MPC-535
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Project Title:
Development of Unmanned Aerial Vehicle (UAV) Bridge Inspection Procedures

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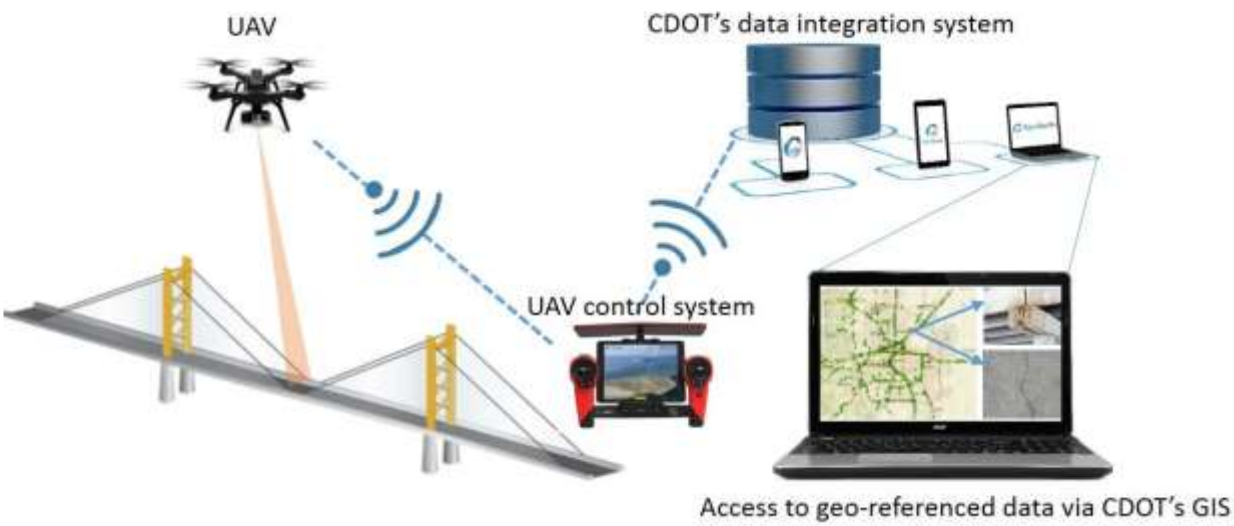
Research Needs:
Maintenance of deteriorating bridges is a pressing need throughout the U.S., and for the Mountain-Plains area in particular, as these infrastructure are critical to economic performance. In the maintenance process, condition evaluation of this sector of the infrastructure is critical, as it informs repair decisions, load-rating and management of limited state resources. Throughout the Mountain-Plains region, the condition of nearly 25,000 bridges must be evaluated by state DOTs regularly. In Colorado, the condition of a total of 8,612 state owned and local bridges are inspected routinely (typically every two years) by CDOT and consultants. About 540 of these bridges are rated as structurally-deficient bridges and thus typically need more frequent inspection and monitoring. The cost of bridge inspection forms the basis of much of the bridge management budget for CDOT, which varies from about $4.5 to $10 million annually. Considering the need for frequent inspection of a large number of bridges in the state and the significant expense, an efficient and cost-effective bridge inspection system is highly desirable. In current practice, the condition assessment of bridges mainly relies on human-based visual

inspection, which often requires inspectors to climb ladders or use specialized equipment such as a “cherry-picker” to be lifted into place. This type of inspection is not only expensive and interrupts traffic, but also poses a danger to inspectors, especially in the Mountain-Plains region where mountain bridges can be difficult to access. In addition, the condition ratings reported by the inspectors might not be consistent due to the subjectivity of individual experience and difficult inspection conditions. The significant cost, safety issues, traffic interruption, as well as the subjective nature in current bridge inspection practice highlight the need to explore a fast, low-cost, quantitative and safe solution for bridge condition assessment.

Recently, remote sensing technology based on unmanned aerial vehicles (UAVs) has emerged as a promising technique to provide such a solution. It has already attracted significant attention from both federal and some state DOTs. The Federal Aviation Administration (FAA) has been working diligently to safely promote drone use to spur job growth, advance critical scientific research and save lives. The first regulations for routine commercial use of small UAVs (weighing less than 55 pounds) released by the FAA in June, 2016 are the result of this effort and are expected to create new opportunities for research communities and government use of drones. Recent research has focused on investigations to use drones for inspecting bridges, large retaining walls, dams, buildings, poles, etc. (Eschmann et al. 2013; Ellenberg et al. 2014; Hallermann and Morgenthal 2014; Hallermann et al. 2014; Khan et al. 2015; Sa et al. 2015). Different remote sensing technologies have been employed in tandem with UAVs. The most common technologies are based on optical and thermographic cameras. A number of potential applications for UAVs in infrastructure inspection have been identified, including quantitative measurement of displacement of structures (Ellenberg et al. 2014; Hallermann et al. 2014; Khan et al. 2015), detection of both surface and subsurface damages (e.g. cracks, spalling and scale of concrete, delamination) (Chen et al. 2011; Eschmann et al. 2013; Ellenberg et al. 2014), geo-referencing the collected images (Harwin and Lucieer 2012; Hallermann et al. 2014), 3D reconstruction of structures (Eschmann et al. 2013; Mauriello and Froehlich 2014; Sa et al. 2015), etc.



Given the unique potential of UAV based remote sensing technology, the proposed research aims to develop and demonstrate a UAV-based bridge inspection framework (Fig. 1). This research is expected to provide the bridge management sectors (e.g. state DOTs) with a highly efficient, cost-effective, quantitative and safe proof-of-concept for bridge inspection. The ultimate goal of this research theme is to develop an automated and quantitative bridge inspection procedure that requires minimum human intervention. The automated procedure includes data (images) acquisition using the UAV, 3D reconstruction of surface models of bridges, identification, localization and quantification of structural damage and documentation of the geo-referenced bridge inspection data in database. This end goal will be achieved in two phases of studies. The first phase is the feasibility study, while the second phase is the development of machine learning tools to fully automate the data post-processing and damage identification process. This proposal will address the first phase of this research theme.

Research Objectives:

1. Study the feasibility of UAV based data (optical and/or thermographic images) acquisition for bridge inspection, especially for bridges in remote and difficult to access locations.
2. Develop geo-referenced three dimensional (3D) surface models of bridges using images collected by UAV and evaluate the feasibility of damage identification/condition assessment using 3D surface models.
3. Develop a guideline for integrating the developed technology in current bridge inspection practice.

(1) In the feasibility study, the UAV flight around bridges will be tested to evaluate the flight time, battery life, and the ability to access various components of bridges. The efficiency of image collecting and quality of the images will also be evaluated.

(2) A three dimensional (3D) surface model of a testing bridge will be developed. The possibility of identifying/localizing damage through the model will be tested.

(3) A guideline for conducting the UAV enabled bridge inspection will be developed, including the equipment requirements, data acquisition and post processing procedures.

Research Methods:

Firstly, the possibility of autonomous flight mission through planned route around a bridge will be tested in field. This will be achieved by GPS-based navigation through pre-determined waypoints. This technology is very useful, as it permits repeatable periodic bridge inspection with low effort and high efficiency. The images of the bridge will be taken automatically by the camera installed on UAV at each waypoint. The efficiency of image collection for the entire bridge will be evaluated by measuring the total time of the inspection, including the time used for pre-flight preparation and actual UAV flight time. In the post-flight analysis, the quality of images collected by UAV will be evaluated according to certain criteria, including the resolution, sharpness, exposure, overlap etc.

Secondly, the images with satisfactory quality will be used to reconstruct the geo-referenced 3D surface models for bridges. The popular computer vision technique Structure-from-Motion (SfM) (Westoby et al. 2012; Daftry et al. 2015) will be adopted for this purpose. The SfM can automatically solve the geometry of the bridge surface and camera pose through the identification of common features in multiple images. This allows flexible image acquisition by UAV without tracking camera positions and orientation during the flight. A sparse 3D point-cloud will be generated by the Bundle adjustment package in the SfM method. Subsequently, a multi-view stereo algorithm will be applied to derive an enhanced density point-cloud. A polygon mesh will be generated based on the dense point-cloud to reconstruct the continuous bridge surface. The images collected by UAV will be geometrically corrected ("orthorectified") such that the scale is uniform. These so called orthophotos can be mapped to the 3D surface model to create a photo-realistic high resolution bridge surface model. Such obtained 3D model is subjected to scale and orientation ambiguity. Control points with known 3D coordinates will be needed to recover the actual scale and absolute coordinates of the model, so that the final 3D surface model becomes fully geo-referenced and correctly scaled. This permits seamless documentation of damage location and measurement of sizes of damaged areas. This photo-realistic 3D bridge model will be sent to professional bridge inspector to conduct the condition assessment. The results will be compared to those obtained by conventional field visual inspection, to evaluate the feasibility of conducting bridge inspection using reconstructed 3D surface model.

Thirdly, a guideline for integrating this new technology to current bridge inspection practice will be developed through discussion with CDOT and a series of pilot implementations. Strategies to integrate the inspection data with the CDOT’s existing Asset Management and data integration system will be proposed. Currently, only the locations of bridges are mapped to the basemap of the CDOT’s GIS. In this research, the conditional assessment report, post-processed orthophotos with damage information as well as the geo-referenced 3D surface model will also be mapped to the basemap, in order to support the bridge management and decision-making on budget allocation.

Expected Outcomes:

(1) A set of techniques that enables UAV based bridge inspection, including automated data acquisition and 3D reconstruction of surface models of bridges.

(2) A limited but valuable database on geo-referenced images, surface models, and conditional assessment results of the tested bridge.

(3) A guideline on UAV based bridge inspection procedure for use by bridge inspectors; the guideline may require further refinement but will pave the way for use of UAV in U.S.

(4) A full report documenting method and results will be provided and one or more TRB papers will be published in collaboration with CDOT researchers.

Relevance to Strategic Goals:

- Safety
- Economic Competitiveness

Safety – The use of UAV can eliminate the need for inspectors to climb ladders and thus provide better safety for inspectors.

Economic Competiveness – The proposed framework can reduce the costs by eliminating the use of specialized equipment such as a “cherry-picker” and reducing the worktime of inspection process.

Educational Benefits:
One graduate student will participate in the project including writing several paper and a report, which will result in part of his/her dissertation, likely combined with Phase II. He/She will gain valuable experience on developing cutting edge techniques for bridge inspection.

Tech Transfer:
The research group will establish collaboration with bridge management staff at CDOT on application of this technology (an initial meeting already took place in May 12, 2017). The developed techniques will be firstly tested on Colorado bridges. A guideline on integration of the new technology to existing bridge management practice will be developed by including the inputs from CDOT to ensure the effective adoption of the technology in practice.

Work Plan:
1. Literature Review
2. Field Test Program
3. Image Post-Processing and Development of 3D Surface Models
4. Visual Inspection Using 3D Surface Model
5. Development of An Implementation Guideline

Task 1 – Literature Review
A literature review will be conducted on relevant fields including (1) the UAV based data acquisition of bridges/large scale structures; (2) the 3D model reconstruction techniques using UAV collected images; and (3) image based visual condition assessment of bridges. The expected completion date for this task is 4 months from the project start date.

Task 2 – Field Test Program
The feasibility of collecting data of the entire bridge within the maximum flight duration of UAV allowed by the battery pack will be tested on Colorado bridges in field. The UAV flight strategy for taking high quality images with significant overlapping will be developed. The expected completion date for this task is 8 months from the project start date.

Task 3 – Image Post-Processing and Development of 3D Surface Models
The images collected in Task 2 will be post-processed using the SfM method to reconstruct the 3D surface model of the bridge. The expected completion date for this task is 12 months from the project start date.

Task 4 – Visual Inspection Using 3D Surface Model
The 3D surface model will be used for bridge condition assessment and the results will be compared with those obtained from conventional field bridge inspection to test the efficacy of this UAV-enabled technique. The expected completion date for this task is 20 months from the project start date.

Task 5 – Development of An Implementation Guideline
A guideline on UAV-enabled bridge inspection for use by bridge inspectors will be developed. The strategy on integrating the UAV-enabled bridge inspection framework with the CDOT's existing Asset Management and data integration system will be proposed. The expected completion date for this task is 24 months from the project start date.

Project Cost:

Total Project Costs:	$114,000
MPC Funds Requested:	$57,000
Matching Funds:	$57,000
Source of Matching Funds:	Faculty time and effort

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