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Adaptive Sensor Network and Intelligent Data Processing System for Structural Health Monitoring of High- Rise Buildings



Abstract: - Traditional sensor networks are often designed based on fixed layouts and are difficult to adapt to changes in structural states. Adaptive sensor networks can intelligently adjust the position, quantity, and monitoring frequency of sensors based on real-time monitoring data, environmental changes, and structural responses, achieving precise monitoring of key areas or potential risk points. This dynamic adjustment mechanism significantly improves monitoring efficiency and accuracy. Faced with massive monitoring data, the intelligent data processing system adopts big data processing technology and machine learning algorithms to automatically identify abnormal signals, predict the trend of structural performance degradation, and timely detect potential structural damage. By training the model, the system can continuously learn and optimize its predictive ability, improving evaluation accuracy. Utilize the powerful computing power and storage space of cloud computing platforms to centrally process and analyze massive amounts of data; At the same time, edge computing nodes are deployed at the sensor end to achieve preliminary data processing and real-time analysis, reduce data transmission delay and improve system response speed. Develop a user-friendly visual interface to convert complex monitoring data into intuitive charts, animations, and other forms, facilitating engineers and managers to quickly understand the structural health status. At the same time, provide decision support recommendations based on data analysis to guide structural maintenance, reinforcement, or renovation work. Adaptive sensor networks can dynamically adjust the deployment and working state of sensors according to environmental changes and monitoring requirements, which improves the flexibility and accuracy of monitoring systems. Intelligent data processing systems utilize advanced algorithms, such as machine learning and pattern recognition, to conduct in-depth analysis of the data, enabling early warning and diagnosis of potential problems with the structure. It provides reference for the establishment of structural health monitoring system of high-rise buildings.

Keywords: Improved particle swarm optimization algorithm; Health monitoring; High-rise building structure; sensor.

1. INTRODUCTION

With the progress of construction technology, the structure of high-rise buildings is becoming more and more complex, and the environmental factors and use conditions it faces are also more changeable [1]. Therefore, it is of great significance to conduct structural health monitoring of high-rise buildings and timely detect and evaluate potential structural damage for ensuring building safety [2]. Through real-time collection and analysis of structural response data, the structural health monitoring technology of high-rise buildings can provide engineers and technicians with key information about the working load, load-induced structural damage, damage growth trend and expected service life of buildings during construction and use [3]. However, the quality and quantity of monitoring data directly affect the effectiveness of the monitoring system, and the acquisition of data depends on the number and layout of sensors [4]. Therefore, how to optimize the layout of sensors to achieve accurate monitoring of high-rise building structure status is the key issue to establish a health monitoring system. In addition, due to the high cost of structural health monitoring of high-rise buildings, traditional monitoring methods are often difficult to provide comprehensive and in-depth monitoring and evaluation information [5]. With the widespread application of steel structures and large-span spatial truss structures in the field of modern architecture,

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these structural forms are highly favored due to their unique mechanical properties and aesthetic value [6]. However, such structures often carry important social functions and are exposed to complex and ever-changing natural environments for a long time, facing multiple challenges such as environmental erosion and material aging. Therefore, implementing efficient and accurate structural health monitoring has become an urgent and necessary task. The continuous development of structural health monitoring technology is gradually moving towards intelligence and integration. Modern monitoring technology can not only capture real-time operational status data of structures and equipment, but also deeply mine and analyze the data through advanced intelligent algorithms, revealing the inherent laws and potential risks of structural performance changes [7]. These information are not limited to traditional load action and structural damage identification, but also cover multiple dimensions such as damage development trend prediction and remaining service life assessment, providing comprehensive and multi-level decision support for engineering and technical personnel [8]. The effectiveness of structural health monitoring fundamentally depends on the quality and quantity of measurement data. High quality data means higher accuracy and reliability, which can more accurately reflect the actual state of the structure; And sufficient data volume provides the possibility for advanced analysis methods such as statistical analysis and model training, which helps to discover subtle performance changes and potential risk factors [9]. Therefore, when developing adaptive sensor networks and intelligent data processing systems, optimization strategies for data quality and quantity should be fully considered. By using high-precision sensors, enhancing data transmission stability, optimizing data storage and processing algorithms, etc., to ensure the accuracy and efficiency of monitoring results [9]. Using BIM technology, data and resources at different stages of the construction project life cycle can be fully described and applied to all parties involved in the construction project. Compared with the traditional engineering design concept, the biggest feature of BIM is its intuitiveness. It can combine the structure of the building and different professional design elements into a three-dimensional image space, so that the builder can intuitively judge the space of the building and discover the existence of the architectural structure design in advance [10]. When BIM is used for building 3D design, it is no longer simply using lines, surfaces or blocks for object design, but directly using components for design [11]. In a sense, the result of the design can even be understood as a three-dimensional physical model of the building [12]. Companies that develop and apply BIM technology software have applied the BIM technology developed in the 1990s to the design of building structures. The application potential of BIM technology in Chinese architectural structural design is enormous. With the promotion of concepts such as smart cities and green buildings by the country, as well as the increasing demand for refined design and efficient construction management in the construction industry. BIM technology, with its powerful data integration capabilities, 3D visualization effects, and full lifecycle management characteristics, is gradually becoming a key means to improve building quality, reduce costs, and accelerate project progress [13]. On the other hand, the popularization and promotion of BIM technology in China also face many challenges. This includes but is not limited to: the unification and improvement of technical standards, the cultivation and introduction of professional talents, the establishment of data sharing and collaboration mechanisms between enterprises, and the deep integration of BIM technology with existing business processes. These issues require joint efforts from multiple parties such as the government, industry associations, enterprises, and research institutions to solve through policy guidance, technological innovation, talent cultivation, and other means. [14]. On the other hand, although China has conducted a lot of research on design, cost, construction and other aspects of construction engineering, there are few building engineering structures based on BIM technology [15].

2. STATE OF THE ART

The construction industry has entered a new stage of development, especially the joint development of China's economy and construction industry, which promotes the continuous progress of relevant technologies in China's construction industry [16]. The traditional construction industry still has many problems. The most prominent is the waste of resources caused by the lack of coordination in the production process, and the repeated modification of the building design has increased a lot of production costs. As the most important part of the construction industry, most of the engineering design still adopts two-dimensional traditional CAD design, which not only has serious problems in coordination and interaction, but also has high cost of multiple modifications due to design reasons. In order to meet the development needs of modern architecture, BIM (Building Information Model) technology is needed to accurately describe engineering objects and build corresponding data models, so as to

technically realize the engineering structure design of three-dimensional building information model [17]. By combining computer technology and BIM technology into modern building structure engineering design, it can effectively reduce the waste of resources in the current construction industry. At the same time, it can improve the efficiency of design, make better communication and collaboration between various professions, and greatly reduce the workload of designers [18]. Introducing particle swarm optimization (PSO), a swarm intelligence based stochastic optimization algorithm, can significantly enhance the capabilities of BIM technology in data processing and optimization. The PSO algorithm simulates the collective behavior of birds foraging in nature, and achieves optimized solutions to complex problems through information sharing and collaboration among particles. Specifically, the PSO algorithm first randomly initializes a group of particles, where each particle represents a potential solution to the problem and has its own position and velocity. Subsequently, the algorithm guides particles towards a better solution space by evaluating the fitness of each particle (i.e., the quality of the solution) [19]. In each iteration, particles update their velocity and position based on their historical optimal position (individual extremum) and the known optimal position of the entire population (global extremum), gradually approaching the optimal solution to the problem. Applying PSO algorithm to BIM technology can optimize for specific goals in architectural design, such as minimizing costs, maximizing structural strength, and improving energy efficiency. Through the detailed design data and simulation environment provided by BIM models, PSO algorithm can simulate the performance of different design schemes and quickly iterate to obtain the optimal or approximately optimal design scheme. This optimization process not only improves the scientificity and rationality of the design, but also significantly shortens the design cycle and reduces design costs [20].

3. METHODOLOGY

3.1 The implementation process of particle swarm optimization

In PSO algorithm, updating individual extremum and global extremum is one of the core of the algorithm. By comparing the fitness function value of the current particle with the individual extremum, the algorithm can evaluate the particle's progress in the search process and update the individual extremum accordingly. This process demonstrates the algorithm's local search capability, which helps particles find better solutions around themselves. Meanwhile, the update of global extremum depends on the comparison of individual extremum values of all particles, which represents the best performance of the entire particle swarm in the search space. The update of global extremum not only provides a common goal for particle swarm optimization, but also promotes information sharing and collaboration among particles, reflecting the swarm intelligence characteristics of the algorithm. According to the core formula of PSO algorithm (usually including velocity update formula and position update formula), particles update their velocity and position based on their current velocity, individual extremum, global extremum, acceleration factor and other information in each iteration. This process is the main manifestation of the algorithm's search ability, which enables particles to effectively move in the solution space and tend towards better solutions. The setting of termination conditions for iterations is crucial for the stability and practicality of algorithms. In addition to the hard condition of reaching the maximum number of iterations, the number of iterations can also be flexibly adjusted based on the convergence of the algorithm (such as no significant change in the global extremum after multiple consecutive iterations) to improve computational efficiency. When the termination condition is met, the algorithm stops iterating and outputs the global extremum as the final solution. The flow chart of the algorithm is shown in Fig.1 below.

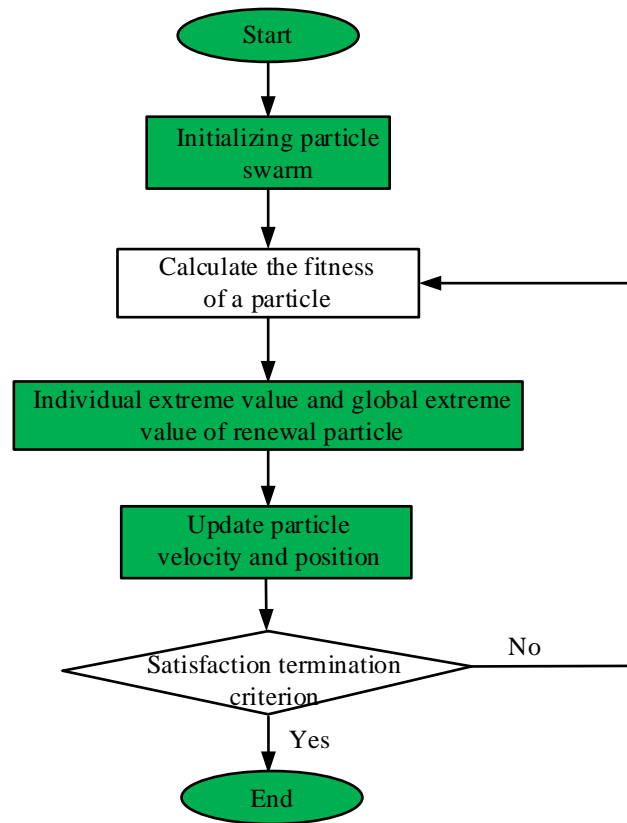


Fig.1 Flow diagram of particle swarm optimization

In BPSO, the velocity update of particles mainly depends on their current velocity, the influence of individual extremum (cognitive part), and the influence of global extremum (social part). By introducing inertia weights, SPSO provides more flexible control over changes in particle velocity. Inertial weight is usually a numerical value between 0 and 1, which determines the degree to which the current velocity of a particle affects its velocity at the next moment. A larger inertia weight means that particles have a stronger tendency to maintain their current velocity, which is beneficial for global search; Smaller inertia weights make particles more susceptible to the influence of individual and global extremum, which is beneficial for local search.

$$\begin{cases} V_{id}^{k+1} = \omega V_{id}^k + c_1 r_1 (p_{id}^k - x_{id}^k) + c_2 r_2 (p_{gd}^k - x_{gd}^k) \\ x_{id}^{k+1} = x_{id}^k + V_{id}^{k+1} \end{cases} \quad (2)$$

Linearly reducing the inertia weight helps the algorithm gradually converge to the optimal solution during the search process. However, a too small inertia weight may cause the algorithm to stagnate in the later stages of the search, making it impossible to further improve the quality of the solution. Therefore, it is necessary to reasonably set the range and rate of change of inertia weights to ensure that the algorithm strikes a balance between convergence and search efficiency.

$$\omega = \omega_{start} - \frac{\omega_{start} - \omega_{end}}{T_{max}} \times T \quad (3)$$

3.2 Improvement of particle swarm optimization

Compared to linear decreasing strategies, nonlinear differential decreasing strategies can better balance the global and local search capabilities of algorithms. In the initial stage of the search, larger inertia weights and slower decreasing speeds help particles explore extensively in the solution space, while in the later stage of the search, as the weights rapidly decrease, particles can converge faster to the vicinity of the potential optimal solution for fine search. By adjusting the value of α , the degree of nonlinearity in the decreasing inertia weight can be flexibly controlled. A larger alpha value will cause the weight to decrease slowly in the initial stage, but rapidly in the later

stage, which helps the algorithm maintain strong global search ability in the early stage of search, and pay more attention to local search in the later stage.

$$\frac{d\omega(t)}{dt} = \frac{2(\omega_{start} - \omega_{end})}{T_{max}} \times T \quad (4)$$

$$\omega(t) = \omega_{start} - \frac{\omega_{start} - \omega_{end}}{T_{max}^2} \times T^2 \quad (5)$$

The experimental results show that in the iterative process of particle swarm optimization (PSO) algorithm, using the nonlinear differential descent strategy to adjust the inertia weight does indeed bring significant performance improvement. In the initial stage of algorithm iteration, due to the large inertia weight and relatively slow decreasing speed, the algorithm can maintain strong global search ability, which enables particles to explore widely in the solution space and quickly locate the approximate region of the global optimal solution, thus saving a lot of time. As the iteration progresses, the non-linear decrease of inertia weights gradually accelerates, the flight speed of particles slows down, and the local search ability is enhanced. This helps the algorithm to conduct fine searches near potential optimal solutions, improving the accuracy of the solution. Compared with typical linear decreasing strategies, the advantage of nonlinear differential decreasing strategies is that they can better balance the global and local search capabilities of the algorithm. The linear decreasing strategy may slow down the search speed and even get stuck in local optima in the later stages of iteration due to the inertia weight being too small. The nonlinear differential descent strategy adjusts the degree of nonlinearity of the descent, allowing the algorithm to converge to the optimal solution faster while maintaining a certain global search capability. This strategy effectively avoids the limitations of later search and improves the optimization ability and iterative convergence speed of the algorithm.

$$V_{id}^{k+1} = \chi \left[V_{id}^k + c_1 r_1 (p_{id}^k - x_{id}^k) + c_2 r_2 (p_{gd}^k - x_{gd}^k) \right] \quad (6)$$

Among them, contraction factor is determined by the following formula:

$$\chi = \frac{2}{\left| 2 - b + \sqrt{b^2 - 4b} \right|} \quad (7)$$

The setting of the contraction factor is usually determined based on specific problems and experimental experience. A suitable contraction factor can accelerate the convergence speed of the algorithm while avoiding premature convergence and getting stuck in local optima. It is worth noting that the introduction of the contraction factor simplifies the setting of algorithm parameters, as it to some extent replaces the role of inertia weights, making the adjustment of algorithm parameters more intuitive and easy to operate. In addition to the shrinkage factor and inertia weight, there are two other important parameters that can be adjusted in particle swarm optimization algorithm: the population size N of the particle swarm and the maximum velocity of the particles. These two parameters also have a significant impact on the performance of the algorithm. The population size determines the diversity of particles in the algorithm. A larger population size helps the algorithm to search in a wider solution space, increasing the likelihood of finding the global optimal solution. However, an excessively large population size can also increase the computational complexity and running time of the algorithm. Therefore, in practical applications, it is necessary to set the population size reasonably according to the scale and complexity of the problem. The maximum velocity of particles limits their range of motion in the solution space. The formula for the relationship between maximum velocity and search space proposed by researchers such as Zhang aims to ensure that particles can fully explore the solution space and avoid unnecessary search waste during the search process by setting the maximum velocity reasonably. Specifically, the maximum speed setting should match the size of the search space to ensure that particles can move freely throughout the entire search space while avoiding skipping potential optimal solution areas too quickly.

$$V_{max} = \lambda x_{max} \quad (8)$$

The population size (N) is another important parameter in PSO, which determines the number of particles searched

simultaneously in the algorithm. The setting of population size has a significant impact on the search diversity and convergence of the algorithm in the solution space. When the population size is small, although the computational cost is low, the diversity of the search is also limited. This may lead to the algorithm being prone to getting stuck in local optima due to the differences between particles and limited exploration ability. Increasing the population size can increase the diversity of the search, making it more likely for the algorithm to discover the global optimal solution. However, excessive population size can also lead to a significant increase in computational costs, and when the population size increases to a certain extent, the improvement in algorithm performance may no longer be significant, and even "redundant" particles may appear, wasting computing resources.

3.3. Optimization of architectural engineering design process based on BIM technology

It is necessary to start from the data creation organization, share and build the model, and finally realize the overall program optimization based on the functional module. By the way, the model that has been created can also be re-optimized by the function module. In the process of creating the model, the customized data can be supplemented according to your own needs, and the created information is continuously improved. The entire optimization process is as shown in Figure 2.

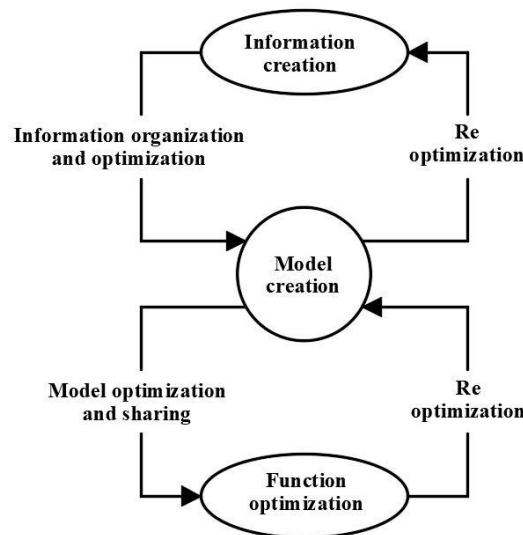


Fig.2 Optimization process of building structure design based on BIM Technology

To build a structural optimization design model that is based on BIM technology, the key is the information. Before the model is built, the information must be processed first, and the key is to create and organize the key data of the entire construction engineering structure design cycle. In order to solve the information needed to build the model, two problems must be solved. One is to determine the way information is organized to satisfy information sharing, and the other is to determine all the information needed for the entire solution. The information required for the engineering structure optimization design must contain all the component geometry, attributes and spatial information required by the BIM project. The application of engineering information to engineering must be gradually accumulated and improved, and the basic information such as the name, materials, and energy consumption of the components must be completely created.

For different application links, the process of information creation and optimization will adopt different strategies and adopt a targeted and effective organization for the links in which they are located. For conventional architectural engineering design, its early information acquisition mainly comes from basic physical information and owner's needs, and contains basic information of various components. Then, based on which, new information is extracted and expanded. At this time, it is more important to design changes, schedules, and equipment purchases. To deepen the design, this type of information must be refined and determined one by one. This information is constantly improved and accumulated as the whole project progresses, thus forming a complete collection of information. The relationship is as shown in Figure 3:

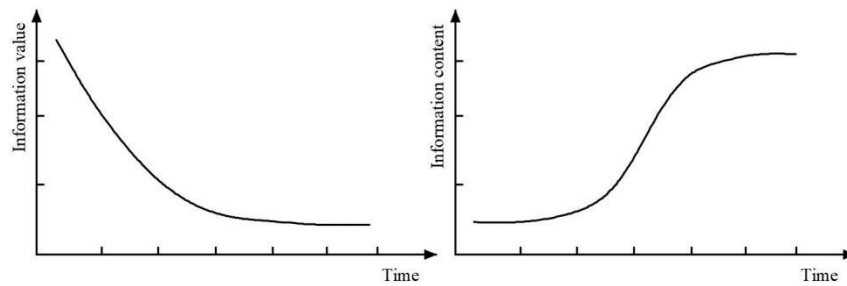


Fig.3 The relationship between information value and information volume over time

3.4 BIM model data information and storage

Because the amount of information required to build an information model is very large, it can take up a lot of computer memory, which leads to a decline in computing power. There is a direct connection between the size of the model data volume and the plane used to create the model. The purpose of optimizing engineering design is to reduce the design time as much as possible in order to improve the design efficiency as much as possible. The optimization function module has five main parts: (1) Statistics on the usage of engineering materials. (2) Automatic placement of three-dimensional components. (3) Net height detection of integrated pipelines. (4) Collision avoidance detection of integrated pipelines, (5) Function avoidance of integrated pipelines.

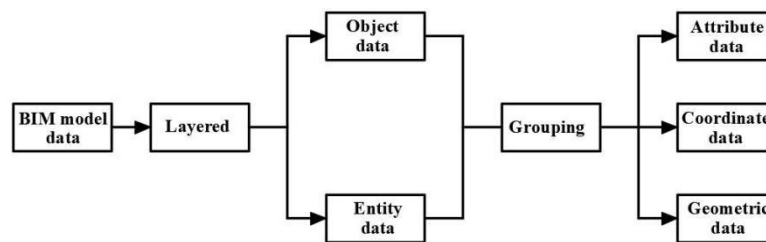


Figure.4 BIM model layering and grouping

At present, the data storage system can be divided into relational, spatial, object-oriented database and XML files. The most mature one is the relational database, which has the advantages of convenient operation and convenient data access. XML, as an extensible markup language for the storage of data transmission, also has a tree structure, plain text format storage and convenient storage. Therefore, the data used in the BIM information model construction is combined with the XML file and the relational database for storage, that is, the appropriate storage system is adopted according to different information data characteristics. According to the different life management requirements of the construction project, all object and entity data are divided into coordinate data, attribute data and geometric data as shown in Fig.4. The coordinate data and geometric data are stored by the XML file, while the attribute data is stored by the relational database. In BIM, each information model has an identification ID that is different from other information models. With this ID, the relational database can be effectively associated with the corresponding XML file.

4. RESULT ANALYSIS AND DISCUSSION

In the practice of high-rise building structural health monitoring, the optimization of sensor configuration is the key link. Different sensor types and structures, as well as the selection of fitness function, have a significant impact on the efficiency of the monitoring system. The facade of the stadium is made up of 36 structural units that are consistent in size and shape and are tightly integrated into the main steel frame through carefully designed connections. In terms of material selection, the main structure uses Q345B steel, while the auxiliary structure uses Q235 steel to ensure the stability and durability of the structure. According to the building code, the concrete structure is classified as a safety class II, while the steel roof is a Class I, in order to meet the seismic fortification requirements of 7 degrees. The building is designed to have an expected service life of 50 years, reflecting an

emphasis on long-term performance and safety. Through these careful design and material selection, the stadium not only presents a unified visual beauty, but also ensures a high degree of safety and reliability in the structure.

$$E = \frac{1}{2} U^T K U \quad (15)$$

In structural dynamics, the relationship between the layout matrix (commonly referred to as the modal matrix or vibration mode matrix, denoted by Φ) and the stiffness matrix (K) is the foundation for understanding the vibration characteristics of structures. Here, we further expand our analysis on the concepts of orthogonality between vibration modes and stiffness matrices, as well as how structural strain energy can be expressed through modal decomposition. When a structure is subjected to dynamic loads, its vibration can be decomposed into a series of modes (also known as vibration modes), which are the inherent vibration characteristics of the structure. There is an important mathematical property between the column vectors of the mode matrix Φ (i.e. the mode vectors of each mode) and the stiffness matrix K : orthogonality. This means that in a free vibration state, different modes do not interfere with each other, meaning there is no energy exchange between them. As shown in Fig.5.

$$E = \frac{1}{2} \sum_{i=1}^n q_i^2 \varphi_i^T k \varphi_i = \frac{1}{2} \sum_{i=1}^n q_i^2 M_i^* \omega_i^2 \quad (16)$$

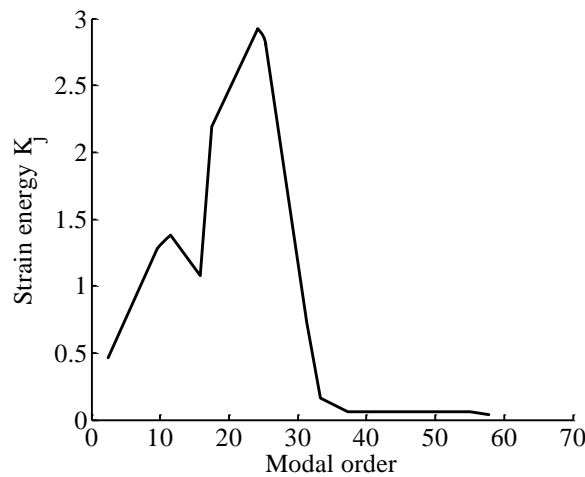


Figure.5 Sum and strain of modal strain energy of each order in gymnasium

Strain sensors can directly measure the local deformation of structures under stress, and this deformation information is crucial for identifying structural damage or evaluating their health status. Curvature mode is an important concept in structural vibration analysis, which reflects the bending shape of a structure under specific modes. For strain sensors, the curvature information of the structure can be calculated based on the measured strain data. Furthermore, it is compared with the curvature modes under theoretical or healthy conditions to evaluate the current state of the structure.

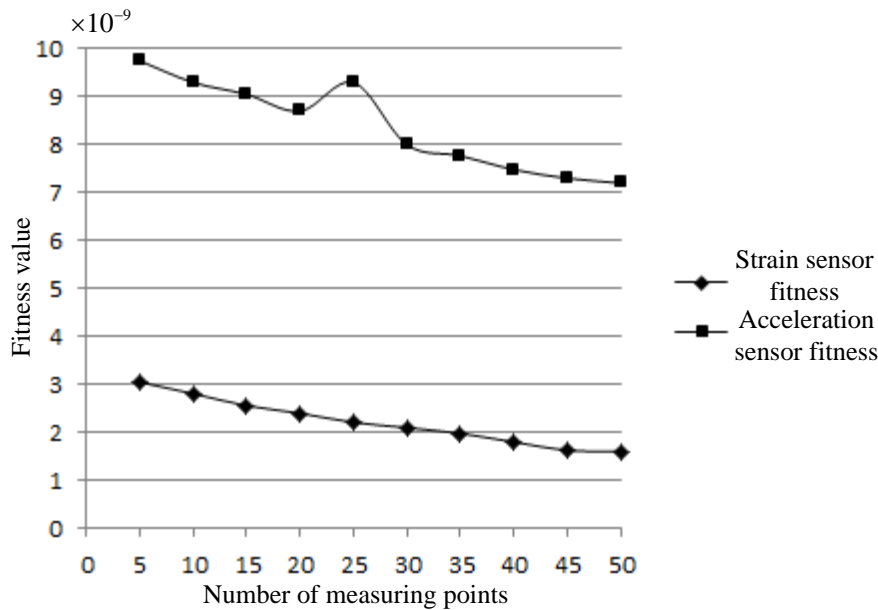


Figure.6 Sensor fitness of different measuring points in the first 20 orders

From the trend of fitness values changing with the number of measurement points shown in Figure 6, we can conduct a more in-depth analysis. Firstly, it is noted that when the number of measurement points is small, both strain sensors and acceleration sensors have higher fitness values, which preliminarily reveals the sensitivity and importance of selecting the location of measurement points. As the number of measurement points increases, the fitness value gradually decreases, which reflects that more measurement points can more comprehensively capture the vibration characteristics of the structure, thereby improving the accuracy and reliability of the measurement results. However, it is worth noting that the downward trend of fitness values is not non-linear, but rather has a turning point or plateau period. After this turning point, even if the number of measurement points continues to increase, the improvement in fitness values becomes less significant. This reminds us that in practical applications, we should balance the relationship between measurement accuracy and cost, and choose the appropriate number of measurement points to achieve the optimal monitoring effect. For the specific structural health monitoring project of Xining Sports Center, we adopted a fitness function based on curvature mode definition to optimize the layout of strain sensors, and a fitness function based on vibration mode definition to optimize the layout of acceleration sensors. These two different fitness functions target two different types of physical quantities, strain and acceleration, respectively, reflecting the specificity and flexibility in the sensor optimization process. The results of numerical simulation not only verify the efficiency and convergence speed of particle swarm optimization algorithm in solving such sensor optimization problems, but also further confirm the effectiveness of the algorithm in dealing with rod space structures with a large number of nodes and degrees of freedom. This effectiveness is not only reflected in the accuracy of the optimization results, but also in the stability and reliability of the algorithm, providing strong support for practical engineering applications.

The algorithm for automatically generating and arranging the entire building component model is shown in Figure 7. Iteratively iterate through all set elements in all plates, secondary beams and frame beams, generate frame beam models using BIM technology, and create corresponding beam and plate model apis. According to the previous calculation process, after the frame beam model is generated according to the topological constraints and size relationship, the secondary beam model is generated on the basis of the structure, and the structural floor model is generated layer by layer.

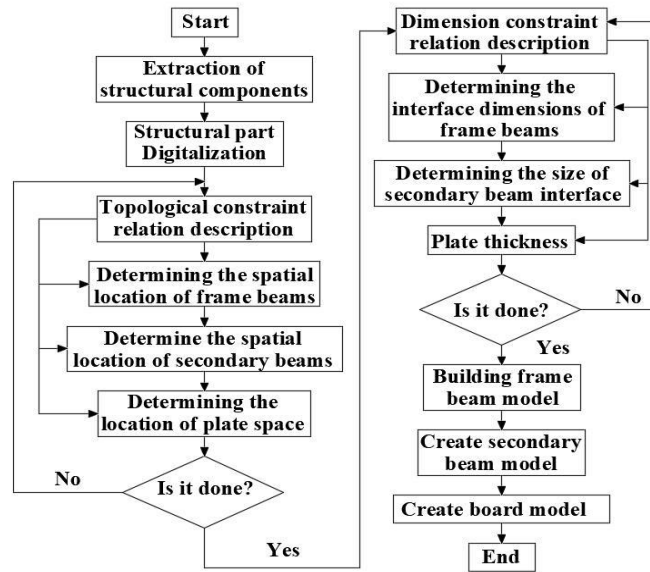


Fig.7 Flow chart of automatic layout algorithm for structural components

On Revit 3D modeling platform, taking school teaching building project as an example, the 3D architectural design information model is improved. The entire model is constructed as shown in Figure 8. By using the automatic column extraction function of structural members, all vertical stress component columns are extracted, and the frame beam model is further generated on the basis of three-dimensional structure column layout. Finally, the secondary beam model is generated. As can be seen from the final model generated in Figure 6, the three-dimensional model of the entire school intuitively reflects the structure of the entire teaching building, which is conducive to a comprehensive understanding of the spatial relationship of the teaching building. Compared with traditional design methods, this method only needs to collect and process building structure data and information, and use BIM technology to generate a complete model. The structural design of building engineering is inferior to the traditional structural design both in efficiency and effect. In addition, after obtaining the complete building structure model, it can be further used to calculate the materials required for the construction project, so as to carry out the research of the project cost. At the same time, the problems existing in the structural design can be observed in advance. Thus, the waste of construction resources caused by the repeated modification of structural design and engineering design is avoided.

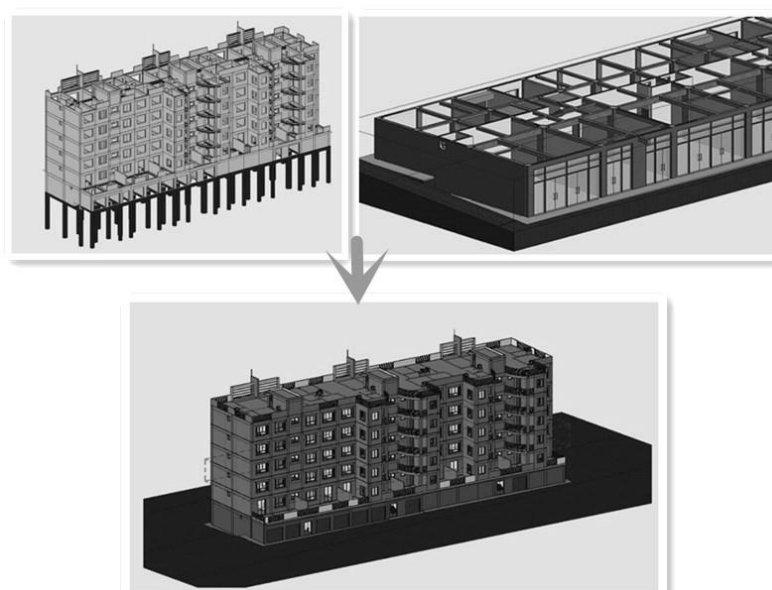


Fig.8 Automatic generation model of 3D building structure

As the core of building informatization, BIM technology has the advantage of integrating information from the entire life cycle of buildings, achieving seamless integration of design, construction, operation and maintenance stages. In architectural structural design, BIM platforms can integrate three major functions: 3D modeling, data analysis, and collaborative work, providing designers with an efficient and intelligent design environment. Through the BIM platform, designers can view the three-dimensional effects of structural design in real time, compare and optimize multiple solutions, and automatically detect and correct errors and conflicts in the design. In addition, BIM can promote information sharing and collaborative work between different professions, break the phenomenon of information silos in traditional design, and improve design efficiency and quality. Then, the data storage and access mechanism for storing the processed data information in XML file and relational database is proposed, and the corresponding optimization function algorithm is designed. The feasibility of the function and algorithm is verified through the application research of the actual teaching building project, and the three-dimensional model components and design of the building structure are completed. In this way, the limitations and deficiencies of traditional architectural structure design are significantly changed, the work efficiency is greatly improved, and the waste of resources generated by architectural design is reduced. It can be further applied to the calculation of building materials and engineering progress, which has positive significance for the whole life cycle of construction projects. It can be predicted that in the future construction industry, BIM technology and other computer technologies will be more and more widely used.

5. CONCLUSIONS

In the field of civil engineering, structural health monitoring is a key technology for ensuring the safety and extending the service life of large-scale infrastructure. Its core lies in building an efficient and accurate sensor network to achieve comprehensive and real-time monitoring of structural performance. This process not only requires sensors to accurately capture the static and dynamic responses of the structure, but also ensures the maximum economy and efficiency of sensor layout. Therefore, the selection and application of optimization algorithms have become a major focus in structural health monitoring research. This article uses an improved particle swarm optimization algorithm (PSO) to optimize the layout of strain and acceleration sensors for the typical complex structure of a sports stadium. Compared with traditional optimization methods, the improved PSO algorithm effectively enhances the global search ability and convergence speed of the algorithm by introducing adaptive adjustment mechanisms, diversity preservation strategies, and local search capabilities, thereby more accurately locating the optimal deployment position of sensors. The results of numerical simulation experiments not only verify the superiority of the algorithm in solving large-scale, nonlinear optimization problems, but also reveal the complex relationship between the number of sensors and monitoring effectiveness. Specifically, as the number of sensors increases, the system is able to capture increasingly rich and detailed structural information, including but not limited to key parameters such as stress distribution and vibration modes, providing a solid data foundation for accurate assessment of structural states. At the same time, the continuous decrease of the fitness function intuitively reflects the effectiveness of the optimization algorithm in continuously improving the efficiency of sensor layout, that is, achieving a significant improvement in monitoring accuracy without significantly increasing costs.

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