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The Visual Inspection Methodology for Ceiling Utilizing the Blimp

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Abstract

This paper proposes a visual inspection methodology for the ceiling element of a gymnasium utilizing a blimp robot with a Wi-Fi camera. In the proposed methodology, the blimp robot with the Wi-Fi camera inspects the damage location and captures the photographic image of the damage condition. The inspection blimp robots will be able to estimate the damage condition without any process of engineers' on-site-inspection involved. To demonstrate the capabilities of such blimp robots, the visual inspections for the ceiling of a gymnasium and the actual bridge deck has been conducted. The results of the application to real structures indicate that the Wi-Fi camera on the blimp robot can estimate the damages from the captured image, and the proposed methodology will provide valuable information for the repair and maintenance decision making of damaged elements located on high attitude.

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Keywords: Visual Inspection, Rapid Damage Assessment, Ceiling Element, Blimp, Remote Control,

1. Introduction

Recently, remarkable attention is paid to the damage assessment for nonstructural elements, especially the ceiling elements, in Japan. The 2011 off the Pacific Coast of Tohoku Earthquake caused damages to many nonstructural elements. Actually the damaged ceiling elements and damage inner wall components, which are among typical nonstructural elements, injured several people and even killed a couple of them [1]. After Kumamoto Earthquake on April 14, 2016, about 70 structures could not be used as the refuge place, because of the ceiling elements dropped down and nonstructural elements damaged [2]. Compared with the structural elements such as columns and beams, the nonstructural elements in general are less earthquake-resistant and less antiaging-resistant. For that reason, the rapid damage assessment for the nonstructural elements is, in a way, more important for the safety. However, only

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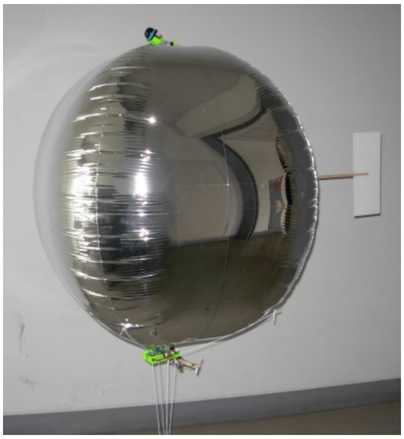


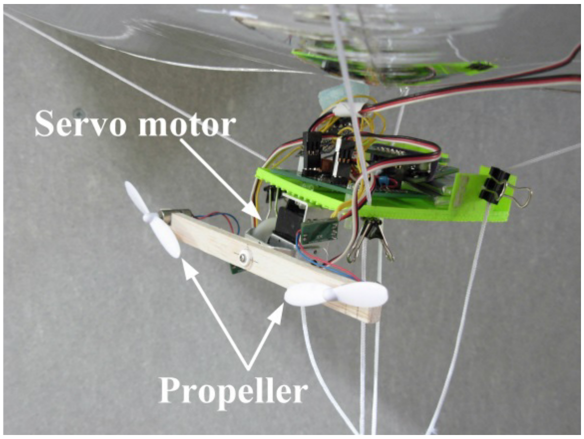


Fig. 1. (a) Blimp with Wi-Fi camera; (b) Drive unit of the blimp.

the visual inspection of those nonstructural elements from the floor has been employed for a certain damage stage.

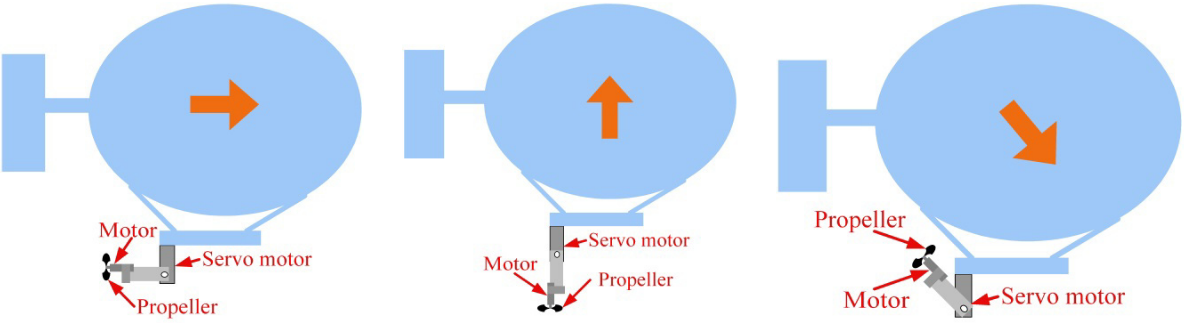
For the infrastructures, the robot technologies are recently used for the inspection and monitoring [3-13]. In particular, the multirotor, which are a typical unmanned aerial vehicle (UAV), are increasing to use for inspecting structures like bridges, highways, tunnels, dams, and railroads [11,12,13]. The UAVs could save the individuals from dull, dirty and dangerous jobs, while making the process much safer and more effective. Because of these benefits, the Ministry of Land, Infrastructure, Transport and Tourism in Japan recommends to use robot technologies for the inspection and monitoring of infrastructures.

Having the above-mentioned background, this paper proposes a visual inspection methodology for the ceiling element of a gymnasium utilizing the blimp robot with the Wi-Fi camera, which is one of the UAVs. In the proposed methodology, the blimp robot with the camera inspects the damage location and captures the photographic image of the damage condition. The blimp robots will be able to estimate the damage condition without any process of engineers' on-site-inspection involved. To demonstrate the capabilities of the camera-equipped blimp robot, the proposed scheme is applied to estimate the ceiling of a gymnasium and the actual bridge deck. And the inspection capability of the blimp will be compared with that of the multirotor, which is one of the useful tools for the high attitude inspection.

2. Developing the blimp robot for visual inspection

For the purpose of practically conducting the visual inspection for those elements in a high location, which are ceiling elements or deck elements of the bridge, the blimp robot with the Wi-Fi camera was developed. The length of the blimp robot including the tail wing, Wi-Fi camera and batteries is about 850mm, the width about 580mm, the height about 850mm and the weight about 300g. The developed blimp robot for visual inspection is shown in Fig. 1. The main components of the developed blimp robot are: an aluminum balloon; a microcontroller; two motorized airscrews mounted on the servomotor; a tail wing; a Wi-Fi camera; a Bluetooth communication unit and batteries. The aluminum balloon is utilizing for the body of the blimp, which is filled by Helium. Unlike the rubber balloon, the aluminum balloon can keep the Helium during several months. The aluminum balloon for the blimp can be easily replaceable, when the body of blimp is damaged by the structural elements, for example, beams or braces, in inspection. The microcontroller is an open-source electronics prototyping platform with an 8-bit RISC-based microcontroller, Arduino Micro. Arduino Micro controls two servo motors with 2ch pulse-width modulation signals and two motors with two digital signals. One servo motor manipulates the Wi-Fi camera position. The other servo motor manipulates the vertical position of the airscrews to move the vertical direction. The relationship between the positon of servo motor head and moving direction is shown in Fig.2. Two motors drive the airscrews for moving vertical and horizontal direction. The tail wing is important to control the moving direction. If the blimp does not have the tail wing, blimp is always rolling and cannot move back and forward. The lightweight Wi-Fi camera, with a mass of about 22g, is integrated. Because the blimp robot can only lift under 50g. The employed Wi-Fi camera is 1/9 inch CMOS sensor with 300,000 pixcels and 802.11 b/g Wi-Fi interface. The limit transmission distance range of Wi-Fi camera is about 20m. The power is supplied to the robot with Wi-Fi camera by one rechargeable battery and two 3.7V Li-Po batteries. Two 3.7V Li-Po batteries provide the power to the microcontroller, the Bluetooth communication device, the two motors and the two servo motors. One rechargeable battery provides the power to the Wi-Fi camera. Depending on the distance to a specific monitoring point, the blimp robot can move about 60 minutes with a single charge. The total cost of manufacturing the blimp robot is about US$350, including the Wi-Fi camera and Bluetooth communication device.

In conducting the inspection, the blimp robot is manipulated by using the tablet PC or Android smart phone accounting for the convenience of the operation. And an operator of the blimp robot sends the command to the blimp utilizing the Wi-Fi camera on the blimp. The Wi-Fi camera on the blimp robot provides the information of the blimp's surroundings. To demonstrate the capabilities of the inspection, Fig. 3 shows how the Wi-Fi camera mounted on the blimp robot captured the crack scale located on ceiling. The picture of the scale gage captured by the blimp robot is shown in Fig.4. Fig.4 indicates the blimp robot can detect over the 0.4mm width of the crack. But the blimp robot cannot measure the width of the crack.



(a) Horizontal direction (b) Upper direction (c) Downward direction

Fig. 2. Schematic figure of the flight direction control.

Fig. 3. Crack scale on the ceiling.

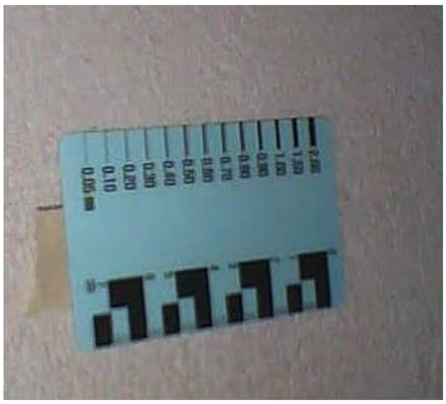


Fig. 4. Crack scale captured by the blimp.

Table 1. Comparison of the inspection capabilities

	Multirotor	Blimp
Resistance to wind (Average wind speed)	< 5 m/s	< 1.5 m/s
Operability for flight control	Require to professional skill	Need not the skill
Payload	< 10kg	< 50g
Flight time	Around 20 min.	Around 60 min.
Safety in accidents	X	O Soft body, Light weight

3. Comparison for the inspection capability of the blimp and the multirotor

The utilization of the UAV for structural inspection and monitoring is rapidly increasing in recent years. The main advantages of the UAV, compared with using the air-plane or satellite, are low in cost of operation, easy in implementation but more useful information. According to the Wikipedia, the UAV is defined as an aircraft without a human pilot aboard. The developed blimp robot is one of the UAVs.

For the estimating the capability of the inspection, the developed blimp robot is compared with a multirotor, which is one of typical UAVs in terms of the capabilities of: (1) resistance to wind; (2) operability of flight; (3) payload; (4) flight time; and (5) safety for accident.

(1) Resistance to wind
The blimp has low capability of the resistance to wind. The developed blimp robot can only be used for the inspection under the average wind speed 1.5m/s. Multirotor can stably fly around an average wind speed of 5m/s. So, the multirotor has the high capability of the resistance to wind than the blimp.

(2) Operability for flight control
The multirotor can autonomously fly, but requires manual control flight for the inspection. The manual control flight of the multirotor needs the professional skill. On the other hand, the flight of the blimp robot does not need the special skill, because the flight speed of the blimp is slow and the blimp is always floating with the helium. In this respect, the blimp is more user-friendly than a multirotor and has the high operability for flight.

(3) Payload
Depending on the size, the payload of a typical multirotor is around 10kg. But, the blimp has the low payload capacity. The developed blimp only lifts up 50g at most.

(4) Flight time
The flight time of a developed blimp robot is over 60 minutes, because the helium filled in the blimp assists with the floating power of the blimp. The flight time of the multirotor is about 20 minutes. So, the blimp has the advantage of the flight time than a multirotor.

(5) Safety in accidents
The mass of the developed blimp robot is around 300g, which is much lighter than a multirotor. And the body of the developed blimp robot, which is an aluminium balloon, is safe in case of its contacting with the people. Even in some accident, the blimp will be dropping slowly down, because of the helium assist with the floating power, but the multirotor will be very rapidly dropping down. In addition, the multirotor propellers have a possibility of getting hurt in an accident. So, in terms of causing certain accidental things, the blimp is safer than multirotor.

Table 1 shows the comparisons of the function capabilities in regard to visual inspections and these results indicate that the blimp robot has the advantage for an indoor use while the multirotor has the advantage for an outdoor use.

Fig. 5. Flight of the blimp in the gymnasium.

Fig. 6. Beam connection captured by the blimp.

(a) Corrosion on the supporting member of the lighting (b) Corrosion on the pipe

Fig. 7. Photographs of the corrosion elements captured by the blimp.

4. Visual inspection for the actual structures utilizing the developed blimp

4.1. The visual inspection of the school gymnasium

To demonstrate the capabilities of the inspection utilizing the developed blimp robot with the Wi-Fi camera, the visual inspection is conducted for the actual ceiling of a school gymnasium. Fig. 5 shows how the developed blimp robot inspected the condition of the ceiling. Fig.6 shows the pictures of the beam connection and the supporting member of the lighting device captured by the Wi-Fi camera mounted on the blimp robot. This figure indicates that the resolution of the Wi-Fi camera on the developed blimp robot is good enough to monitor the conditions of the ceiling elements. The corrosion on the ceiling elements shown in Fig.7 can be detected by the blimp. These corrosions would be difficult to detect and estimate from the floor. The results of applying the presented scheme to the ceiling of the gymnasium indicate that the developed blimp robot with the Wi-Fi camera can estimate the condition of the ceiling without any scaffolding, and make the whole process of the inspection much safer and much more effective.

4.2. The visual inspection of the bridge deck

For investigating the capability of the developed blimp robot with Wi-Fi camera, different inspection tests are also conducted for the actual bridge deck, which was constructed about 45 years ago. The height of the bridge deck on the inspection site is about 5m from the ground to the deck and the width is about 10.5m. The average wind speed during the inspection was under 1.5 m/s. If the average wind speed is around 2.0 m/s, the blimp robot could

Fig. 8. Blimp under the bridge deck.

Fig. 9. Beam connection captured by the blimp.

(a) Original image (b) Image applied by the edge detection

Fig. 10.Cracks on the bridge deck.

not be controlled and would be flowed by the wind.

It is shown in Fig. 8 how the flight of the developed blimp robot under the bridge deck is. The picture in Fig. 9 is the captured image photograph. This figure indicates how close the blimp robot can go to the bridge deck and beam connections and how easily it inspects the elements of bridge deck, which would be difficult to estimate from the ground.

With the inspection based on the developed blimp robot, even the cracks on the bridge deck, shown in Fig. 10, are detected. To have more clear image of resulting cracks, the edge detection based on the Canny edge detector [14] is applied to the original image shown in Fig. 10 (a). The result processed with the edge detection, as shown in Fig.10 (b), indicates the edge detection helps to clearly recognize the cracks, but the edge detection cannot perfectly extract crack width. In this regard, certain appropriate image processing methodology is required to be developed in the future work.

5. Conclusion

A visual inspection methodology for the ceiling elements utilizing the blimp robot with the Wi-Fi camera has been presented. In the proposed methodology, the blimp robot with the Wi-Fi camera inspects the damage location and captures the photographic image of the damage condition.

Firstly, the inspection capability of the blimp robot is compared with multirotor, which recently increases in use for inspection. In comparison to the use of a multirotor, the use of the blimp robot has the advantage for the operability of flight, flight time and safety in case of accident, but has the disadvantage for the resistance to wind and the payload. These results indicate that the utilizing of the blimp is suitable for indoor inspection, while that of the multirotor is suitable for outdoor.

Secondly, for investigating the effectiveness and validity of the developed methodology, the blimp robot with the Wi-Fi camera has been applied to the visual inspection of an actual ceiling and a bridge deck. The obtained results indicate that utilizing the developed blimp robot will make the whole inspection process much safer and more effective. The inspection methodology utilizing the blimp robot without any scaffold required would reduce the cost and the time. With the blimp robot, the ceiling elements could be more frequently inspected. Then, the visual image data, captured by the Wi-Fi camera mounted on the blimp robot, would provide significant information in making decision for the repair and the maintenance.

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