A STUDY ON THE EVALUATION TECHNIQUES OF WIND RESISTANCE FOR UAV-BASED BRIDGE INSPECTION

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Abstract - An Unmanned Aerial Vehicle (UAV) is defined by the FAA as an aircraft flown with no pilot on board. UAVs are sometimes referred to as drones and the name can be used interchangeably. UAVs are an emerging technology with many potential applications in the civil engineering field. One application that is routinely mentioned is the area of bridge inspection due to the logistical challenges to efficiently and effectively visually inspect a wide variety of structure types in challenging locations. However, to date an organized study on this application has not been performed. When drones fly outside, they are affected by various winds. In high wind conditions, drone flight stability cannot be guaranteed. Drones need to be able to withstand and wind certain wind directions and wind speeds. This paper provides a method for evaluating the maximum wind speed that a drone can withstand and the time it can fly in the wind.

Keywords - Unmanned Aerial Vehicle (UAV), Drone, Bridge Inspection, Wind Resistance

I. INTRODUCTION

The emerging utilization of unmanned aerial vehicles (UAVs) has been accelerated by the maturing of microelectronics technology. UAVs offer an agile and cost-effective solution for many demanding civilian applications, with the Federal Aviation Administration expecting a 10-fold market growth from 2016 to 2021 to over 5 million drones in the United States alone [1]-[3]. Drone applications are numerous, ranging from package delivery, aerial photography, agriculture and pest control, site inspection, and surveys to public safety services such as providing coverage for remote areas [4]-[6].

UAVs are equipped with high resolution cameras capable of capturing images, recording videos, and having infrared vision to examine bridges, among other uses. They are capable of carrying additional attachments, such as flashlights or thermal cameras, to perform a wider variety of damage identification. This emerging technology presents great potential for the inspection of bridges, as these structures often present inaccessible areas for inspectors. To date, limited research for UAV-enabled bridge inspection in junction to computational simulations have been made[7].

At present, there is no standardized evaluation method for external environmental variables for drone flight. In this paper, we propose an evaluation technique for test bed of indoor wind resistance test to evaluate the reliability of bridge unmanned drone technology. This paper presents an evaluation technique for performance testing of various scenarios such as wind change, wind speed hovering, mission flight and autonomous flight of various drones. This can be used as basic data on the development of drones that can withstand the strong winds generated under the bridge.

This paper is organized as follows. Section II introduces related work, section III proposes wind resistance evaluation method, and section IV concluding remarks and summarizes this paper.

II. RELATED WORK FOR UAV-BASED BRIDGE INSPECTION

2.1. Bridge Inspection Protocol

Due to a lack of systematic damage identification and drone inspection procedures, a five-stage bridge inspection protocol that allowed for an efficient drone-enabled bridge inspection in Fig.1. was developed. The protocol was based on holistic information related to drone limitations, drone operation conditions, and data acquisition methodology. The regulations were also considered. The protocol is detailed below:

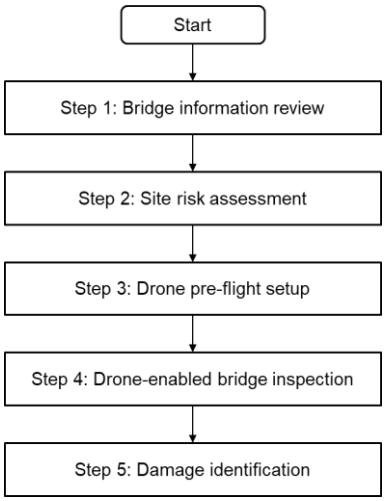


Fig.1. Basic concept of bridge inspection protocol

Stage 1 is to complete the Bridge Information Review. Information such as as-built plans, historical inspection reports, and other applicable documents

should be studied in this stage to ensure a complete inspection of the bridge structure. Stage 2 is to perform a thorough Site Risk Assessment of the bridge's surrounding areas. This stage is intended to identify potential risks such as near trees or traffic lanes to safely proceed with the drone-enabled inspection. Stage 3 is to perform the Drone Pre-flight Setup. It is recommended, by both the FAA and drone manufacturers, to conduct a thorough inspection of the drone prior to the first flight of the day. Stage 4 is to complete the Drone-Enabled Bridge Inspection. Once all the preliminary information has been gathered during the previous stages, the inspection using the drone can be conducted. During the operation of the drone, it is necessary to consider weather conditions such as wind as it can negatively affect the performance of the drone. Stage 5 is to complete the Damage Identification. For a successful drone-based bridge inspection, the damage should be easily identified from the gathered information. The images captured using the drone serve as the basis for further computational analysis including photogrammetry based inspection[7].

2.2. Advantages of Applying UAV at Bridge Inspection

Based on our observations in the field and extensive literature research, the following conclusions were made[8,9]:

- UAVs can be used in the field during bridge inspections safely. Based on the UAVs size, weight, controllability and built-in fail safes, the risk to inspection personnel and public is very low.
- UAVs are more suitable as a tool for inspections of larger bridges, but there can also be some advantages for smaller bridge inspections.
- Defects can be identified and viewed with a level of detail equivalent to a close-up photo.
- UAV technology is evolving rapidly and inspection-specific UAV features are just coming into the marketplace that will increase their effectiveness as it relates to bridge safety inspection. These new technologies should be included as a Phase II of this study.
- In some types of inspections, a UAV has the capabilities to be used in lieu of an under bridge inspection vehicle and would provide significant savings. These savings would come in the form of reduced or eliminated traffic control and reduced use of under bridge inspection vehicles and lifts.
- UAVs can provide a cost effective way to obtain detailed information that may not normally be obtained during routine inspections.
- Infrared images of bridge decks and elements are already a common and accepted way to obtain information on concrete delamination. UAVs can provide a very efficient way to collect infrared images of bridge decks and elements as they can be equipped with an infrared camera.
- Safety risks associated traffic control, working at height and in traffic could be minimized with the use of UAVs.
- UAVs can be utilized as an effective method to determine stream or river bank conditions upstream or downstream of the bridge as well as capture large overall aerial maps of dynamic bank erosion and lateral scour conditions.
- UAVs can provide important pre-inspection information for planning large-scale inspections. Information such as clearances, rope access anchor points and general conditions can easily be obtained with a UAV and would aid in the planning of an inspection.

Fig.2. shows an example photograph of a UAV-based bridge inspection.



Fig.2. Example photograph of UAV bridge inspection

III. PROPOSED EVALUATION TECHNIQUE OF WIND RESISTANCE

When drones fly outside, they are affected by various winds. In high wind conditions, drone flight stability cannot be guaranteed. Drones need to be able to withstand and wind certain wind directions and wind speeds. This section presents methods for evaluating the maximum wind speed that a drone can withstand and the time it can fly in a windy state. Fig.3. shows the procedure of the wind resistance evaluation technique.

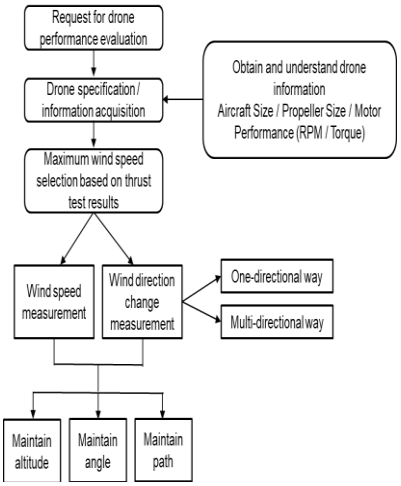


Fig.3. Flow chart for evaluation techniques of wind resistance

3.1. Units for evaluation the evaluation techniques of wind resistance

- Hovering : Drones do not move at a constant altitude
- Stop flight : Drones fly without hovering while hovering
- Maximum wind resistance : Maximum wind speed for drones to maintain constant altitude and position
- Maintain hovering : Drones can fly without being overturned by wind
- Hovering Reactivity : The time the drone returns to normal when the posture changes due to the wind

3.2. Evaluation test condition

- The test bed is to be indoor space.
- Test in a space where no external wind enters.
- Wind direction, wind speed and wind area of wind generator for test should be constant.
- For safety during the test, connect the fixing wire to the drone for the test.

The test bed consists of an interior space, as shown in Fig.4. below. Test space A is the test site for the examiner during the test, and B is the place for the drone. C is a wind generator and blows wind in the B direction.

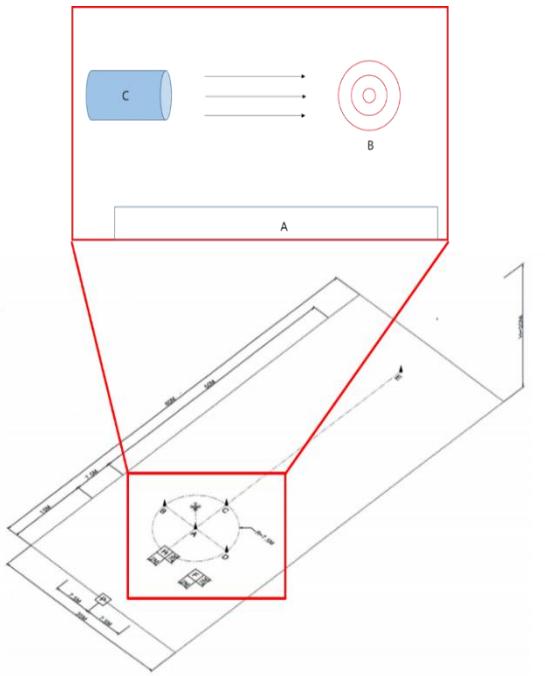


Fig.4. Proposed test bed configuration

3.3. Maximum wind resistance measurement test method

- Perform the test without applying any external conditions.
- In the fixed evaluation position, guidelines for maintaining altitude and attitude are installed and timely flight performance tests are conducted within the guidelines.
- Turn the drone on and raise it vertically above the 1m evaluation position through the controller.
- Afterwards, the 1m altitude and posture maintenance evaluation is performed without any manipulation.
- Posture maintenance is based on the result of attaching angle sensor to the center of drone.
- Perform performance records according to the evaluation items.

3.4. Maximum flight time measurement test method

- The drone is to be fully charged before the start of the test.
- The test position is to be raised 1 m vertically from the fixed evaluation position.
- Measure the maximum flight time without any external conditions in the stationary flight.
- Measure the maximum flight time by applying the wind speed corresponding to 1/2 of themaximum wind speed based on the results of the maximum wind speed measurement test.
- The drone then measures the time without any manipulation.
- Perform performance records according to the evaluation items.

3.5. Wind resistance test method

- Refer to Fig.5. and apply wind speed in each direction in 8 directions.

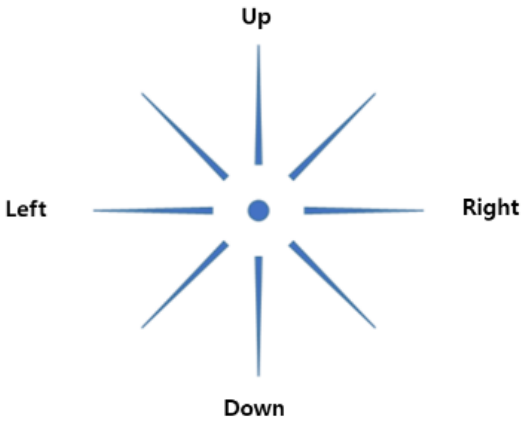


Fig.5. Direction of test wind

- The test position is to be raised 1 m vertically from the fixed evaluation position.
- Wind direction and wind speed are measured in real time through the measuring sensor.
- The wind speed is increased by + 0.5m/s (± 0.1) at intervals of 1m/s from 30 seconds within the range not exceeding the maximum wind speed.
- Increased wind speed is only allowed if it meets the evaluation criteria.
- Perform performance records according to the evaluation items.

3.6. Standard for Evaluation Techniques

When measuring the moving distance, measure the distance to the X and Y axes as shown in Fig.6., and measure the distance to the Z axis when measuring the altitude maintenance.

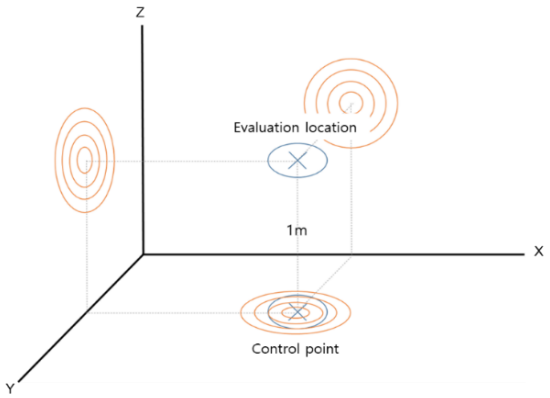


Fig.6. Direction of test wind

First, the stop flight test of standard for evaluation techniques are as follows.

- Position maintenance : within ± 10 °
- Hovering responsiveness : within ± 5 ° range
- Holding time (= test time) : 10 minutes

Second, the maximum wind resistance test of standard for evaluation techniques are as follows.

- Moving distance : Within 0.5m radius of horizontal evaluation position (X, Y axis)
- Altitude maintenance : Within 0.2.m radius of fixed evaluation position
- Position maintenance : within ± 20 °
- Hovering responsiveness : Maintain ± 10 ° within 15 seconds
- Maintenance time (= test time) : 60 seconds for each item
- Maximum wind speed : Maximum wind speed that the drone can withstand

Third, the maximum flight time test of standard for evaluation techniques are as follows.

- Position maintenance : within ± 20 °
- Hovering responsiveness : Maintain ± 10 ° within 15 seconds
- Wind velocity off : Specification of drone under test and within 3% of error range
- Wind velocity on : test result record

Finally, the wind resistance test of standard for evaluation techniques are as follows.

- Moving distance : Within 0.5m radius of horizontal evaluation position (X, Y axis)
- Altitude maintenance : Within 0.2.m radius of fixed evaluation position
- Position maintenance : within ± 20 °
- Hovering Responsiveness : Maintain ± 10 ° within 15 seconds
- Retention time : 60 seconds

IV. CONCLUSIONS

The area of bridge inspection due to the logistical challenges to efficiently and effectively visually inspect a wide variety of structure types in challenging locations. However, to date an organized study on this application has not been performed. At present, there is no standardized evaluation method for external environmental variables for drone flight. In this paper, we propose an evaluation technique for test bed of indoor wind resistance test to evaluate the reliability of bridge unmanned drone technology. Wind resistance evaluation method is proposed for performance test of various scenarios such as wind change of various drones, hovering by wind speed, mission flight and autonomous flight. This can be used as a basic data on the development of drones that can withstand the strong winds generated under the bridge in future studies.

ACKNOWLEDGMENTS

This research was financially supported by the Ministry of Trade, Industry, and Energy (MOTIE), Korea, under the "Regional Innovation Cluster Development Program (R&D, P0002073)" supervised by the Korea Institute for Advancement of Technology (KIAT).

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