Research on Bridge Deck Health Assessment System Based on BIM and Computer Vision Technology

Zhixin Qian¹*, Yuxiang Li², Yaowen Chen³

¹School of Civil Engineering and Architecture, Wuhan University of Technology, Wuhan, China
²School of Electronic Information, Wuhan University, Wuhan, China
³School of Mechanical Science and Engineering, Huazhong University of Science and Technology, Wuhan, China

*Corresponding author: qianzhixin@whut.edu.cn

Abstract. As one of the components of the transportation system, the bridge is safe to operate due to vehicle driving, human factors, or natural factors such as wind and earthquake and the degradation of the material itself. Affected. To avoid the impact on the service life and driving safety of the bridge deck caused by these reasons, this article uses the browser side as the development end, uses the BIM bridge model technology, and combines the computer vision technology sensor data to provide a computer visualization for the bridge deck management and maintenance department. Information-based bridge health information detection and evaluation program to solve difficult detection problems, high risk, high cost, time lag, and data fragmentation in the management department.

1. Introduction
Chinese bridge construction has advanced by leaps and bounds in recent years, but the bridge's service status is not optimistic. The performance degradation rate under the continuous action of complex environmental loads far exceeds design expectations. How to ensure the bridge structure's safe operation has become a problem for the government, owners, and the public. Fundamental issues of concern. The structural health assessment system evaluates bridges' safety performance through real-time evaluation of external effects and structural responses. It is an internationally recognized necessary technical means to ensure the safe operation of bridges and has been applied in many bridges at home and abroad. However, the various sensors of the bridge health assessment system collect massive assessment data every day. Managing and using these assessment data scientifically and effectively to prevent these assessment data from becoming "furnished" is a central problem faced by the bridge health assessment system. The application of BIM technology is triggering significant changes in the engineering world. The value of BIM lies in providing a carrier for information sharing and transmission during the entire life cycle of projects such as design, construction, management, and efficient decision-making and management. Among them, the management and maintenance stage is the final link in the application of BIM technology throughout the life cycle of a project, and it is also the critical link that can best reflect the value of BIM application and improve the level of project informatization. At present, when bridge engineering, exceptionally long and extensive bridges enter the operation and management stage,
they generally establish a bridge structure health assessment system during the operation period, such as the Hong Kong-Zhuhai-Macao Bridge and the Jiashao Bridge. The structural health assessment technology of long and large bridges has become a hot spot in the engineering and academic circles at home and abroad in recent years. The long and large bridge structural health assessment system measures essential information reflecting the environmental excitation and structural response of the bridge to evaluate the performance of the bridge in real-time and evaluate the working conditions of the bridge, help ensure the safe operation of the bridge and provide a scientific basis for the maintenance and repair of the bridge [1].

Based on thoroughly investigating the existing problems of the traditional bridge health assessment system, combining BIM visualization technology and its BIM model application, this paper developed a bridge health assessment system under the new "BIM+health assessment" mode and established a self-diagnosis. The integrated management platform of visualization, real-time warning, and safety assessment realizes the multi-user collaborative management of bridge safety operation and the integrated operation and maintenance management of assessment and maintenance. It provides new ideas and methods for the application of BIM technology in bridge health assessment.

2. Introduction of bridge health assessment system and BIM technology

2.1. Composition of bridge health assessment system
The bridge health assessment system is generally divided into five parts: the sensor subsystem, data acquisition, and transmission subsystem, data processing and management subsystem, structural safety assessment and early warning subsystem, and maintenance management platform. The system evaluates the bridge's health based on the data measured by the sensor subsystem and provides data support for the operation and maintenance personnel to judge the damage. The sensor subsystem, data acquisition, and transmission subsystem, and data processing and management subsystem in this system are composed of hardware systems, which are responsible for data acquisition and transmission; the structural safety assessment and early warning subsystem and the maintenance management platform are completed by the Web terminal and are responsible for data display and early warning work [2]. The overall composition of this system is shown in Figure 1.

![Fig 1. The overall composition of the bridge health assessment system](image_url)

2.2. Standard assessment content of bridge health assessment system

2.2.1. Standard assessment content of environmental load assessment. (1) Wind speed and direction evaluation: mainly evaluate the wind load situation near the bridge evaluation point, including the size
of the wind direction and wind direction, and provide a basis for related mechanical analysis and bridge management. (2) Temperature and humidity assessment: mainly assess the temperature and humidity of the environment where the bridge is located and key bridge components’ temperature. (3) Rainfall detection: Evaluate the rainfall in the bridge's environment and provide a basis for bridge management. (4) Dynamic weighing system: Weigh the vehicles passing the bridge to obtain the bridge's load capacity and provide a basis for the vehicle limit. (5) Camera: By photographing the vehicles on the bridge, the traffic flow can be counted to provide a basis for bridge management. Standard sensors for environmental load are shown in Figure 2.

Fig 2. The environmental load assessment instrument

2.2.2. Standard evaluation content of geometric feature evaluation. When the bridge is subjected to external forces, the structure will be deformed. Compared with the environmental assessment, the assessment of bridge deformation can better reflect the bridge's health. The specific assessment content includes the following points: (1) GPS positioning system: locates the bridge's location to facilitate centralized management of multiple bridges. High-precision GPS can measure bridge health information, such as deflection and displacement. (2) Deflection evaluation: Bridge deflection is an essential indicator of bridge health. By selecting inclinometers, deflection information can be accurately obtained, and relevant information can be provided for sensor placement. (3) Displacement evaluation: The displacement of a particular part of the bridge can be accurately measured by the laser rangefinder. (4) Settlement assessment: The displacement of the bridge support and the settlement of the pier can be measured by the displacement meter. (5) Camera: Take pictures of the bridge surface to identify the bridge surface's wear for timely maintenance. The commonly used evaluation instrument types for the evaluation of bridge geometric characteristics are shown in Figure 3.

Fig 3. Bridge geometric feature evaluation instrument
2.2.3. Bridge response assessment. Bridge response assessment is divided into static response and dynamic response. The static response is generally stress and strain, and the dynamic response is vibration acceleration. Both reflect the changes in the bridge structure’s internal forces and are important indicators in the bridge health assessment. The specific monitoring content is as follows:

1) Stress and strain assessment: assess the strain of key bridge components.
2) Vibration acceleration assessment: Measure bridge acceleration changes and detect dynamic bridge characteristics.

The commonly used assessment instrument types of bridge response assessment instruments are shown in Figure 4.

![Bridge response assessment instrument](image)

**Fig 4. Bridge response assessment instrument**

2.3. The calculation method of bridge health assessment threshold

2.3.1. Deflection threshold evaluation method. This method adopts the inclinometer method to measure the deflection value. According to the mechanical analysis, for Euler beams, the first derivative of the beam’s deflection function is equal to the rotation angle function of the beam section. A minimum of 5 inclinometers is arranged uniformly along the main beam's span axis to realize the measured deflection value calculation. By summarizing the values of each inclinometer, a graph of the rotation angle function is drawn. The area between the rotation angle curve and the x-axis in the figure represents the deflection value; that is, the deflection curve can be obtained by integrating the rotation angle curve, and any position can be obtained by substituting in the position. A little deflection value. The bridge will be deformed under load. Choose the appropriate deflection curve equation according to the bridge:

\[ y = \sum_{j=0}^{n} M_j g(x_j) \]  

In the formula, \( g(x_j) \) is a group of linearly independent special function groups \( M_j \) is the constant matrix of each function group and \( j \) is the \( j \) measuring point. To establish the functional relationship between deflection and inclination angle, the derivative of \( x \) in equation (1) can be obtained:

\[ y(x_j) = \sum_{j=0}^{n} N_j g'(x_j)|_{x=x_j} = \theta(x_j) \]

In the formula, \( \theta(x_j) \) is the value measured by the \( i \) inclinometer, and \( N_j \) is the product of the coefficients derived from \( g(x_j) \), which is a constant matrix. The boundary condition of the target deflection curve equation is: under the test load's action, the bearing will undergo vertical settlement. Suppose the vertical settlement of the left and right supports are \( y(0) \) and \( y(L) \) respectively, then:

\[ y(0) = \sum_{j=0}^{n} M_j g(x_j)|_{x=0} \]
2.3.2. **The calculation method of stress and strain.** During the bridge’s service, the bridge is continuously exposed to external forces, vehicle loads and vibrations, structural damage caused by temperature and humidity changes, and natural settlement of bridge piers, which cause the bridge to face health threats. Strain assessment can collect the internal force of bridge components and effectively see the disease’s substantial changes through the surface. When it is detected that the stress and strain value exceeds the threshold range, an alarm will be sent in time to ensure the bridge’s health and safety. The actual stress is not easy to measure directly. Generally, the stress change is reflected by measuring the deformation of the object [3]. The stress and strain evaluation in this system collect the strain gauge value using the stress and strain acquisition module. According to the formula:

$$\Delta R / R = K \times \varepsilon$$  

Among them, \( R \) is the original resistance value of the strain gage, \( \Delta R \) is the change of the resistance value of the strain gage after receiving external force, and \( K \) is the proportional constant of the strain gage, which is determined according to different materials, which is the required strain variable. The principle of the full-bridge circuit of the acquisition module is shown in Figure 5.

![Fig 5. Schematic diagram of the full-bridge circuit](image)

Formulas (6) and (7) can be obtained from the principle of full-bridge circuit balance.

$$U_i = \left[ \frac{R_1 R_2 - R_1 R_3}{(R_1 + R_0)(R_2 + R_0)} \right] U_0 \quad (6)$$

$$U_i = U_0 \left[ \frac{R_1 R_2}{(R_1 + R_0)} \left( \frac{\Delta R_1}{R_1} + \frac{\Delta R_2}{R_2} + \frac{\Delta R_3}{R_3} + \frac{\Delta R_4}{R_4} \right) \right] \quad (7)$$

2.4. **BIM technology**

The BIM concept of building an information model was first proposed by Autodesk in 2002. The core of BIM technology is the information exchange and sharing of the project’s entire life cycle. The Chinese engineering construction industry began to introduce BIM technology in 2003. The current application is dominated by design companies. Various BIM consulting companies, training institutions, government, and industry associations also began to pay more attention to the application value and significance of BIM. In recent years, with the implementation of some complex design projects and large-scale construction projects, the domestic construction, railway, highway, and other fields have gradually carried out the research and development and application of BIM technology. Among them, the construction industry is at the forefront of the promotion and application of BIM technology. BIM technology has been implemented in some major projects, and several national, industry, and local
standards for BIM technology have been published or are being prepared. Developed countries (regions) such as Europe and the United States have promoted the promotion of BIM technology to the national level and have established a clear timetable for promoting and applying BIM. Many countries (regions) have established relatively mature BIM standards (such as IFC standards) or related systems. BIM has become one of the necessary capabilities for design and construction units to undertake projects, and many large enterprises already have BIM technology ability to apply. Specific to long-term bridge projects, the application of BIM technology is also increasing. However, there is still a lack of mature and unified technical standards and guidelines and in-depth application in the entire life cycle of bridge design, construction, and operation and maintenance, especially in the operation and maintenance phase. The application of BIM technology is still in its infancy.

In the operation and maintenance stage, before introducing BIM technology, the structural health assessment system is one of the more in-depth management systems for bridge operation and maintenance informatization. The health assessment system was gradually introduced into the civil engineering industry in the 1980s, and its application in the field of bridges, exceptionally long bridges, has developed rapidly. In the beginning, countries (regions) such as Japan, South Korea, Hong Kong, China, and other countries (regions) in Europe, the United States, and Asia clearly put forward the concept of "proactive prevention" structural health assessment, and successively installed health assessment systems on some crucial bridges, and began to study bridge structural health Evaluation of maintenance technology has attracted significant attention in the industry. After 2000, the concept and technology of bridge health assessment entered mainland China, and it has accumulated nearly ten years of experience in the research, design, and implementation of the health assessment system [4].

3. Design of bridge deck health assessment system based on computer visualization

3.1. Related requirements

3.1.1. Evaluation data self-diagnosis. As the data obtained by the bridge health assessment system has the characteristics of massiveness, multidimensionality, complexity, and randomness, there will be a large amount of invalid and interference information in the evaluated data, which will cause the monitoring results to be invalid. Therefore, it is necessary to establish a self-diagnosis method for the acquired evaluation data to ensure the evaluation result's accuracy.

3.1.2. Visualization of evaluation data. Bridge health assessment is due to the diversity of evaluation indicators involved and a large amount of information for each indicator. It has caused particular difficulties for practitioners to correctly understand such evaluation data. Therefore, the monitoring data needs to be visualized to meet the needs of relevant personnel in the industry.

3.1.3. Real-time early warning. The bridge will remain in operation from the time it is built to the date it reaches its service life. To meet the needs of long-term safe service of bridges, failure analysis and prediction of critical locations of bridges are needed, and possible bridge safety issues can be early-warned, controlled, and dealt with, realizing real-time early warning making bridge health problems preventable and controllable [5].

3.2. Overall design

Bridge health assessment data has the characteristics of a large amount of data, multiple and complex data. Combining these characteristics, this paper proposes a multi-level BIM assessment model. The overall system block diagram is shown in Figure 6.
Fig 6. The overall plan of the BIM bridge health assessment system

The system collects bridge health assessment-related data through various sensors placed on the bridge and connects to the collector, sends the data processed by the collector to the DTU, and sends the collected evaluation data to the server's database through the DTU. In this way, we can obtain bridge health data by accessing the server wherever a network connection can be achieved. Simultaneously, the BIM technology is combined with the web browser display, and the assessed bridge BIM model is lightweight and imported into the browser. The front-end interface is constructed by HTML5 programming in the browser, and the server is accessed to obtain data. The bridge health assessment data realizes health assessment function through the host computer interface [6].

3.3. Software system architecture

To integrate the bridge structure health assessment system information, the integrated bridge deck construction and maintenance BIM platform adopt advanced MVC4 architecture, 3D model display engine technology, large-scale remote assessment data transmission, big data storage technology, and data processing and analysis evaluation technology, etc. Supporting hardware facilities such as VPN system, switch system, extensive screen system, server system, etc., build a bridge deck health assessment information fusion solution of the BIM platform, as shown in Figure 7 and Figure 8.
Fig 7. BIM platform and health assessment system information integration software system architecture

Fig 8. The hardware system architecture of the BIM platform and health assessment system information integration

4. Implementation of main functions

4.1. Evaluation data self-diagnosis and online processing

Most of the data distortion in the bridge health assessment system is caused by the information acquisition link's sensing equipment. The US “Intelligent Maintenance System Center” research shows that more than 40% of fault alarms in general systems are false alarms caused by the sensor system itself. Besides, there is a massive gap between the use of the equipment and the bridge's service life. Once the sensing equipment fails or fails, it will not provide objective and accurate information, which will adversely affect the bridge safety early warning and assessment. For this reason, the sensor maintenance module was first established using BIM technology, as shown in Figure 9. Establishing the sensor model in the BIM model can quickly locate the sensor, visually display its location, and count the types and quantity of sensors. For the sensor's location, the model can be sectioned in multiple directions to view the plane position. In the viewing interface, the sensor's working status can be distinguished and marked with different colors. Repair the damaged sensor and save its repair record for future management and maintenance reference.
4.2. BIM visualization of health assessment data

Traditional health assessment systems have shortcomings such as dull and incomprehensible real-time display of assessment data. Using the excellent visibility of BIM technology, a visualization module for health assessment data such as temperature, deflection, vibration, and acceleration has been established. Because traditional bridge health assessment can only deploy a limited number of sensors, the collected data cannot reflect the entire bridge [7]. To this end, a visualization technology for the full-bridge structure response based on health assessment data was developed. The data of limited collection points were used for analysis and fitting, and the corresponding types of data estimates for different positions of the full-bridge were obtained. The predicted full-bridge data is stored in the extended database. The BIM database reads information from the comprehensive database, stores it in the form of components, and displays it in association with BIM. At present, bridges generally have a large number of operating vehicles and overloaded operations.

For this reason, a vehicle load effect recognition technology has been developed, which is to judge the vehicle category based on the health assessment data collected when the vehicle is loaded. First, store the static and dynamic responses of various types of vehicles when they pass the bridge structure, and then use big data analysis technology to combine the stored responses to match the data collected by the sensors when vehicles pass by and obtain the vehicle load effects of all components of the full bridge. According to the analysis results, the visual display is performed in the BIM model, as shown in Figure 10.
5. Conclusion
The research purpose of this system is to introduce BIM technology into the traditional bridge health assessment system, combine the integration of sensors, match 4G network communication modules and web-site interface development to optimize the full link to the best, and provide a universal bridge health assessment. The framework of the system fulfills the requirements of remote web monitoring bridges. Provide a visual and informalized bridge health information assessment program for the bridge management and maintenance department to solve difficult detection problems, high risk, high cost, time lag, and data fragmentation for the management and maintenance department.

References
[1] Boddupalli, C., Sadhu, A., Rezazadeh Azar, E., & Pattyson, S. Improved visualization of infrastructure monitoring data using building information modeling. Structure and Infrastructure Engineering, vol. 15, pp. 1247-1263, September 2019.
[2] Wang, Q., Sohn, H., & Cheng, J. C. Automatic as-built BIM creation of precast concrete bridge deck panels using laser scan data. J. Comput. Civ. Eng, vol. 32, pp. 04018011, March 2018.
[3] Fanning, B., Clevenger, C. M., Ozbek, M. E., & Mahmoud, H. Implementing BIM on infrastructure: Comparison of two bridge construction projects, Practice Periodical on Structural Design and Construction, vol. 20, pp. 04014044, April 2015.
[4] Zhou, X., Wang, J., Guo, M., & Gao, Z. Cross-platform online visualization system for open BIM based on WebGL. Multimedia Tools and Applications, vol. 78, pp. 28575-28590, Twenty 2019.
[5] Zou, Y., Kiviniemi, A., Jones, S. W., & Walsh, J. Risk information management for bridges by integrating risk breakdown structure into 3D/4D BIM. KSCE Journal of Civil Engineering, vol. 23, pp. 467-480, February 2019.
[6] Ganah, A., & John, G. A. Integrating building information modeling and health and safety for onsite construction. Safety and health at work, vol. 6, pp. 39-45, January 2015.
[7] Roshandeh, A. M., Poormirzaee, R., & Ansari, F. S. Systematic data management for real-time bridge health monitoring using layered big data and cloud computing. International Journal of Innovation and Scientific Research, vol. 2, pp. 29-39, January 2014.