

# Research on Bridge Structural Health Monitoring System Based on Sensor Data

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**Abstract.** As an important transportation infrastructure, bridge directly affects public safety and economic operation. With the aging of Bridges and the increase of traffic load, the traditional bridge maintenance methods cannot meet the current needs. Therefore, it is particularly important to develop a bridge structural health monitoring system based on sensor data. The purpose of this paper is to explore and implement a comprehensive monitoring and early warning system for bridge structural health, evaluate bridge health status in real time, and warn potential structural problems in time. The results show that the sensor-based bridge health monitoring system can not only monitor the health status of the bridge in real time, but also predict and warn the potential structural problems through data analysis technology, so as to provide decision support for the maintenance and repair of the bridge. Based on the continuous progress of technology, future bridge health monitoring systems will become more intelligent and automated.

**Keywords:** Bridge structural health monitoring, sensor technology, data acquisition and analysis, structural safety warning, intelligent transportation systems.

## 1. Introduction

Bridges constitute a vital component of transportation infrastructure, facilitating the movement of goods and people across geographical barriers. However, aging infrastructure, coupled with increasing traffic loads and environmental factors, poses significant challenges to the structural integrity and safety of bridges [1]. To address these challenges, there is an urgent need for robust bridge structural health monitoring and early warning systems, enabling engineers and maintenance personnel to detect potential issues and facilitate timely maintenance interventions.

The implementation of effective monitoring systems holds paramount significance for bridge structures. Aging bridges are susceptible to various forms of damage, including corrosion, fatigue, and deformation, which may compromise their structural integrity and pose risks to public safety [2]. By continuously monitoring the health status of bridge structures, authorities can identify potential issues early, enabling proactive maintenance and repair measures before they escalate into critical safety concerns.

Furthermore, the economic impact of bridge failures is substantial. A report by the American Society of Civil Engineers (ASCE) estimates that defective bridges cost billions of dollars annually in repair and delay expenses for motorists in the United States alone [3]. Implementing effective monitoring systems can mitigate these costs by facilitating timely interventions to address structural deficiencies and prevent catastrophic failures.

The focus of this study is to explore the design and implementation of a comprehensive bridge structural health monitoring and early warning system based on sensor data. Leveraging advancements in sensor technology, data analysis, and communication systems, such a system aims to provide real-time insights into the structural condition of bridges, enabling timely interventions to mitigate risks and ensure the long-term usability of infrastructure assets.



### 3. Data Collection and Analysis Techniques Based on Sensors

Based on the parameters of interest and specific requirements of monitoring tasks, various types of sensors are utilized in bridge health monitoring applications [7]. Commonly deployed sensors include strain gauges, accelerometers, displacement sensors, temperature sensors, and corrosion sensors. These sensors provide valuable information about the structural behavior and condition of bridge components, enabling engineers to accurately assess the health status of bridges. The monitoring data collected from sensors are integrated with early warning systems to provide timely alerts and maintenance or repair recommendations [8].

#### 3.1. Selection and Deployment of Sensors

The selection and deployment of sensors directly influence the accuracy and reliability of monitoring systems. When choosing sensors, various factors such as accuracy, sensitivity, stability, durability, and cost need to be considered. Additionally, the deployment of sensors should be designed based on the structural characteristics of the bridge and monitoring requirements to ensure comprehensive and effective monitoring of the bridge's health.

When selecting sensors and deployment methods, it's essential to consider the structural characteristics of the bridge and monitoring requirements. For strain sensors, they are often installed at key locations of the bridge, such as main girders, piers, and suspensions, to monitor structural strain. Vibration sensors are typically installed on the bridge deck, main girders, or piers, as well as in the nearby foundation, to capture the vibration frequency and amplitude of the structure. Temperature sensors can be installed on the surface or inside the bridge to monitor temperature changes in real-time. Pressure sensors are usually installed on the bridge deck or piers to capture the pressure exerted on the structure by vehicles or pedestrians passing through the bridge. Sound sensors can be installed on the structure's surface or nearby positions to capture potential abnormal sounds for analysis. By appropriately selecting and deploying these sensors, the monitoring system can comprehensively and accurately assess the health status of the bridge and promptly detect potential issues.

#### 3.2. Data Collection and Analysis

The principles and processes of data collection and analysis are crucial components of monitoring systems as they directly affect the effectiveness and accuracy of the monitoring system. The data collection system consists of sensors, data acquisition equipment, and communication devices. Its task is to collect various parameters of the bridge structure in real-time and transmit the data to the monitoring center. Sensors are responsible for collecting various structural parameters such as strain, vibration, and temperature, while data acquisition equipment is responsible for storing and transmitting the data collected by sensors. Communication devices ensure the timely and accurate transmission of data to the monitoring center.

Data analysis involves processing and analyzing the collected data to extract useful information and assess the health status of the bridge. The data analysis process includes several steps such as data cleaning, feature extraction, model training, and result evaluation. Firstly, the raw data collected needs to be cleaned and pre-processed to remove noise and outliers, ensuring data quality and reliability. Next, through feature extraction and selection, the data is transformed into feature vectors that can be used for analysis and modeling. Then, statistical analysis, model identification, and machine learning methods are used to analyze and model the feature vectors to assess the health status of the bridge. Finally, through evaluation and validation of the analysis results, the health status of the structure is determined, and appropriate recommendations and decision support are provided.

Through the principles and processes of data collection and analysis, monitoring systems can comprehensively and accurately assess the health status of bridges, providing timely information and decision support for management authorities.

### 3.3. Structural Health Assessment and Safety Warning

Based on sensor-based monitoring systems, the goals of structural health assessment and safety warning can be achieved. Structural health assessment evaluates aspects such as integrity, stability, and performance of bridges based on monitored data to identify potential structural issues. Safety warning systems utilize data analysis techniques to identify possible structural problems and trigger alarms or notifications when predefined thresholds are exceeded, enabling timely maintenance and repairs to ensure the safety and reliability of bridges. Firstly, the system continuously collects monitoring data from bridges, including parameters such as strain, vibration, temperature, and pressure. These data are transmitted to the monitoring center for real-time storage and processing.

In terms of structural health assessment, the monitoring system processes and analyzes the collected data using data analysis algorithms. By monitoring changes in data trends, detecting anomalies, and comparing with historical data, the system can assess aspects such as integrity, stability, and performance of bridges. Based on these assessment results, engineers can identify potential structural issues and further analyze their impact and severity.

In terms of safety warning, the monitoring system sets predefined thresholds to identify possible structural problems. Once the monitored data exceeds the predefined thresholds, the system automatically triggers alarms or notifications to alert relevant personnel of potential safety risks. Additionally, the system provides detailed analysis reports, including the nature, location, and possible impacts of the issues, to enable engineers and decision-makers to take timely maintenance and repair measures. Through the comprehensive process of structural health assessment and safety warning, monitoring systems help management authorities to timely detect and address potential issues with bridges, ensuring their safety and reliability.

### 3.4. Case Study

This paper takes the Wuhan Yangluo Yangtze River Bridge as a case study. As the fifth Yangtze River Bridge in Wuhan, it holds significant importance for the region's transportation network and economic development. Spanning from Yangluo Street in Xinzhou District to Xiangjiawei Village in Qingshan District, it officially opened to traffic on December 26, 2007. Renowned for its cable-stayed design and a main span of 1280 meters, it ranks among the world's leading cable-stayed bridges. As a crucial transportation hub for Wuhan, the safe operation of the Wuhan Yangluo Yangtze River Bridge is vital for the city's transportation and economic development. To ensure its safety and reliability, the Wuhan municipal government commissioned a professional engineering company to develop an intelligent monitoring system.

This system employs various sensor technologies covering key parts of the bridge, such as piers, main girders, and the bridge deck. By continuously monitoring parameters such as vibration, deformation, and stress in real-time, the monitoring system comprehensively evaluates the structural health of the bridge.

The collected monitoring data are transmitted to the monitoring center in real-time using data acquisition equipment to ensure data timeliness and accuracy. Utilizing advanced data analysis techniques, the monitoring center processes and analyzes the collected data to assess the bridge's health status. Data analysis includes statistical analysis, model identification, and machine learning methods to extract useful information and detect potential structural issues.

Through the intelligent monitoring system, engineers and decision-makers can real-time understand the structural health status of the bridge, promptly identify potential structural issues, and take effective maintenance and repair measures, ensuring the safety and reliability of the bridge. Additionally, the application of the monitoring system provides scientific evidence for bridge maintenance and management, prolongs the bridge's service life, and provides crucial support for the city's development and transportation.

Fig. 2 illustrates the core components of the health monitoring system for the Wuhan Yangluo Yangtze River Bridge, aimed at comprehensively monitoring the bridge's status to ensure its safety and reliability [6]. The system comprises a series of key sensors and devices, each responsible for

specific monitoring tasks. Firstly, the Cable Force Accelerometer (CFA) accurately measures the cable tension of the bridge, monitoring tension changes in real-time. The Liquid Level Sensor (LLS) monitors liquid accumulation in the structure to prevent potential corrosion and damage. The Accelerometer (ACCEL) records the bridge's vibration, assessing its dynamic characteristics and stability. The Digital Temperature Sensor (DTS) monitors the temperature at various points of the bridge, detecting temperature anomalies and taking corresponding measures. The Magnetostrictive Displacement Sensor (MDS) monitors the structure's displacement and deformation, providing crucial health information. The High-Definition Camera (CAM) real-time monitors the bridge's external status and potential damage. The Environmental Temperature and Humidity Sensor (ATH) records environmental conditions, assessing their impact on the bridge structure. The Ultrasonic Anemometer (ANE) monitors meteorological conditions, helping understand the wind's impact on the structure. The comprehensive application of these devices provides comprehensive health monitoring for the Wuhan Yangluo Yangtze River Bridge, ensuring its safe operation.

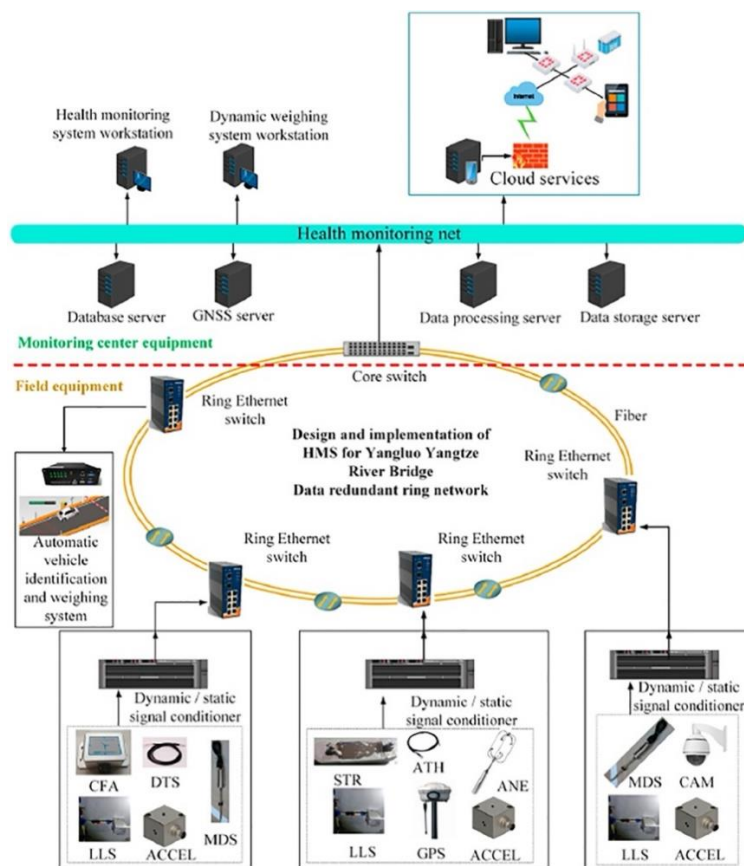


Figure 2. Data transmission framework on Yangluo Yangtze River Bridge [6]

#### 4. Conclusion

(1) In this paper, the design, implementation and application of the bridge structural health monitoring system are discussed, and the important role of the structure health monitoring system in ensuring the safety and reliability of the bridge is discussed. These systems significantly improve maintenance and management efficiency by early detection of structural damage, assessment of structural health and performance, prediction of maintenance needs, and optimization of resource allocation. Taking Wuhan Yangtze River Bridge as an example, the effectiveness of the bridge health monitoring system in practical application is verified. By deploying various sensors, the system monitors key parameters such as vibration, deformation and stress of the bridge in real time, comprehensively evaluates the health status of the bridge, timely finds potential structural problems, and ensures the safety and reliability of the bridge.

(2) However, this paper also reveals the shortcomings of the existing bridge health monitoring system and points out future research directions. The long-term stability and durability of the monitoring system requires further study to adapt to changing environmental conditions. In addition, improving the accuracy and real-time performance of data analysis and early warning algorithms is crucial to improving system efficiency. In addition, the economics and scalability of monitoring systems are also key areas for future research to enable wider applications and more efficient use of resources.

(3) Looking to the future, with the advancement of sensor technology, data analysis methods and communication technology, the bridge health monitoring system is expected to achieve a higher level of intelligence and automation. Future research will focus on developing monitoring technologies with higher sensitivity, wider coverage and stronger data processing capabilities. Moreover, data sharing and standardization are essential for international cooperation aimed at ensuring the safety of Bridges on a global scale. In short, through continuous research and technological innovation, the bridge health monitoring system will provide a solid scientific foundation for the long-term safe operation of Bridges and make greater contributions to social and economic development and public safety.

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