Towards Autonomous Drone-Based Dynamic and Seismic Response Monitoring of Bridges

Quarterly Progress Report
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1. PROJECT ABSTRACT

There has been increasing interest and use of unmanned aerial vehicles (UAVs), especially in the past decade, for infrastructure inspection. The goal of this study is to extend the use of UAVs to a new application in the area of infrastructures rapid assessment under service conditions and extreme events such as earthquakes. The project will leverage several well-established technologies such as autonomous UAVs systems along with extensive expertise in vision-based monitoring of infrastructure systems like bridges. Our objective is two-fold: (1) extend the use of video cameras and principles of digital image correlation and target-tracking to UAV systems for dynamic displacement measurements and monitoring; and (2) provide foundational work towards establishing a framework that benefits from early warning systems to launch UAVs and collect vibration videos to use for near real-time post-disaster assessment of infrastructure systems and rapid decision making. We will focus on earthquakes, but the results from the project could be generalized in the future and extended to other extreme events. This project will provide unique testbeds in the Earthquake Engineering Laboratory at the University of Nevada, Reno where UAVs will be used to monitor online shake table tests, and results from the monitoring will be used in establishing the future infrastructure assessment framework.

2. RESEARCH PLAN

2.1. STATEMENT OF PROBLEM

The status of our aging infrastructure in the US or elsewhere around the world has been recently one of the biggest challenges facing governments and decision-makers. Maintaining, repairing, or replacing existing infrastructure systems is a major undertaken activity in the US and around the world. Nonetheless, there is a dire need to have a forward look at future and next-generation infrastructure systems. In the US, the ASCE has laid three pillars for solving the nation's infrastructure problems, i.e. (a) strategic and sustained investment, (b) bold leadership and thoughtful planning, and (c) careful preparation for the needs of the future. A major component of the ASCE's "Preparing for the Future" vision is to utilize emerging technologies to ensure infrastructure resilience in the face of extreme events and develop processes that modernize and extend the life of infrastructure, expedite repairs or replacement, and promote cost savings. The innovative applications of emerging technologies in infrastructure assessment and structural health monitoring has shaped several research thrusts among the civil and structural engineering communities and is one of the key motives of this proposed study.

Several global technologies are on the rise such as aerial robotics, which are commonly referred to as unmanned aerial systems (UAS) or unmanned aerial vehicles (UAVs), or simply "drones". Many of the critical lifelines and infrastructure systems such as bridge networks or power grids and transmission lines have taken serious steps towards adopting UAVs for regular maintenance and inspection. In fact, the federal National Cooperative Highway Research Program (NCHRP) has recently solicited research proposals for "Evaluating and Implementing UAS into Bridge Management Methods Through Element-Level Data Collection". Further using bridges as one example of critical infrastructure systems, we find that a large deal of research studies has been sponsored, mostly through various Departments of Transportation (DOTs), to use UAVs for visual bridge inspections. However, none of the ongoing or emerging efforts have properly considered the use of UAVs for dynamic vibration and structural system identification of bridges or other infrastructure systems, nor considered real-time or near real-time structural assessment in the case of extreme events such as earthquakes. Future applications of UAVs to rapidly inform post-disaster decisions such as assessing a bridge condition to open it for traffic or not would be of great importance, which is the specific motivation of this proposal.

2.2. RESEARCH APPROACH AND OBJECTIVES

Our specific objectives are: (1) validate and verify (V&V) the use of UAVs videos along with principles of digital image correlation (DIC) and target-tracking for dynamic displacement measurements and structural health monitoring (SHM); and (2) provide foundational work, towards establishing a future autonomous assessment framework, such as exploring target-based and targetless UAVs vibration monitoring, or exploring feasibility of two- vs. three-dimensional (2D vs. 3D) and one vs. two UAVs-based measurements if budget and time allows. Thus, it is important to note that the main developments sought in this study will be in the algorithms and methods in video processing and structural assessment. Developing new algorithms for UAVs path finding or seismically-triggered launch systems is not part of the scope for instance, but rather commercial auto-pilot or autonomous navigation systems will be used to prove or demonstrate the concept. Once the viability of UAVs dynamic and seismic monitoring solutions is demonstrated through this project and further knowledge gaps are identified from the synthesis of available technologies, future multi-disciplinary efforts, through a second year extension of this project for instance, could leverage expertise from computer science, robotics, civil engineering, etc. to optimize or enhance the UAVs triggering, launching, navigation, and data transfer within the envisioned framework.

To accomplish the above objectives, the PI will leverage extensive expertise in vision-based dynamic response and seismic monitoring of infrastructure systems like bridges. We will provide unique testbeds in the Earthquake Engineering Laboratory at the University of Nevada, Reno where UAVs will be used to monitor online shake table tests, and results from the monitoring will be used in establishing the future infrastructure assessment framework as explained in the work plan section. Examples of our previous work that will be further extended in this study focused on vision-based target-tracking measurement errors, demonstrating large-scale and field monitoring of bridges, and tackling image and signal processing challenges. Fig. 1 provides some of the vision-based monitoring applications conducted by our team including a recent unique full-scale building test at world largest shake table in Japan through an NSF-funded US-Japan collaboration (Fig. 1b). Most of the work so far has used stationary cameras, but we are recently extending many of our established concepts and developed tools to UAV-based video monitoring (Fig. 1d).

Fig. 1 Sample of vision-based monitoring of large-scale seismic tests and SHM field applications

2.2.1. SUMMARY OF PROJECT ACTIVITIES

An experimental approach will be used and several research activities will be executed to accomplish the objective of this study. A summary of the proposed research tasks is as follows:

- Task 1 – Synthesis of existing methods and technologies towards building a fully or semi-autonomous UAV-based infrastructure dynamic response monitoring and assessment framework
- Task 2 – UAV-based displacement measurement accuracy (V&V tests)
- Task 3 – Large-scale seismic monitoring test framework validation
- Task 4 – Summarize the results in a final report

2.2.2. PROGRESS OF RESEARCH TASKS

An overview of each research task and progress-to-date is presented in this section.

Task 1 – Synthesis of existing methods and technologies towards building a fully or semi-autonomous UAV-based infrastructure dynamic response monitoring and assessment framework

Our ultimate goal from this project is to provide foundational work and outline future needs towards establishing a successful fully or semi-autonomous UAV-based infrastructure dynamic response monitoring and assessment or inspection framework, which can be employed under service conditions or extreme events such as earthquakes. The objective of the first task of this project is to identify all the pieces and component that need to be integrated to achieve such framework. The readily and well-established parts from previous studies or other disciplines will be synthesized and tested as part of Tasks 2 and 3.

Task 2 – UAV-based displacement measurement accuracy (V&V tests)

A wide-range of methods will be surveyed and synthesized for the various components of the envisioned assessment framework. In this task, we will conduct two sets of V&V tests for UAV static and dynamic displacement measurement accuracy to understand the limitations and potential of hardware effectiveness and control (e.g. gimbals versus UAV motion correction) and post-processing methods. For the two sets of tests, we will additionally explore target-based and targetless UAVs vibration and displacement monitoring, and ideally if budget and time allows, the feasibility of 2D (using one UAV) versus 3D (using two spatially correlated UAVs) measurements. The first set of tests will use the static V&V test previously devised by our research group to measure tracking points displacements against the standard one-inch block. The second set of tests will be more elaborate and consider both static and dynamic motion of a rigid small-scale tower on a shake table as shown in Fig. 2. The sought V&V tests in this task are expected to properly quantify both static and dynamic UAV-based displacement measurements, which has not been comprehensively done yet.

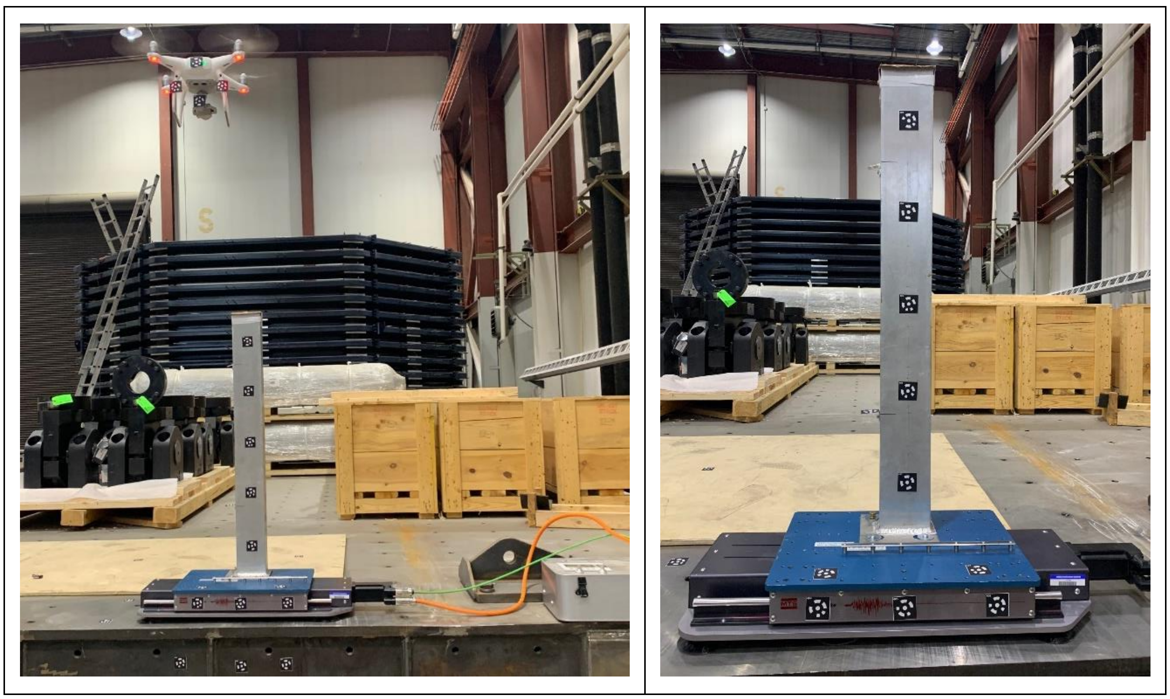


Fig. 2 – Example of a V&V test for drone-based dynamic response monitoring.

Task 3 – Large-scale seismic monitoring test framework validation.

The objective of this task is to investigate the viability and/or demonstrate UAV-monitoring as part of a full integrated system using at least one large-scale shake table test to be conducted at the Earthquake Engineering Laboratory at UNR. As mentioned before, the PI has been conducting and monitoring several large-scale single or multiple shake table tests over the past few years. In this task, we will “piggyback” a natural gas pipeline system (representative large-scale infrastructure system) that will be tested using two shake tables at UNR as shown in Figure 3. It is again noted that the purpose of these tests is to validate for the first time the tracking algorithms used in UAV-based dynamic response monitoring systems.

Fig. 3 – Example of a large-scale drone-based dynamic response monitoring of an infrastructure system tested at multiple shake tables at UNR.

TASK 4 – Results dissemination and Final report

A final report will be prepared and submitted for wide dissemination through the ABC-UTC. The report will be complemented with ABC-UTC guide for the roadmap of future implementation of UAV-based dynamic response assessment of bridges. At least one journal paper will be produced from this project and will be submitted for potential publication in a peer-reviewed journal.

2.3. ANTICIPATED RESEARCH RESULTS AND DELIVERABLES

- Final Report and ABC-UTC guide on UAV-based dynamic response assessment of bridges
- One comprehensive manuscript that lay the foundation for future-implementation of drones for dynamic and seismic response monitoring of bridges
- Five-minute video summarizing research study and findings

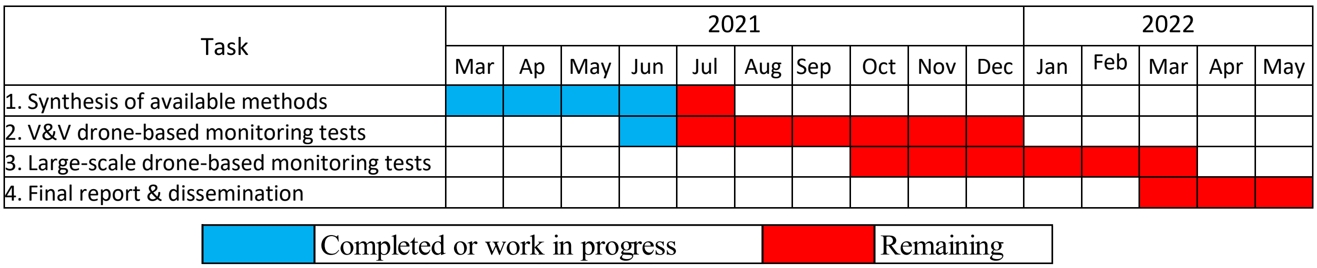
2.4. APPLICABILITY OF RESULTS TO PRACTICE

The results from this project are expected to benefit different states DOTs in the future, but an immediate impact is not expected from this fundamental research project.

3. TIME REQUIREMENTS (GANT CHART)

To allow for the completion of all the project tasks, the study will be conducted over a period of 15 months (5 quarters) following the schedule in Table 1.

Table 1 – Gantt schedule of major project tasks



Percentage of completed work: 15%

Percentage of remaining work: 85%