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# Research Progress and Application Analysis of Intelligent Non-destructive Testing Technology for Cable Supported Bridges

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**Abstract:** Intelligent non-destructive testing technology for bridges is a technical method to achieve adaptive detection and quantification of structural damage and defects, and provide reliable technical data and basis for bridge maintenance and repair, without damaging or affecting the operational performance of the bridge being tested, with the aid of modern intelligent testing equipment or testing methods. This paper systematically summarizes the mainstream structural appearance defect detection, internal and concealed damage detection, geometry parameter detection, mechanical parameter detection and material parameter detection techniques and equipment in recent years, analyses the current status of various intelligent inspection methods and applications for the main components of cable-supported bridges. The limitations, technical bottlenecks and main technical development directions of existing intelligent inspection technologies and equipment in practical inspection scenarios are analyzed, providing useful references for subsequent research, technical expansion and engineering applications of intelligent inspection technologies in the field of cable-supported bridges, as well as for significant improvements in the breadth, accuracy and efficiency of cable-supported bridge inspection.

**Keywords:** Cable Supported Bridge; Intelligence; Non-destructive Testing Technology.

## 1. Introduction

Bridge detection technology is a multi-disciplinary comprehensive application technology, which involves the calculation theory of bridges, experimental testing technology, instrument performance, data acquisition and transmission technology, mathematical statistical analysis, etc. It has strong comprehensiveness and applicability. and complexity. Bridge inspection mainly relies on modern inspection methods, through on-site testing, disease diagnosis and analysis, to understand the location, severity, cause and impact on bridge safety of bridge diseases, and to evaluate its technical status and bearing capacity, so as to provide bridge maintenance and repair. Reliable technical data and evidence [1]. At present, the commonly used detection methods mainly include the detection technology of using portable test equipment to evaluate the technical status of bridges, and the real bridge load test technology to test the mechanical properties of the structure. The former detection method can be divided into nondestructive, semi-damaged and damaged detection. The damage detection adopts physical means to sample, and the results are intuitive and accurate. It is often used in severely damaged structures, but it is expensive and will cause great damage to the structure or components.

With the rapid development of management concept, quality level, equipment and communication technology, efficient and accurate testing technology and equipment, especially non-destructive testing technology has become the mainstream of engineering quality testing and evaluation, and tends to be more reasonable, efficient and suitable Bridge maintenance needs. The use of intelligent non-destructive testing technology for cable-supported bridges is crucial for ensuring the safety and structural integrity of these complex infrastructures. Various studies have been conducted to develop innovative methods and tools for efficient and accurate testing procedures [2]. One such development is the OSSCAR project, which focuses on the development of an on-site scanner for automated non-destructive testing of bridges [3]. This technology aims to streamline the testing process and improve the reliability of bridge inspections. In the field of smart grid infrastructure, non-destructive testing based on terahertz technology has shown promising results [4-6]. This technology has been applied in cable accident warning, intelligent anti-theft systems, and electronic components monitoring, highlighting its potential for enhancing the safety and performance of cable-supported bridges[8]. Additionally, research has been conducted on the use of magnetostrictive guided wave technology for health detection of round steel structures in power systems (Figure 1) [7]. This method offers a new approach to non-destructive testing, particularly for complex steel structures commonly found in cable-supported bridges. Furthermore, the development of fiber Bragg grating (FBG) force-testing rings has enabled intelligent monitoring of cable forces in cable-supported bridges (Figure 2, Figure 3) [9]. This technology provides a reliable and long-term solution for monitoring cable tensions and ensuring the structural stability of these bridges. Overall, the integration of intelligent non-destructive testing technologies in the inspection and maintenance of cable-supported bridges is essential for ensuring their long-term safety and performance [10]. Continued research and development in this field will further enhance the reliability and efficiency of testing procedures for these critical infrastructure assets.

This paper systematically summarises the mainstream structural appearance defect detection, internal and concealed damage detection, geometry parameter detection, mechanical parameter detection and material parameter detection techniques and equipment in recent years, analyses the current status of various intelligent inspection methods and applications for the main components of cable-supported bridges. The limitations, technical bottlenecks and main technical development directions of existing intelligent inspection technologies and equipment in practical inspection scenarios are analysed, providing useful references for subsequent research, technical expansion and engineering applications of intelligent inspection technologies in the field of cable-supported bridges, as well as for significant improvements in the breadth, accuracy and efficiency of cable-supported bridge inspection.

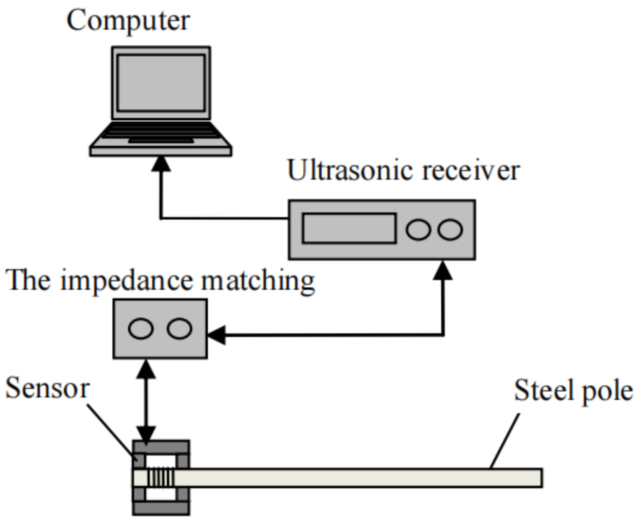
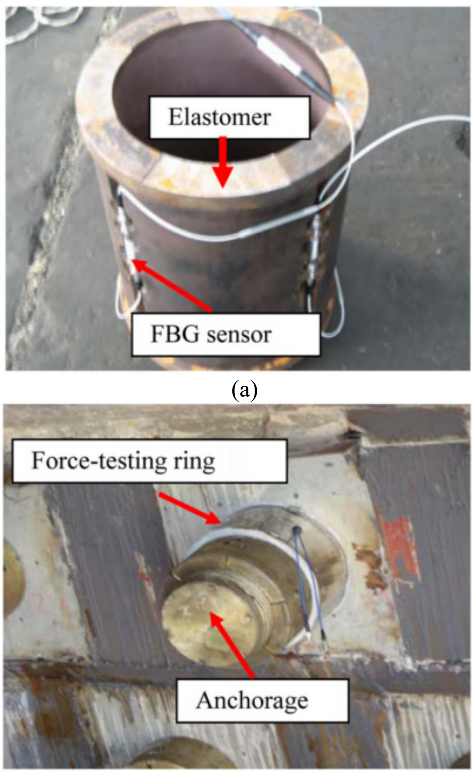


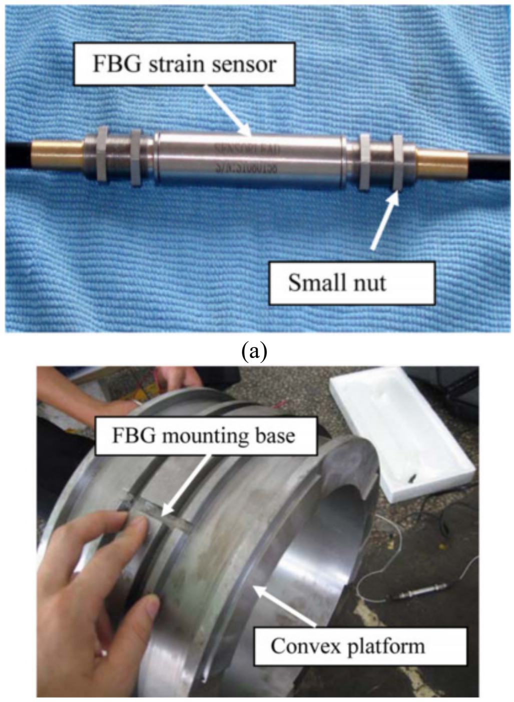

**Figure 1.** Schematic Diagram of Experimental System [7]




(a)

(b)

**Figure 2.** FBG force-testing ring. (a) FBG force-testing ring. (b) FBG force-testing ring installation on the stayed-cable [9]




(a)

(b)

**Figure 3.** Design of FBG force-testing ring. (a) FBG strain component.(b) FBG mounting base and bulges in the elastomer [9]

# 2. Nondestructive Testing Technology and Equipment

Bridge non-destructive testing technology can be divided into structural appearance defect detection, internal and concealed damage detection, geometric shape parameter detection, mechanical parameter detection, material parameter detection technology according to the detection purpose. With the development of test methods and electronic technology, many new test methods have emerged. New technologies such as microwave absorption, radar scanning, infrared thermal spectroscopy and pulse echo have enriched bridge detection methods, and non-destructive testing instruments have also developed to a new level. In recent years, the continuous emergence of highly sensitive sensing systems (such as infrared, microwave, and ray systems) has made non-destructive testing equipment develop in the direction of intensification, miniaturization, digitization, and intelligence; unmanned aerial vehicles, attached climbing robots The technological progress of other vehicle platforms has also brought about the rapid development of the automatic identification technology of bridge appearance diseases based on computer vision.

## 2.1. Appearance Defect Detection

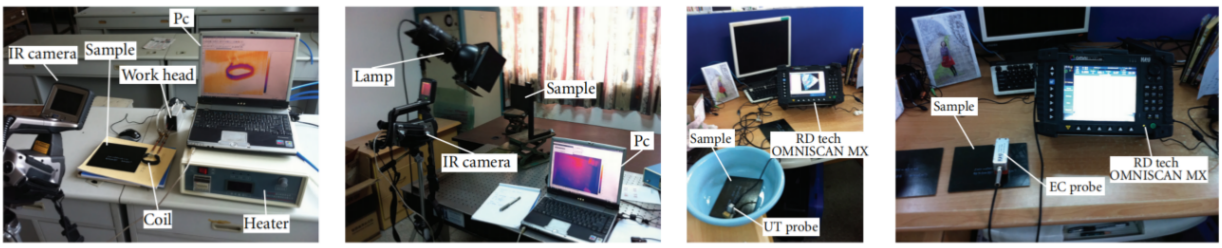
The traditional appearance of non-destructive defects is mainly operated manually by a handheld digital camera or a handheld crack observer. There are also some attempts to use an auxiliary mechanical extension arm equipped with a camera to collect images for human-computer interaction analysis. It is urgent to cooperate with intelligent robots and deep learning. Advanced technologies such as identification, precise target positioning, image correction, 3D restoration of defects, and VR demonstration are deeply integrated [11]. UAV-mounted camera equipment is currently the most concerned technology for appearance non-destructive monitoring. It can realize automatic detection of structural cracks [12], automatic calculation of 3D models, and recognition of typical damage patterns based on machine learning [13]. Laser holographic image photography technology has the advantages of more intuitive and more comprehensive detection. It has been successfully used in the detection of texture depth, flatness and distance of roadbed and pavement [14]. The intelligent identification of the width [15] can also be used with vehicle-mounted equipment and automatic beam bottom detection robots to achieve cracks (Figure 4), honeycomb pitted surface analysis, etc. [11]. In addition, the coating defect detection technology of bridge steel structure based on active infrared thermal imaging technology has also become a hot spot in current engineering applications [16].

## 2.2. Internal and Covert Damage Detection

The non-destructive testing of bridge structures and hidden damage mainly relies on non-contact non-destructive testing technologies such as acoustic waves, magnetic fields, thermal imagers, rays, and radars. In the field of non-destructive monitoring of internal structures and hidden damage, inspection robots can make up for the lack of UAV inspection, and realize the inspection and evaluation of bridge structures at close range and even the internal health of the structure. The intelligent inspection robot is equipped with ultrasonic technology, which can realize the identification of structural fracture surfaces and defect positions; the crawling robot equipped with ultrasonic phased array imaging equipment can realize intelligent detection and location of fatigue cracks in orthotropic steel bridge decks [14]. Ground penetrating radar technology has also been used in the detection of bridge deck thickness and base layer compactness. Passive infrared thermal imaging technology and active infrared thermal imaging technology (Figure 5) [17] have achieved certain results in the monitoring of internal defects of bridge structural concrete (Figure 6) [18]. Some testing items have not made breakthroughs in non-destructive testing technology in recent years, such as steel corrosion detection, which still requires time-consuming and complex AC impedance detection technology [14] and steel corrosion EIR detection technology. However, the application scope of the above-mentioned technologies is still relatively narrow at present, and mainly focuses on qualitative testing. Quantitative standardized testing is the direction of future development.

(a) (b) (c)

**Figure 4.** Structural apparent disease visual recognition and analysis techniques. (a) Concrete spalling. (b) Crack. (c) Crack width




(a) (b) (c) (d)

**Figure 5.** Experimental systems at NUAA: (a) PEC-stimulated thermography; (b) flash thermography; (c) UT scan; (d) EC scan. [17]

## 2.3. Geometry Parameter Detection

At present, the detection of geometric parameters is still mainly based on total stations, levels or liquid communication pipes. The detection technology of geometric parameters based on image and radar technology has developed rapidly in recent years. Ultra-telephoto lens and industrial charge-coupled element (CCD) are used to collect the digital image of the part to be measured at high frequency, and then the dynamic displacement monitoring system of the structure can be applied in the actual bridge linear detection. At the same time, the radar technology (GPR) technology, which uses the radio waves emitted by radar to measure the high-resolution deformation and vibration of the cable or bridge span structure, has also become a hot spot in engineering. In addition, the micro-pressure difference semi-closed connecting tube type high-precision vertical displacement/ settlement monitoring sensor has also been successfully applied in the field of high-precision automatic bridge vertical displacement monitoring (Figure 7) [19]. In general, fast, efficient, large-scale, high-precision, multi-point synchronization detection methods still need to be developed.

## 2.4. Mechanical Parameter Detection

The non-destructive testing of mechanical parameters is still dominated by contact-type fiber grating sensors or strain gauges. In recent years, my country has made great progress in the detection technology of structural dynamic characteristics. Chinese scholars have realized the high-precision detection of the amplitude of the stay cable based on the non-contact detection technology based on the radar, and solved the problems of low sensor efficiency and unstable signal in the detection of the cable force of the stay cable (Figure 8) [20]. The monitoring radar, which solves the difficulty of vibration detection of long-span suspension bridges, has realized high-precision detection of complex vibrations of bridges and modal analysis of vibrations [21]. However, compared with actual needs, there is still a lot of room for improvement in accuracy and reliability.

(a) (b)

**Figure 6.** Infrared thermal imager [18]. (a) host computer. (b) collection card

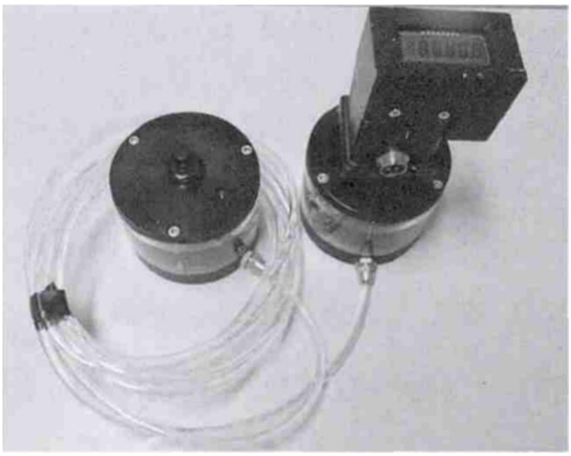


**Figure 7.** Differential air pressure type high accuracy vertical displacement sensor [19]

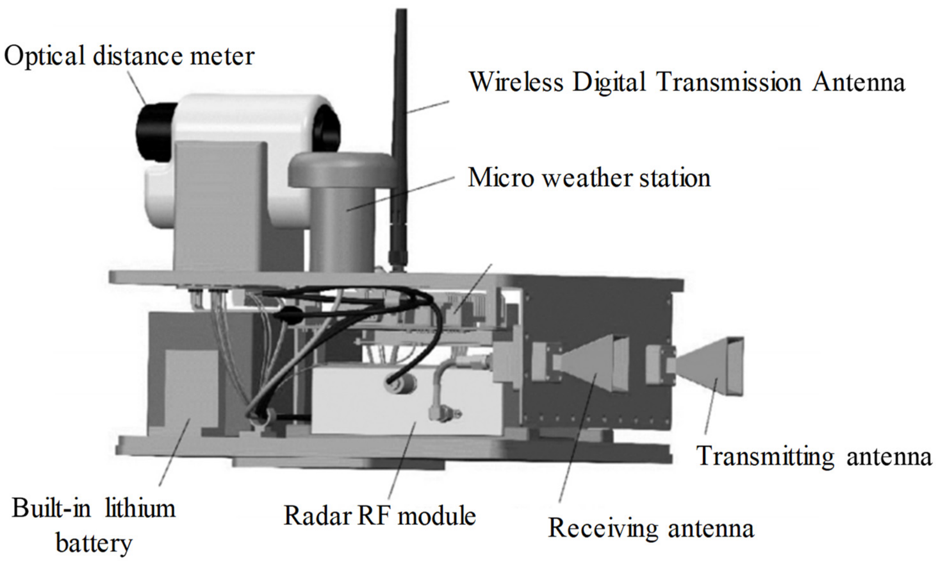



**Figure 8.** Prototype of the radar monitoring system for cable force [20]

## 2.5. Testing of Material Parameters

The non-destructive testing of material parameters is mainly based on traditional ultrasonic, ray, rebound hammer and other methods combined with manual operation equipment. In recent years, the representative non-destructive testing technologies for material parameters include the quantitative assessment of concrete beam damage based on acoustic emission technology [22], and the new technology for corrosion detection of galvanized steel strand cables based on metal magnetic memory technology. Conventional techniques are difficult to detect the problem of internal corrosion of galvanized steel strand cables (Figure 9) [23]. At present, the detection process still needs to gradually realize unmanned, automated and standardized.

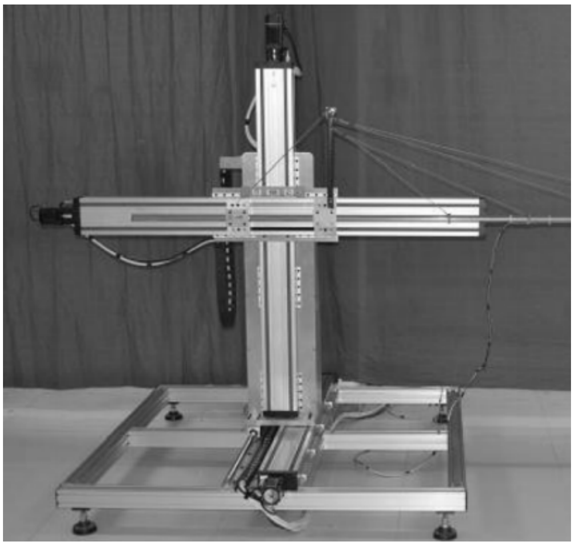


**Figure 9.** Tree-dimensional scanning device based on metal magnetic memory [23]

# 3. Conclusion

This paper systematically analyzes the mainstream non-destructive testing technologies and equipment in recent years, as well as various concealed engineering testing methods and application status for the main components of cable-supported bridges, and draws the following conclusions:

(1) In terms of non-destructive testing technology and equipment, the continuous emergence of high-sensitivity sensing systems such as infrared, microwave, and ray has made non-destructive testing equipment develop in the direction of intensification, miniaturization, digitization, and intelligence.

(2) The comprehensive system of thermal imaging, ultrasonic phased array, radar and other equipment is developing in the direction of development, but the detection process still needs to gradually realize unmanned, automated and standardized.

(3) Technologies such as wireless sensor testing technology, data acquisition and communication are developing rapidly, but the accuracy and stability of the instruments still need to be improved; at present, there is still a lack of non-destructive testing technology and equipment for key components of long-span cable-supported bridges, and the internal defects of the structure are rapidly increasing. The cutting-edge detection and diagnosis technologies, key detection technologies and autonomous equipment are far from meeting the needs of bridge maintenance management.

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