An Optimized Unmanned Aerial System for Bridge Inspection

Cheng-Hsuan Yang[a], Ming-Chang Wen[a], Yi-Chu Chen[a] and Shih-Chung Kang[a]

[a] Department of Civil Engineering, National Taiwan University, Taiwan
E-Mail: jason610155@gmail.com, raywen@caece.net, yie@caece.net, sckang@ntu.edu.tw

ABSTRACT

This paper provides an innovative approach for conducting bridge inspections by optimizing an unmanned aerial system (UAS). A rotorcraft prototype, a camera gimbal mechanism, and a workflow is developed in this study. The rotorcraft is used to carry the camera gimbal for capturing images. Since visual inspection is a primary method of evaluating the structural conditions of a bridge, bridge inspectors need to work in dangerous environments such as cliffs and riversides. Current methods employ vehicles equipped with massive robot arms developed for lifting workers to the outbound of bridges, which increase the risk associated with an inspection. In addition, such methods are time, money, and labour intensive, and can be applied only on large-scale brides due to working space requirements. In order to develop a low-cost and more flexible approach, this paper offers an optimized UAS to acquire images of a bridge from underneath, and serve to provide a visual aid for bridge inspectors. An on-board camera gimbal mechanism is developed for acquiring stable image data and remote control. Furthermore, we designed a workflow for using this system based on our field test. The workflow included bridge investigation, path planning, image acquisition, and post processing. To verify the proposed approach, we tested our system on the Hsia-kuei Shan Bridge in Wulai, north of Taiwan. The results showed that the proposed approach can save costs and be efficient for bridge inspections.

Keywords: Bridge inspection; UAS; robotics.

1 Bridge Inspection

Techniques for improving bridge inspections are considered critical as such inspections are important to ensure the safety and serviceability of bridges. Since a bridge is always constructed on cliffs or riversides, evaluating the condition below the bridge becomes the most difficult part during the inspection. Currently, there are three main approaches for conducting an inspection: via scaffolding, a special inspection vehicle, and innovative inspection robotics.

1.1 Scaffolding

Scaffolding is a traditional method for bridge inspections. The workers build scaffolds underneath a bridge and the bridge inspectors need to climb under the bridge to check the condition of the bridge deck. This approach can be applied on most bridges; however, it is labor-intensive and time-consuming to construct scaffolding under the bridge. Since the bridge inspectors should perform the inspection outdoors, especially underneath the bridge, the safety of the inspectors is a problem of concern [1].

1.2 Inspection Vehicle

In order to increase the safety of bridge inspections, an inspection vehicle with a large robot arm has been developed (Figure 1). A bridge inspector will be positioned on the end of the arm and sent underneath the bridge for a direct visual inspection [2]. Compared to the method of building scaffolding, using such an inspection vehicle can allow the inspection to be performed in a safer and more efficient manner. However, the vehicle is always very large so as to balance the weight of the robot arm. Thus, the large size of an inspection vehicle makes it difficult for use on small-scale bridges.

Figure 1. A bridge inspection vehicle with a large robot arm [3].

1.3 Innovative Robotics

Table 1 shows the comparison of the scaffolding method and an inspection vehicle in terms of efficiency, feasibility, and safety. Since by means of scaffolding the inspectors need to climb under the bridge, the efficiency and safety are lower than that of an inspection vehicle. However, the scaffolding approach has a higher feasibility since an inspection vehicle cannot be used on small-scale bridges.

Various innovative bridge inspection robotics have been developed to achieve high efficiency, feasibility, and safety during inspections. For instance, Chen et al. (2014) used a dual-cable suspension mechanism to capture images below bridges [3]. Further, Murphy et al. (2011) proposed an unmanned marine vehicle (UMV) to collect related data by crossing the water [4]. Furthermore, Metni and Hamel published their research on applying a helicopter unmanned aerial vehicle (UAV) for bridge inspection in 2007 [5].

Table 1. A comparison between scaffolding and an inspection vehicle in terms of efficiency, feasibility, and safety.

	Efficiency	Feasibility	Safety
Scaffolding	Low	High	Low
Inspection Vehicle	High	Low	Medium

2 State-of-Art UAS

An unmanned aerial system (UAS) includes two parts: the vehicle and the sensors. With this system a human pilot is not required to control the aircraft on board; instead, he can control it remotely via a ground station.

2.1 Unmanned Aerial Vehicle

An unmanned aerial vehicle (UAV) can be controlled autonomously using microprocessors, actuators, and sensors located on board. Nowadays, there are two types of UAVs, namely fixed-wing UAVs and multi-rotor UAVs [6].

The fixed-wing UAV was initially developed for military applications. It can stay in the air for more than 30 minutes due to its lightweight properties. It requires a runway to take off and it cannot stay at the same place in the air.

Meanwhile, the multi-rotor UAV is a newly developed aircraft. It can be categorized via the numbers of rotors it contains. Quadcopters, hexacopters, and octocopters are common multi-rotor UAVs. Attributing to the structure of the vehicle, a multi-rotor UAV can ascend directly without a runway and can hover at the same place in the air. However, the flying time is about 15 minutes due to the weight of the entire vehicle.

2.2 Sensors

To fly the aircraft autonomously, five kinds of sensors must be equipped on board, namely a microprocessor, a GPS sensor, gyroscopes, a radio receiver, and a barometer. The GPS sensor receives the coordinates for localizing the aircraft. The aircraft can maintain its position in the air stably by utilizing the gyroscopes. In addition, the radio receiver can receive the signal sent from the manipulator on the ground so that the pilot can control the aircraft immediately. Meanwhile, the barometer can assist with estimating the altitude of the UAV. Finally, the microprocessor serves as the brain of the UAS. It combines all the information gathered from the other sensors and processes the flight algorithm. With those sensors the aircraft can be controlled autonomously in the air.

3 Methodology

To verify the extent to which a UAS would assist in bridge inspections, we prototyped a bridge inspection UAV and conducted two site experiments. One was for validating the possibility of optimizing the UAS for the inspection. The other was for showing whether this system can be employed in a real scenario and whether it increased efficiency. We also developed a standard workflow for decreasing the preparation time of the inspection.

3.1 Goal

This paper proposed an innovative bridge inspection approach by optimizing the UAS. To improve limitations of existing inspection methods, this method has to increase the efficiency, feasibility, and safety of inspections. For achieving a high efficiency, the number of people required to operate this system should be less than three and the time for collecting images on a 300 m long bridge should be less than 8 hours. This approach should be applied on every kind of bridge regardless of the scale. Finally, bridge inspectors should not be required to climb under the bridge to capture an image. Additionally, we also developed a standard workflow that can save the preparation time of the whole process.

3.2 Bridge Inspection UAS

The UAS we designed for bridge inspections contains an improved UAV and a ground station. For capturing images below the bridge efficiently, we prototyped a special UAV with a camera on top of the aircraft. Further, a ground station with high mobility is also designed in this system.

3.2.1 Improved UAV

In order to achieve high efficiency and feasibility, a six-propeller UAV was utilized and improved in this study. Figure 2 shows a typical six-propeller UAV. The frame is the main structure of the aircraft, and sensors, actuators, and a camera are all loaded on it. For capturing a clear photograph, there is sometimes a camera gimbal equipped under the frame, which can prevent motion blur during flight.

We prototyped a six-rotor UAV with a 2 km control radius. The size of the aircraft is 1 m in radius and half a meter in height. It allows 15 minutes of hovering time. The weight of the UAV is about 7 kg, which includes the camera, batteries, and all other mechanics. Since we need to acquire images under the bridge, the camera should be installed on top of the frame (Figure 3.)

Figure 2. A typical six-propeller UAV consists of a frame, six rotors, propellers, batteries, and measuring equipment [7].

Figure 3. The improved UAV for a bridge inspection has the camera installed on top of its frame.

3.2.2 Ground Station

A ground station plays an important role in a UAS. Usually, a ground station contains a remote control, a laptop, some tools, and sometimes an electricity generator (Figure 4.) The pilot can view the image delivered from the aircraft and control the aircraft via the remote control instantly. Meanwhile, the tools are used for maintaining the aircraft. After the flight, we can immediately check the image by using the laptop. One thing worthy of being mentioned is that the ground station has a high mobility. All the equipment can be set up in 10 minutes and packed in 5 minutes. This property greatly reduces the preparation time of the inspection.

Figure 4. The ground station usually contains a remote control, a laptop, some tools, and sometimes an electricity generator.

3.3 Workflow

In order to save preparation time of an inspection, this paper developed a standard workflow.

Figure 5 shows the steps for performing a bridge inspection via a UAS. As soon as the bridge inspectors decide which bridge to inspect, they need to carry out an investigation to determine bridge specifications, such as length, width, structural type, and age. They can then use that information to compute a path plan, and determine aspects such as where to set up the ground station, where to take off from, and how to fly the UAV to capture accurate images. After planning, the bridge inspectors can visit the site and collect the image(s). Finally, they can use those images for post processing and analyze the status of the bridge.

To perform the task smoothly and efficiently, we developed a standard workflow for the image acquisition step (Figure 6). The bridge inspectors have to set up the ground station upon arriving at the planned site. They then need to load batteries on to the UAV and turn it on. Before performing the task, it is important for the aircraft to take off and hover at a height of 3 m to check the signal of the remote radio, since losing the signal during flight may cause the aircraft to crash. When everything is satisfactory, the bridge inspectors can commence the task of acquiring images underneath the bridge. Finally, the collected images must be confirmed. If the accuracy of the images meets requirements then the inspectors can perform the other path; otherwise, the inspectors should repeat the process of image acquisition again.

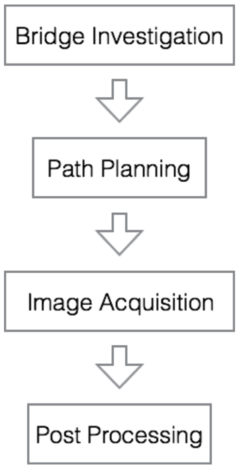

Figure 5. The inspection process includes four steps: bridge investigation, path planning, image acquisition, and post processing.

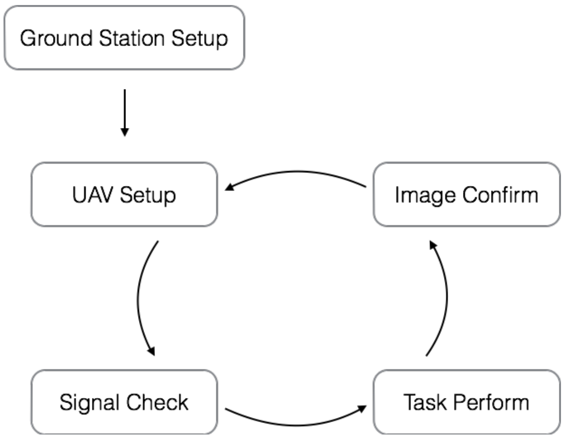

Figure 6. The developed standard workflow to save preparation time of an inspection.

3.4 Site Experiment

3.4.1 Feasibility Experiment

A feasibility experiment was conducted to analyze the feasibility of optimizing the UAS for bridge inspections by employing the improved UAV. In this experiment we chose the frames located at the entrance of the parking lot at the National Taiwan University. They are 5 m in width and 3 m in height, and are similar to a very small-scale bridge. We flew the aircraft through the frame and captured images under it to ensure that the improved UAV works.

3.4.2 Real Case Experiment

For a real case experiment, we chose the Hisa-kuei Shan Bridge as the experimental site. This is a two-lane bridge that crosses the Beishi River, which is located at Wulai, north of Taiwan (Figure 7). The bridge is a small-scale bridge that is 8.5 m in width and 240 m in length (Figure 8). This bridge is also the only passage of traffic connecting the Wulai District and the Xindian District. Due to the scale and the location of the Hsia-kuei Shan Bridge, it is difficult to perform bridge inspections by scaffolding or by using an inspection vehicle. Therefore, it is worthwhile to apply an innovative inspection approach for this bridge.

Figure 7. The Hsia-kuei Shan Bridge is located at Wulai, north of Taiwan.

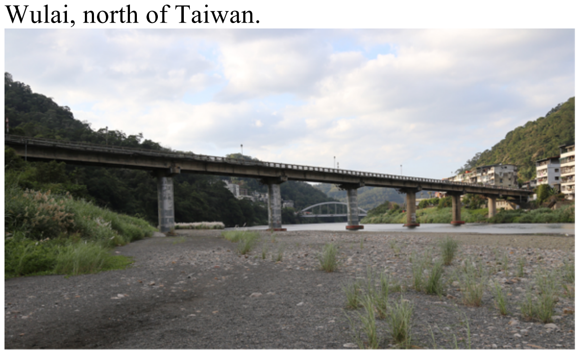

Figure 8. The Hsia-kuei Shan Bridge is a small-scale bridge, which is 8.5 m in width and 240 m in length.

4 Result and Discussion

After conducting a feasibility analysis and a real case study, results and feedback were obtained.

4.1 Results of the Feasibility Experiment

Figure 9 shows the results of the experiment. The left image displays the side view of the frame and the right one displays the view of the frame from underneath. These pictures can be used to confirm the existence of cracks, and the surveyors can point them out easily. This indicates that it is possible to optimize a UAS for bridge inspections.

When performing this experiment, we found a common problem, which was the nonexistence of a GPS signal while flying under the frame. This caused the aircraft to fly in an unusual manner; hence, in order to solve this problem, we turned off the GPS sensor and controlled the aircraft manually.

Figure 9. The side view and the bottom-up view of the frame taken by the UAV shows the possibility of implementing a UAS for bridge inspection.

4.2 Results of the Real Case Experiment

It took us 42 minutes to collect the images of one frame of the Hsia-kuei Shan Bridge. Specifically, 25 minutes were spent setting up the ground station and the aircraft, 10 minutes were spent in the first round of image collection, and 7 minutes for the second round. Furthermore, there were only three people involved in this task, namely the observer, the pilot, and the recorder (Figure 10). The pilot was in charge of controlling the aircraft to complete the mission. The observer needed to check the condition of the aircraft and ensure that it followed the planned path. The recorder was required to record details such as the time and the weather, and take outtake photos during the experiment. Figure 11 shows the images collected below the bridge. The surveyor can easily analyze the condition of the bridge by checking such images. In addition, we also took pictures of the side of the bridge (Figure 12). The existence of cracks on the beam can be pointed out by a surveyor immediately.

This experiment validated that the bridge inspection UAS can not only be utilized in a real scenario, but also lead to an increase in the inspection efficiency. There is still a serious problem to solve – the aircraft will lose the remote signal while flying through the bridge, and turning down the GPS sensor also makes the aircraft difficult to control. To address this problem we are now trying to apply other technologies on it, such as lasers and image navigation.

Figure 10. There were only three people involved in this task, namely an observer, a pilot and a recorder.

Figure 11. The surveyor can easily analyze the status of the bridge by checking the pictures taken below the deck.

Figure 12. We also took images of the side view of the bridge so that if the beam has cracks on it the surveyor can point them out immediately.

5 Conclusion

This paper proposed an innovative approach to conduct bridge inspections by optimizing an unmanned aerial system (UAS). This approach can increase the efficiency, feasibility, and safety of an inspection. As the results of the experiment show, only three people were required to be involved during the image collection process. Since our unmanned aerial vehicle (UAV) has a 2 km control radius, this system can be implemented at every bridge regardless of the scale. By employing a UAS for bridge inspections, inspectors are not required to climb under the bridge to check the condition of the bridge deck; therefore, the problem of safety for bridge inspectors is solved.

References

[1] Oh J.K., Jang G., Oh S., Lee J.H., Yi B.J., Moon Y.S., Lee J.S. and Choi Y. Bridge Inspection Robot System with Machine Vision. *Automation in Construction*, 929-941, 2009.

[2] Hartle R.A. Bridge inspector's training manual/90, U.S. Dept. of Transportation, Federal Highway Administration, Washington D.C., 1995.

[3] Chen Y.C., Yang C.E. and Kang S.C., A Lightweight Bridge Inspection System Using a Dual-cable Suspension Mechanism. *Automation in Construction*, (46):52-63, 2014.

[4] Murphy R.R., Steimle E., Hall M., Lindemuth M., Trejo D., Hurlebaus S., Zenon M.C. and Slocum D. Robot-Assisted Bridge Inspection. *J Intell Robot Syst*, (64):77-95, 2011.

[5] Metni N. and Hamel T. A UAV for Bridge Inspection: Visual Servoing Control Law with Orientation Limits. *Automation in Construction*, 3-10, 2007.

[6] Wen M.C., Yang C.H., Sung E.X., Wu T.H. and Kang S.C. Optimized Integration of UAVs, Surveys, and Image-based Modelling Strategies for Digital Terrain Model Reconstruction. *Proceedings of 14th International Conference on Construction Applications of Virtual Reality (CONVR) in Construction and Islamic Architecture*, Sharjah, UAE, 2014.

[7] Wen M.C. and Kang K.C. The application of Augmented Reality and Unmanned Aerial Vehicle for Construction Management. *Proceeding of International Society for Computing in Civil and Building Engineering,* Vol.128, 2014.