

Research on a UAV-Based Inspection and Monitoring Scheme for Rural Bridges

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Abstract

To address the problems that rural bridges are numerous and some are approaching the end of their service life, whereas the current manual visual inspection is labor-intensive and cannot rapidly cover a large number of bridges during flood seasons, this paper first establishes a hierarchical assessment system in which UAV inspection is the main means and manual inspection is the supplement. A two-level mechanism consisting of a UAV-based overview preliminary screening and a refined detailed investigation is proposed, and bridge condition is classified into three levels: Normal, Concern and Dangerous. For the stone arch bridges and concrete girder bridges most commonly found in rural areas, five key indicators are then determined, namely foundation scour of piers and abutments, deformation of the main structure, cracks in main load-bearing members, the deck system and ancillary facilities, and encroachment of the space beneath the bridge, and the UAV data acquisition scheme together with the rapid judgment criteria for each indicator are specified. Finally, a Bridge is taken as a case study for field verification. The results show that the proposed scheme can accomplish risk screening of bridges in a region.

Keywords

Structural Health Monitoring, County Economy, Low-Cost Monitoring Technology, Vocational Education

1. Introduction

Rural bridges are the “arteries” of rural revitalization. However, rural bridges were built in different periods, and some have already reached the end of their service life; consequently, a large number of bridges need to have their safety condition and

traffic capacity re-evaluated [1].

According to the Standards for Technical Condition Evaluation of Highway Bridges (JTG/T H21-2011) issued by the Ministry of Transport, the technical condition of highway bridges is rated in five grades [2], and the method currently adopted in the assessment process is dominated by manual visual inspection. Because there are so many rural bridges, inspection by manual visual means alone not only consumes a great deal of manpower and increases the burden on maintenance personnel, but also makes it difficult to rapidly assess a large number of bridges in the periods when centralized assessment is required, such as the flood season [3].

As a new type of monitoring tool, unmanned aerial vehicles (UAVs) offer the following advantages: 1) they are less restricted by the geographical environment and can be used to inspect across different terrains [4]; 2) they provide clear imaging and can be equipped with high-definition zoom cameras and LiDAR for clear observation [5]; and 3) inspection is convenient, since no scaffolding, aerial work platforms or traffic closure are required [6].

Therefore, studying how to use UAVs to rapidly assess the condition of rural bridges is of great research significance.

2. Establishment of a Hierarchical Assessment System Based on “UAV Inspection as the Main Means and Manual Inspection as the Supplement”

The core of the rapid assessment of rural bridges is not to immediately replace the periodic detailed inspections required by the standards, but to achieve rapid screening and risk ranking. With this objective, a two-level mechanism of “preliminary screening-detailed investigation” is proposed.

2.1. Level 1: UAV-Based Overview Preliminary Screening

Route planning is adopted for one-key automatic flight. Three standard routes, namely the upstream, downstream and deck routes, are used to rapidly acquire data on the bridge. Bridge condition is classified into three levels: “Normal, Concern and Dangerous”. The limited expert and financial resources are then immediately directed toward the “Dangerous” and “Concern” bridges. According to the “Standards for Technical Condition Evaluation of Highway Bridges” (JTG/T H21-2011), the overall technical condition evaluation level of bridges is divided into 5 categories, and the corresponding attention levels are shown in **Table 1**.

2.2. Level 2: Refined UAV-Based Detailed Investigation

Manual control or more advanced close-range photogrammetry is used to acquire centimeter-level or even millimeter-level close-up data on key locations such as pier foundation scour, cracks at the girder soffit and bearing displacement. For “Concern” and “Dangerous” bridges, as well as bridges subjected to the action of floods or heavy vehicles, component-level refined inspection is carried out.

Table 1. Corresponding attention levels for bridge overall technical condition assessment grades.

Technical condition assessment level	Bridge technical condition description	Attention level
Class 1	Brand new condition, fully functional	Normal
Class 2	There is a slight defect that does not affect the functionality of the bridge	Normal
Class 3	Moderate defect, able to maintain normal functional use	Concern
Class 4	The main components have significant defects, which seriously affect the functionality of the bridge; Or it may affect the load-bearing capacity and cannot guarantee normal use	Dangerous
Class 5	The main components are severely damaged and cannot be used normally, endangering the safety of the bridge. The bridge is in a dangerous state	Dangerous

3. Core Assessment Indicators and the UAV Data Collection Scheme

For the structures most common among rural bridges, such as stone arch bridges and concrete girder bridges, the indicators to be considered are listed in **Table 2**. The advantages of the scheme are as follows:

1) The indicators are highly targeted and focus on the typical defects of rural bridges. The five indicators cover foundation scour of piers and abutments, deformation of the main structure, cracks in main load-bearing members, the deck system and ancillary facilities, and encroachment of the space beneath the bridge, which are the most common sources of instability and safety hazards in rural stone arch bridges and concrete girder bridges. This avoids redundant “large and comprehensive” inspection and fits the reality that funds for rural maintenance are limited.

2) The data collection scheme is operable and lowers the professional threshold. Each indicator is accompanied by specific details of the UAV acquisition method, gimbal orientation, flight distance and camera configuration, which front-line maintenance personnel and even vocational college students participating in social practice can follow directly, thereby achieving both “low-cost monitoring” and “in-house talent cultivation”.

3) The judgment criteria are explicit and enable rapid grading. Each indicator is provided with rapid judgment criteria for the three-level assessment of “Normal-Concern-Dangerous”, which connects with the hierarchical assessment system of “UAV inspection as the main means and manual inspection as the supplement”. A large number of bridges can therefore be rapidly screened and risk-ranked during centralized assessment periods such as the flood season, and the limited experts and funds can be preferentially directed to dangerous bridges.

4) Non-contact, safe and traceable. UAVs require neither scaffolding nor traffic closure, which avoids the risks of working at height and in water. The collected imagery and real-scene 3D models can be archived and compared, providing an objective basis for full-life-cycle dynamic monitoring and maintenance decision-making for bridges.

Table 2. Key monitoring indicators for rural bridges and the corresponding UAV data collection scheme.

Key indicator	UAV data collection scheme	Key points of assessment and rapid judgment criteria
Foundation scour of piers and abutments	Low-altitude hovering: the gimbal is aimed vertically downward upstream of and on both sides of the piers. A current meter may be installed if conditions permit.	Check whether the riprap protection apron is washed away and whether there is a “necking” phenomenon caused by the downward shift of the waterline on the pier shaft. If local undercutting (hollowing) of the pier or abutment foundation is found, it is directly rated as “Dangerous”.
Deformation of the main structure	3D observation along a surrounding route: oblique photography of the whole bridge is carried out to generate a real-scene 3D model.	Visually check whether the alignment of the main arch ring/main girder is smooth; measure on the model whether there is obvious waviness or settlement in the longitudinal direction of the deck. If obvious deflection is found, it is rated as “Concern”.
Cracks in main load-bearing members	Close inspection of the girder soffit/arch ring: the gimbal is aimed upward, the UAV flies close to the structure at a distance of less than 2 m from the surface, and a high-definition zoom lens is used.	Focus on transverse and U-shaped load-induced cracks at critical stressed locations of the structure. For rural stone arch bridges, if arch-stone fracture or serious mortar loss at the joints is found, the assessment level is directly upgraded.
Deck system and ancillary facilities	Orthophoto of the deck: the camera is aimed vertically downward and images are captured automatically along a planned route.	Check whether railings are missing over a large area and whether there are potholes or settlement in the deck pavement. This is a direct indicator concerning the safety of vehicles and pedestrians, and where the problem is serious, it can be directly rated as “Dangerous”.
Encroachment of the space beneath the bridge	Medium- and long-distance patrol: fly along the river channel upstream and downstream of the bridge to check the clearance.	Check whether there is illegal stockpiling or construction, serious siltation that narrows the flood-discharge section, or burial of piers by soil that alters the force conditions.

4. Practical Example

The Fuhe Bridge (in **Figure 1**) is located on Provincial Highway S380 in Zhongxin Town, Zengcheng District, Guangzhou. It has a total length of 50 m and is a T-girder bridge that opened to traffic in January 1992; to date, it has been in service for 34 years. Because the bridge is located on a provincial highway, heavy vehicles pass over it frequently. In addition, there is a traffic light 30 m from the bridge, so vehicles have to wait on the bridge, and the bridge is thus under a relatively heavy load throughout the year. The Fuhe Bridge crosses the Xifu River, which flows through rural areas and has a large flow rate and high velocity in the rainy season, carrying a large amount of sediment that scours the piers. The Fuhe Bridge therefore needs to be monitored.

The drone platform is DJI Mini 3, with a 1/1.3-inch CMOS image sensor, 48 million effective pixels, and a video capture resolution of 1920×1080 @ 30 fps. The flight altitude is 30m, the speed is 1m/s, and the weather is sunny. The pier and foundation can only be seen above the water surface, while the concealed load-

bearing area and shaded eaves can be observed up close, but require drone pilots with good flying skills.



Figure 1. The Fuhe Bridge.

The scheme for monitoring the Fuhe Bridge with a UAV is shown in **Table 1** and mainly covers five items: foundation scour of piers and abutments, deformation of the main structure, cracks in main load-bearing members, the deck system and ancillary facilities, and encroachment of the space beneath the bridge. Field measurements showed that the erosion marks on the foundations of the piers and abutments of the Fuhe Bridge are not obvious, no significant deformation has been found in the main structure yet, the main load-bearing structure has not been found to be significantly damaged yet, no obvious abnormalities were found in the bridge deck system and ancillary facilities, and only a small amount of lightweight objects occupy the space under the bridge; the bridge was preliminarily judged to be in a relatively normal working state.

5. Conclusions

1) The main contradiction in the maintenance of county-level and rural bridges lies in the large number of bridges as against insufficient inspection capacity, and manual visual inspection alone can hardly cover a large number of bridges rapidly during periods such as the flood season. The value of applying UAVs to condition assessment lies in expanding inspection capacity at low cost and enabling risk ranking, rather than replacing the periodic detailed inspections required by the current standards.

2) The hierarchical assessment system of “UAV inspection as the main means and manual inspection as the supplement” proposed in this paper consists of two levels: preliminary screening and detailed investigation. Preliminary screening rapidly acquires data along three standard routes and classifies bridges into three levels: Normal, Concern and Dangerous; detailed investigation carries out component-level refined inspection of Concern and Dangerous bridges. This system connects with the inspection regime specified in the Standards for Technical Condition

Evaluation of Highway Bridges (JTG/T H21-2011), improving assessment efficiency without lowering safety standards.

3) Looking ahead, the judgment criteria in this paper are still mainly qualitative, and the samples are concentrated in a county and in a single bridge, the Fuhe Bridge. In subsequent work, criteria such as crack width, structural deflection and foundation scour depth should be quantified in accordance with the current standards, and the sample range of bridge types and regions should be expanded so as to carry out tracking verification on multiple bridges over multiple periods. At the same time, the geometric accuracy of real-scene 3D models should be improved, and underwater scour observation and intelligent identification of hidden defects should be explored, so as to provide a more reliable basis for the routine safety screening of county-level rural bridges.

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Author Contributions

Conceptualization, F.C.; methodology, F.C.; validation, F.C.; investigation, F.C.; visualization, F.C.; writing—original draft preparation, F.C.; writing—review and editing, F.C.; supervision, S.Y. All authors have read and agreed to the published version of the manuscript.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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