Based on Random Forest Model

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ABSTRACT

In the context of global urbanization, the rise of super tall buildings has brought new challenges to safety management. The development of artificial intelligence technology provides a new solution for the safety warning of super high-rise buildings. Random forest model is an integrated learning algorithm, which has good anti-noise ability and excellent prediction performance, can handle a large amount of data, and is not easy to overfit, so it is very suitable for constructing safety early warning system of super tall buildings. The comprehensive safety early warning system of super tall building constructed by random forest model algorithm can monitor and early warning the safety state of super tall building in real time, effectively reduce the safety risk of super tall building, and has important practical application value. In view of this, this study designed and verified a comprehensive safety early warning system that integrates real-time monitoring, data analysis and intelligent early warning, aiming at comprehensively monitoring building health status and timely preventing safety hazards. This paper discusses the overall design of safety early warning system of super tall buildings from the aspects of system architecture, key technology and early warning algorithm, and verifies the effectiveness of the system through typical building cases. The research focuses on intelligent early warning algorithm development, early warning level design and user interface optimization. Through technological innovation, this research builds a real-time, accurate and reliable warning platform for super tall buildings, which makes an important contribution to the safety, durability and sustainability of super tall buildings, lays a foundation for the construction of urban safety environment, and has important practical significance for the sustainable development of cities.

Keywords: Random forest model, super high-rise building, safety management, safety monitoring, early warning system

1. INTRODUCTION

With the accelerated pace of urbanization, as a landmark element of modern cities, super high-rise buildings not only symbolize the height of urban development, but also carry people's pursuit of space utilization efficiency. However, the rise of these skyscrapers has not only brought visual shock, but also brought a series of complex safety management challenges. The structural complexity, high particularity and personnel density of super high-rise buildings make them face unprecedented challenges in structural stability, fire safety, maintenance cycle, environmental adaptability and so on. Negligence in any link may lead to disastrous consequences and pose a serious threat to the safety of people's lives and property.

Traditional safety management methods, such as regular inspection and post-repair, have been difficult to meet the dynamic changes in the safety needs of super high-rise buildings. Especially in the management of long-term accumulated risks such as structural aging and material performance degradation, traditional methods are inadequate. Therefore, the construction of an efficient and intelligent safety early warning system has become an urgent need for the safety management of super high-rise buildings. Such a system can realize the comprehensive monitoring of building health status through real-time monitoring, data analysis and intelligent early warning, and timely detect and prevent potential safety hazards.

At present, the research on the comprehensive safety early warning system for super high-rise buildings is still in its infancy, and there is a lack of mature technical solutions and a wide range of application cases, which brings many challenges to the design and implementation of the system. The purpose of this study is to fill these 1 research gaps and

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design and verify an efficient safety early warning system for super high-rise buildings. The research will comprehensively discuss the overall design of the safety early warning system of super high-rise buildings from the system architecture, key technologies, early warning algorithms and other dimensions. By selecting a typical super high-rise building as an application case, the actual effectiveness of the system is verified, aiming to provide scientific solutions and practical technical support for the safety management of super high-rise buildings.

This study focuses on the safety early warning needs of super high-rise buildings. Through technological innovation and practical exploration, it aims to build a real-time, accurate and reliable early warning platform to contribute to the safety, durability and sustainability of super high-rise buildings. In the context of the continuous advancement of urbanization, the establishment of the safety early warning system for super high-rise buildings is not only an innovation in construction technology, but also an upgrade of the concept of urban safety. It is of far-reaching significance to ensure the safety of people's lives and property and promote the sustainable development of the city.

2. DESIGN OF VARIOUS SAFETY WARNING METHODS

2.1The framework of the integrated safety early warning system of super tall building based on random forest model algorithm

Super high-rise buildings have the characteristics of long service life, long construction period, complex structural form and huge consumption of funds. During the construction period, the height and loading mode of the building structure continue to change with the construction process, resulting in the constant adjustment of the force of the structural components. In order to reduce the safety risk during the construction application of super tall building projects, it is essential to diagnose and monitor the health status of super tall buildings and accurately evaluate the safety and effectiveness of building structures. Based on the theoretical research results of artificial intelligence technology, the overall architecture of the comprehensive safety early warning system of super tall buildings is constructed by using the random forest model algorithm, as shown in Figure 1 below:

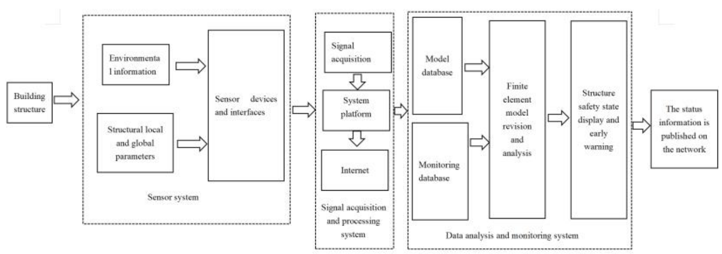

Figure 1 System architecture

According to the above analysis, the system architecture is divided into four parts: First, the sensor system. Including accelerometer, displacement meter, thermometer, wind direction and anemometer and other technical equipment, the main use of sensor components and data acquisition equipment, all-weather uninterrupted monitoring of the working state of the structural system; Second, data acquisition and transmission system. The information collector and the corresponding data, storage equipment, etc., will be installed in the measurement structure, after collecting the corresponding data according to the network architecture real-time transmission; Third, data analysis and monitoring systems. Under the support and control of computer hardware and software, the whole module can analyze and process the data information to be tested and collected in real time, accurately determine the location and degree of damage, and present the overall or local safety state of the building structure to the staff. Fourth, information release system. The network platform of the safety monitoring system is constructed, and the relevant data is presented according to the monitoring data tables and graphs, so that the system staff can visually see the real-time monitoring information of the building structure and publish the relevant content on the network.

The safety early warning of super high-rise building is a comprehensive early warning and forecast management of building risk factors, the severity of unsafe state and the feedback of alarm information disposal. According to the characteristics of each warning type, combined with the research results of key technologies of construction safety management, construction safety management information system and practical research, this chapter gives the implementation path method and management method of each warning type.

2.2 Stochastic forest algorithm research model

Random forest, as a combination classifier, uses bootstrap resampling to obtain multiple samples from the original data set, conducts decision tree modeling for all bootstrap samples, and then combines the decision trees together to obtain the final classification or prediction results by voting. Existing theories and empirical studies have proved that random forest algorithm has high prediction accuracy, good tolerance to abnormal values and noise, and is not prone to overfitting phenomenon. As an integrator of random forest, the generation and decision-making process of decision tree is divided into three parts. Firstly, the training set is analyzed recursively to generate an inverted tree structure. Secondly, the path from the root node to the leaf node of the tree is analyzed, and the corresponding rules are generated. Finally, the new data is classified or predicted according to the rules. In essence, the classification idea of decision tree is to complete the whole process of data analysis and data mining according to a series of rules. At present, there are many generation algorithms proposed for decision trees, such as ID 3, C4.5 and CART node splitting algorithms.Taking C4.5 algorithm as an example, combined with the flow chart shown in Figure 2 below, it is an improvement of ID3 algorithm. The actual implementation steps are as follows: First, sort out all the data information in the initial data set. After data preprocessing, if there are no continuous variables in the data set and no missing data, then proceed directly to the next step; Second, judge whether the current training set meets the end condition of the algorithm. If yes, the algorithm ends; otherwise, proceed to the next step. Thirdly, all the attributes in the training set are extracted, and the information dispute of each attribute is analyzed according to the value of the attribute and the value of the target attribute, and the information gain rate of each attribute is understood according to the calculation formula. Fourth, select the attribute with the largest information gain rate as the split node, divide the training set into multiple subsets, the number of subsets is determined by the number of values of the selected attribute, and then transfer all subsets to the second step for processing.

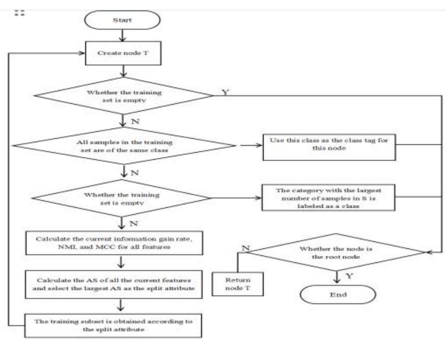

Figure 2 Flow chart of C4.5 algorithm

According to the practical application effect, C4.5 algorithm solves many problems of traditional ID3 algorithm, improves the rationality of decision tree generation process, and enhances the classification accuracy of applied algorithm. However, because the algorithm needs to iterate over the data set many times during execution, the algorithm takes a long time to execute, and the data set is usually loaded into memory, so the spatial complexity of the algorithm is high.Taking the construction of a super high-rise building project in a certain place as an example, during the construction, the staff found that there were problems in the pouring process of the main structure, which mainly carried the concrete-filled steel tube columns. By using ultrasonic inspection and acoustic detection and analysis, it was found that the concrete inside some concrete-filled steel tube columns was not dense, and it was necessary to strengthen them. However, according to the analysis of the construction conditions and testing conditions on site, it is found that in order to ensure the safety and effectiveness of the building during the later construction period, the structural response of the high-rise building should be monitored in real time. Design management is carried out according to the system architecture shown in Figure 3. Based on the reliability design classification early warning strategy, reliability refers to the scale to measure the reliability of the structure from the probability sense. Compared with the safety degree, reliability has a broader meaning, which can fully demonstrate the reliability of the building structure. At present, there are four methods for structural reliability analysis: firstly, the distance method, secondly, the exponential word simulation method, thirdly, the function substitution method, and finally, the probability density evolution method. Each method has its own advantages and disadvantages and application range. In this paper, simplified equation of probability density is used for calculation and analysis. The experimental results are shown in Table 1 below:

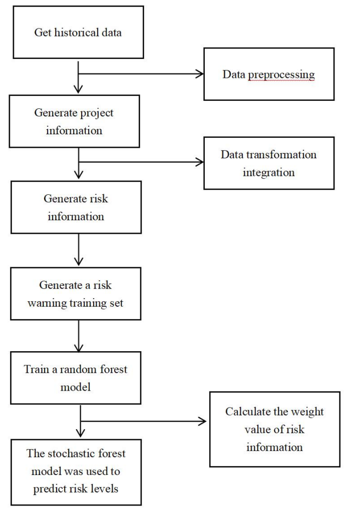

Figure 3 Reliability system structure design

Table 1 Experimental results

Warning level	Reliability (normal distribution)	Failure probability	Degree of safety	Acceptance criteria
Without warning	$\beta \geqslant 3.89$	$P_f \leqslant 5\times10^{-5}$	Very safe	negligible
three-level	$3.29 \leqslant \beta \leqslant 3.89$	$5\times10^{-4} \geq P_f > 5\times10^{-5}$	secure	acceptability
Second level	$2.57 \leqslant \beta \leqslant 3.29$	$5\times10^{-3} \geq P_f > 5\times10^{-4}$	safer	unacceptability
first-order	$\beta \leqslant 2.57$	$P_f > 5\times10^{-3}$	It's not safe to go there	Refuse to accept

According to the analysis in the above table, it can be seen that during the integrated security early warning system, the reliability based hierarchical early warning threshold can achieve excellent results by following the design principles of effectiveness, economy and openness, identifying the installation position of the sensor, monitoring the whole process of data collection, transmission and analysis. It should be noted that the current design and research on the comprehensive safety early warning system of super high-rise buildings is not perfect, and the system design principles are proposed according to the accumulated experience of engineers. In the future, more theoretical analysis and research results should be combined to optimize and improve. At the same time, the measured data is regarded as the basic random variable of the probability density evolution analysis method. In the future, it is necessary to continue to refer to the sensitive problem that the measurement parameters and the structural system can be highly variable to conduct in-depth research, and analyze how to choose to achieve the accuracy required for early warning. In addition, it is necessary to strengthen the training of professional talents for comprehensive safety early warning of super high-rise buildings, and provide basic impetus for the innovative development of the construction industry in the new era.

There are two ways to source the warning information of the comprehensive health grade (grade C and D) of super high-rise buildings: automatic database reading and manual input. After the early warning information is generated, the system notifies relevant departments or personnel to deal with it through SMS, WeChat, etc., such as inspection, repair, etc., and requires feedback on the disposal results. The early warning management system adjusts the early warning status according to the feedback, including releasing the early warning or adjusting the early warning level, and records all operations into the building history. The module realizes the unified early warning management of unsafe buildings, forms a closed-loop management mechanism of automatic correlation, reporting, feedback and recording, and ensures the efficient processing of early warning information and the continuous monitoring of building safety. The early warning implementation path for the comprehensive health level (C and D) of super high-rise buildings is shown in Figure 4, specifically:

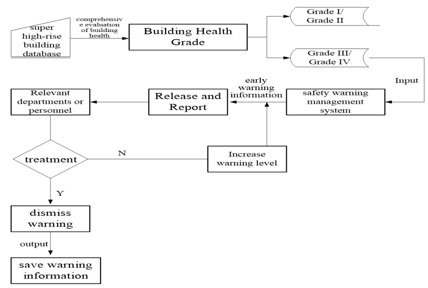

Figure 4. Schematic diagram of the implementation path of the comprehensive health level (C and D) early warning unit for super high-rise buildings

2.3 Design Life Exceeding Warning

The design life exceeding early warning mechanism takes the construction completion time as the starting point, monitors the service life, and triggers the early warning when the design service life is reached (default 50 years, depending on the design), indicating potential safety risks and requiring safety inspection. The system automatically calculates the warning time by reading the construction time information in the database, displays the remaining time limit when the deadline is not reached, and generates a blue warning when the deadline is reached. After the warning information is reported, the management status is adjusted according to feedback to ensure the timeliness and effectiveness of building safety monitoring. The implementation path of the over-design useful life warning is mainly shown in Figure 5, as follows:

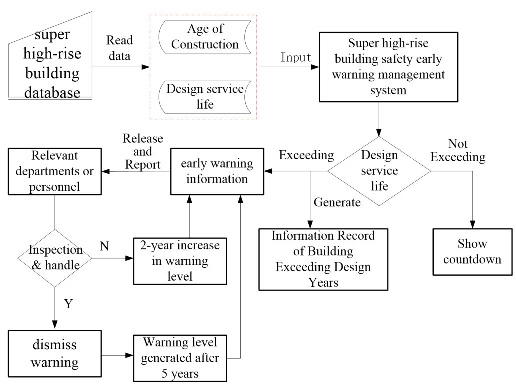

Figure 5 Schematic diagram of the implementation path of the over-design service life warning unit.

1) When the building reaches the design service life, the initial warning level is IV, showing blue warning.

2) After the warning information is sent and reported, if the feedback information indicates that the safety has been checked and handled, the warning shall be canceled and the timing shall be re-timed, and the warning shall be re-alerted to level IV after 5 years.

3) After the warning information is sent and reported, if the feedback information is not handled safely or has not been handled, the warning level will be increased step by step every 2 years until it is level I, and the red warning will be displayed; if the feedback information is checked and handled safely during this period, the warning will be canceled, and the warning will be level IV again after 5 years.

2.4 Detection Time Exceeding Warning

In view of the situation that the undetected time of the building exceeds the theoretical cycle, it is suggested that the first test of the building should be carried out after 30 years within the service life, and then every 10 years after that, and every 5 years beyond the design life. The system automatically displays the countdown to the next detection, and generates an early warning when the cycle is reached. After the early warning is reported, the early warning level is adjusted or the early warning is released according to the feedback, and the countdown to the next detection is updated to realize dynamic detection management. All disposal feedback information is filed in the building history record to ensure the continuous safety monitoring of the building. A specific implementation path is shown in Fig 6.

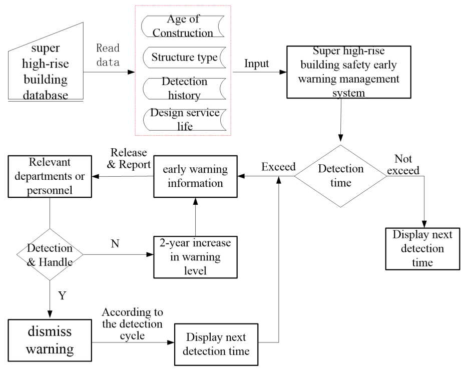

Figure 6 Schematic diagram of the implementation path of the over-detection cycle early warning unit.

In addition, for the super high-rise building of glass curtain wall, the periodic inspection of glass curtain wall is one of the important contents to ensure the safe use of glass curtain wall. Similar to the building super-detection cycle early warning, the glass curtain wall super-detection cycle early warning reads the glass curtain wall information from the super high-rise building database, and designs the early warning method according to the glass curtain wall use condition classification, in which the relevant parameters are obtained according to the investigation and practical experience.

2.5 Repair Time Exceeding Warning

Over-repair cycle warning is used to warn buildings whose unrepaired time range has exceeded the theoretical repair cycle value, and the forecast indicates that a survey should be conducted to check whether there is a need for repair. The early warning method is basically the same as the over-detection cycle early warning method, in which the relevant parameters of the early warning are determined according to research and practical testing, specifically:

1) For buildings with a service life of 30 to 100 years, the repair cycle is set to 10 years. When the building has been used for 30 years, the corresponding warning level is IV, according to the feedback information, the blue warning will continue to be displayed or the warning will be canceled. When the building has been repaired, the blue warning will be displayed again based on the last repair time and with a 10-year cycle.

2) For buildings that exceed the design service life, the repair cycle is set to 5 years.

The early warning management mode is the same as "over-detection cycle early warning".

2.6 Building Damage Behavior Warning

The early warning objects of building damage behavior mainly include the safe use behavior of man-made damaged buildings such as illegal decoration and renovation, illegal construction, and buildings found to have serious potential safety hazards during daily inspection, testing and safety investigation.

The warning information is mainly input manually, and the warning level can be filled in by manual evaluation. Relevant personnel can fill in the building damage behavior according to the actual situation, and determine the initial warning level according to the severity.

For the early warning information management of building damage behavior, the early warning level is not adjusted. When the early warning information receives the disposal feedback information, it is necessary to manually cancel the early warning information and generate the early warning history information in the building early warning unit module.

2.7 Early Warning of Nearby Construction Impact

The early warning objects of nearby engineering construction mainly include subway, shield construction, deep foundation pit construction, municipal pipe network construction and other projects that may cause damage to nearby super high-rise buildings. The early warning of the influence of nearby engineering construction is mainly based on the construction parameters of engineering conditions, such as excavation depth, excavation range, etc., to analyze the influence range, and then determine the influence degree of nearby buildings.

The construction impact early warning of nearby projects shall be accompanied by manual input or import of working condition parameters, such as route path, excavation depth and scope, and the system will automatically calculate the impact scope of the construction project, including the affected area of equal degree and the information list of affected buildings, and issue and report the early warning information, as shown in Figure 7.

Taking the construction of deep foundation pit as an example, the early warning module of the impact of deep foundation pit construction is designed, and the degree of building impact is divided into four levels, specifically:

Blue warning: when the building is 1.5 times to 2.0 times the construction depth from the construction boundary;

Yellow warning: when the distance between the building and the construction boundary is 1.0 times to 1.5 times the construction depth;

Orange warning: when the distance between the building and the construction boundary is 0.5 times to 1.0 times the construction depth;

Red warning: when the building is within 0.5 times the construction depth from the construction boundary.

When the project is adjacent to important buildings (structures) or facilities, such as excellent historical buildings, factories with precision instruments and equipment, other important buildings with natural foundation or short pile foundation, rail transportation facilities, tunnels, flood prevention walls, common ditches, raw water pipes, water mains, gas mains, etc., and the distance from the construction boundary is within 2 to 4 times of the excavation depth, blue warning will be displayed.

Similarly, the construction impact early warning information of nearby projects can be sent and reported, and managed according to the disposal feedback, including the cancellation of early warning information and the increase and decrease of early warning level.

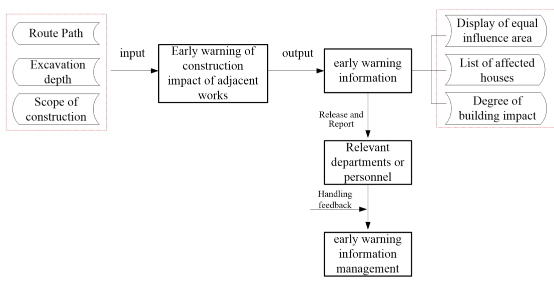

Figure7 Schematic Diagram of Implementation Path of Construction Impact Early Warning for Nearby Projects

3. BASIC FRAMEWORK AND FUNCTIONAL DESIGN OF SAFETY WARNING SYSTEM

3.1 Basic Framework of safety Early Warning System

The early warning module of the integrated health system of the super high-rise building is an operational application management platform for the early warning and early warning information management of the health status, and the early warning module of the integrated health system of the super high-rise building includes the data layer, the logic layer and the application layer, as shown in Figure 8.

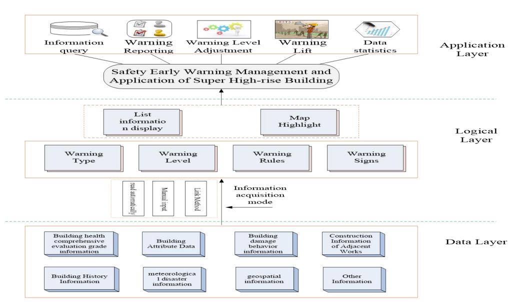

Figure8. Basic framework of super high-rise health assessment and early warning system

3.2 Design of Early Warning Function Module

According to the actual needs of super high-rise building health management and the implementation of the technical path, the functions of the early warning system are divided, including early warning information display, early warning information query, early warning information reporting, early warning information management and early warning authority management. The sending and reporting of early warning information is the key to the health warning system of super high-rise buildings, and the efficient mechanism and technology ensure the timely and accurate transmission of information. The system supports three reporting methods: SMS, mobile phone client and WEB, with flexible selection. Single or multiple messages can be sent to individuals or groups. The early warning reporting object is based on the early warning project and management department database to ensure accurate information transmission. The system designs feedback receiving functions, such as APP, automatic receiving feedback, user viewing and processing, automatic updating of early warning status, realizing closed-loop management of early warning information, and improving early warning response efficiency and building safety management efficiency.

4.CONCLUSION AND PROSPECT

This study focuses on the design and implementation of the safety early warning system of super high-rise buildings, and constructs a set of intelligent early warning system integrating data collection, analysis, early warning generation and information release for the unique safety management needs of such buildings. By integrating multi-source data and using advanced intelligent algorithms, the system realizes real-time monitoring and early warning of key indicators such as structural health, environmental safety, and personnel activities, and provides strong technical support for the safety management of super high-rise buildings. Research highlights include:Although this study has made some achievements in the design of safety early warning system for super high-rise buildings, there is still much room for improvement and expansion. Future research should deepen the application of intelligent algorithms in early warning systems to improve the system's ability to adapt to complex environmental changes; explore the integration of emerging technologies such as the Internet of Things and big data to build a more comprehensive data sharing and analysis platform; optimize the user interface and interaction design to improve the ease of use and user experience of the system. In summary, through continuous technological innovation and application expansion, the safety early warning system of super high-rise buildings will bring revolutionary changes to the safety management of urban buildings and lay a solid foundation for building a smart and safe urban environment.

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