An Autonomous Concrete Bridge Inspection System Using Unmanned Aerial Vehicle

Huai Yu, Heng Zhang, Wensheng Cheng and Wen Yang

Abstract— **With numerous concrete bridges being constructed all over the world, crack inspection is of vital importance for concrete bridge monitoring. Previous studies mainly focus on the detection of cracks on bridge deck using high resolution images [1]. However, it is difficult to obtain high resolution images of the lateral and under sides. Traditionally, most existing crack inspection systems mainly rely on human observation. Inspectors often have to count on bridge inspection units. As a consequence, such inspections are unsafe and inefficient. Therefore, an automatic crack inspection system is quite necessary. Recently, legged robots with powerful permanent magnets and bridge-climbing robots with adhesion adaptive control were developed. These climbing robots make it possible to capture high resolution images of bridges' lateral and under sides, nevertheless facing the difficulties to freely shuttle over different piers.**

To overcome this problem, a novel unmanned aerial vehicle (UAV) based inspection system is developed to detect cracks on the lateral and under sides of bridges. By applying simultaneous localization and mapping (SLAM), UAV can reach bridges' lateral and under sides within a safe distance. Thus the onboard camera can capture images of bridge surface in a very high resolution. To detect cracks in these images, an edge detection method using a modified Beamlet Tree is utilized. Then a fast feature-based stitching algorithm is developed to connect broken cracks in single image. Finally these cracks can be accurately located by using LiDAR point cloud and visual information. The preliminary experimental results validate the applicability and efficiency of the proposed UAV-based crack inspection system.

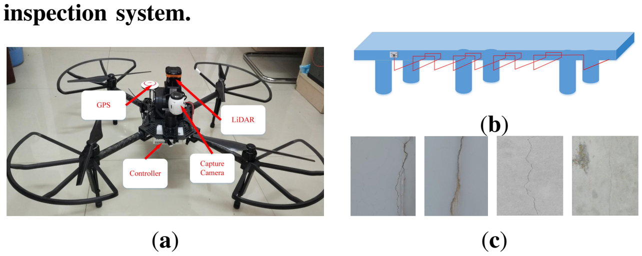

Fig. 1. The UAV-based bridge inspection system. (a)the UAV system; (b)working scenario; (c)crack images from bridges' lateral and under sides

Fig.1(a) shows the hardware of UAV system which includes: one DJI Matrice 100 UAV embedded with Inertial Measurement Unit (IMU), GPS module, Manifold controller, Hokuyo UTM-30LX LiDAR and a rotatable HD camera; one remote control with a display device. With the support of a flexible gimbal, the upward HD camera can capture images of the lateral sides and underside. The onboard Manifold controller uses multiple sensor data (LiDAR point cloud, IMU, Compass etc.) to achieve SLAM. Then we use path planning as Fig.1(b) to keep the altitude of UAV and keep it flying around bridges. There are mainly three steps for our UAV-based crack inspection system. The flow chart of the proposed system is shown in Fig.2.

- **Flight mission and data collection: The UAV will fly around the lateral and under sides with the help of SLAM [2] and path planning. Therein high resolution images will be collected at different locations using the HD camera. The image data can be stored in the storage card.**
- **Crack detection and localization: Cracks will be detected by a modified Beamlet Tree-based framework [3]. Because every captured image corresponds to the LiDAR scan point cloud, thus we can use scan matching to locate the position of cracks in the point cloud map.**
- **Crack measurement: Depending on the multiple sensor information, some key crack parameters will be measured, such as length, width, density. These crack parameters are very vital to guide the maintenance work.**

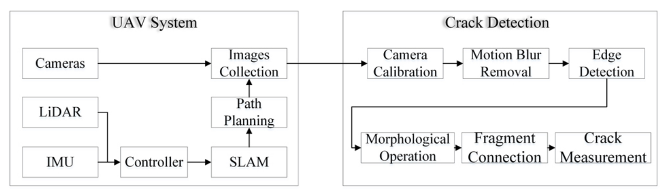

Fig. 2. Flow chart of the whole UAV crack inspection system

The experiments on real bridges (Fig.1(c)) demonstrate the effectiveness of the proposed framework. Regarding to crack detection, we compare our method with classical Canny, Structured Edges (SE) and PMI. The quantitative indexes include detection accuracy, completeness and quality (Table 1). We can observe that our method outperforms the other three methods in crack inspection. In the future, we will improve the robustness of our system and integrate more sensors to estimate the depth of crack.

TABLE I

QUANTITATIVE ANALYSIS OF CRACK DETECTION RESULTS

Strategy	Accuracy	Completeness	Quality
Canny	0.7964	0.8769	0.7163
SE	0.8423	0.8220	0.7124
PMI	0.7702	0.8176	0.6572
Beamlet Tree	**0.9247**	**0.9451**	**0.8776**

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