Transportation Infrastructure Assessment Through the Use of Unmanned Aerial Vehicles

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ABSTRACT

Advances in unmanned aerial vehicle (UAV) technology have enabled these tools to become easier to use and afford. In a budget-limited environment, these flexible remote sensing technologies can help address transportation agency needs in operations, maintenance, and asset management while increasing safety and decreasing cost. The ever expanding diversity of types and sizes of UAVs also allows for their application to a variety of transportation needs. This paper will cover UAV applications for traffic monitoring using a blimp, confined space assessment using a micro quadcopter, and bridge deck inspection using a hexacopter to loft a high resolution digital camera and thermal camera. These demonstrations showed that UAV technologies provide many advantages to helping transportation agencies cost-effectively assess, manage, and maintain its resources, providing benefit to staff and the traveling public.
INTRODUCTION

Unmanned Aerial Vehicles (UAVs) have become a useful tool to carry a variety of remote sensing sensors (1-6). With advances in UAV technology and reduction in cost, they have the potential to supplement and improve current transportation assessment methods. This paper focuses on demonstrations and results developed through a UAV evaluation research project funded by the Michigan Department of Transportation, which focused on three applications in its recently completed first phase: traffic monitoring, confined spaces, and bridge deck inspection.

Traditional traffic monitoring cameras are mounted on mast poles near intersections or stretches of highway that are known to be congested. While useful, these cameras require the installation of mast poles to support the cameras and network infrastructure to transmit the signal to a traffic operations center (TOC), not to mention legacy operations and maintenance issues. While these permanent camera systems are successful in providing long-term monitoring of parts of the transportation network, they are not optimal for shorter-term events such as construction zones and large sporting events. A UAV can be easily moved to areas where additional traffic monitoring is needed that is lacking coverage with the traditional mounted cameras. This flexibility would allow a transportation agency to keep track of areas where it is known there will be short term congestion instead of investing in a permanent structure.

Confined spaces inspection which includes pump stations and culverts are not considered to be a traditional use for UAVs. However, with advances in technology, there are UAVs small enough to be flown into these locations that can send out useful data. Pump stations along freeways can be hazardous to inspectors after major storm events or power outages. An example of these types of events would be the flooding of the Detroit area freeways during storm events in August 2014 (7). A small UAV has the capability of flying into a pump station while transmitting video back to the inspector without the inspector entering, to help determine if it is safe to enter. Micro UAVs are small enough to fly through doorways, hatches and other small openings. These UAVs are typically less than $200 and if lost in a pump station are easily replaced. They would also help keep inspectors safe as they would not have to enter into the stations without knowing what the conditions are first.

Traditional methods of inspecting bridge decks typically include having two inspectors walking along the shoulder or sidewalk on a bridge and visually inspecting the deck surface (8). For inspections for subsurface delaminations, traffic lanes on the bridge are normally closed to traffic while inspectors perform hammer sounding or chain dragging. With these methods bridge inspectors are routinely exposed to traffic. Furthermore, visual assessment of bridge decks for spalling can be inaccurate as the inspectors have to estimate the size and depth. It has already been shown how remote sensing techniques from vehicle based systems can provide accurate measurements of distresses as well as keep inspectors safe and reduce traffic impacts (9, 10)). UAVs offer another method for assessment where they can be flown over the bridge decks to collect optical and thermal imagery for both surface and subsurface inspection.

METHODS

Traffic Monitoring

Blimps (aerostats) can provide a persistent observation platform where traffic monitoring cameras would be useful but the time and cost to install the cameras is prohibitive or not desired on a long-term basis. Unlike other types of UAVs (multi-rotor, fixed-wing, or single-rotor systems) which need a constant power source to stay aloft, once filled with helium, blimps do not require batteries or a power cable to operate (however, on board sensors need power). Therefore there only restriction on “flight” time is the length of time in which the helium leaks out and it is no longer able to lift the payload. This still enables a blimp to remain on station for several days at a time, with sensor provided power through a cable or recharged periodically with fresh batteries.

For demonstration purposes an advertising blimp was used (Figure 1). The blimp was 4.5 meters long and 1.7 m in diameter; it requires about 8.5 cubic meters of helium (just about one tank of helium) to fill. The net lift is 3.6 kilograms and its working lift is approximately 50 percent of net lift or 1.8 kilograms. This was enough to allow for a three-axis gimbal and a 20 mp camera with 1080p video and a
built-in “4G” mobile data connection (the Samsung Galaxy camera) to be attached (Figure 2). The camera transmits video for display using the 4G connection that can be displayed in near real time via a streaming service (such as UStream, used in this project) that is accessible web browser. The blimp setup was used to stream several hours of traffic video during the project.

FIGURE 1: The blimp being launched for a test flight with the gimbal and camera are visible underneath.

FIGURE 2: The gimbal and camera assembly under the blimp. The battery on top of the gimbal supplies power to the gimbal.
The altitude of the blimp and the focal length of the camera lens can be adjusted to optimize the field of view for each deployment site. Once moored in place, a camera mounted to the blimp on a 3-axis gimbal can provide stabilized video which can be transmitted back to a traffic operations center (TOC). The Michigan Department of Transportation (MDOT) worked with the project team to connect the video feed to a booth of the TOC for demonstration at the 21st World Congress on Intelligent Transportation Systems (ITS) held in Detroit in September 2014.

**Confined Space Assessment**

Pump stations are confined spaces providing access to pumps that keep water off roadways during storm events, where there is usually a small doorway or hatch for entry. The interior can be 3m or more in diameter with pipes or other obstruction making it difficult for larger more traditional UAVs to operate. Micro UAVs which could fit in the palm of a hand are ideally suited for this environment (Figure 3). They come equipped with a small cell phone style camera which could either record video, transmit video back to a cell phone (usually via WiFi), or both depending on the model.

With their small size and video transmitting capabilities they can be flown through the hatch of a pump station ahead of an inspector to ensure the environment is safe for inspectors before inspections after flooding events. Micro UAVs such as the Heli-Max 1 Si and the Walkera QR 100S were demonstrated in pump stations along I-696 in the Detroit area.

**Bridge Deck Inspection**

UAV inspections were conducted over two bridges which were closed to traffic (to comply with Federal Aviation Administration (FAA) safety and operations rules) along with the freeway underneath. Both the bridges and freeway were already completely closed for repairs as part of the “I-96 Fix” project in Livonia, MI. This large 11-km long project allowed for the UAVs to be flown over bridges without vehicles driving under the collection area. The bridges were also scheduled entirely or in part to be replaced as the decks had low National Bridge Inventory (NBI) ratings. For these collects, a Bergen Hexacopter was selected as it has a payload capacity of 4.5 kg, a two-axis gimbal, and a flight time of up to 20 minutes. It also has an integrated GPS which helps it maintain its position while flying. The GPS also offers a return to home safety feature if it should lose connection with the remote. In this situation, the Hexacopter will ascend to 45m fly back to and land at the point it started from.

For optical inspection, a Nikon D800 DSLR, which has a resolution of 36.6MP, fitted with a 50mm prime lens was selected as this combination has shown that it can provide sub centimeter resolution imagery from an altitude of 30m (1). A small GPS was attached which geotagged the imagery for geospatial referencing. Imagery was collected at one frame per second as the Hexacopter flew at 2 meters/sec which provided at least 60% overlap for processing in 3D photogrammetric software such as Agisoft PhotoScan. Agisoft PhotoScan would provide a Digital Elevation Model (DEM) and an
orthoimage of the entire bridge deck which was used to locate and characterize the spalls on the bridge deck. At least four control points recorded with decimeter-accuracy Trimble GeoXH units were recorded for each bridge to provide higher-accuracy positioning than onboard GPS. The DEMs were run through a spall detection algorithm (10) to locate the spalls on the bridge deck.

Thermal imagery was collected using a FLIR Tau 2 camera with a resolution of 336 x 256 pixels. Attached to the Tau 2 was the TeAx ThermalCapture module which captures and stores the thermal image frames in a local USB memory, as 14 bit binary files, at rates up to 1.2 frames per second. Processed thermal imagery was mosaicked and georeferenced as geotiff files to the orthoimage created from the Nikon D800 imagery. This allows for both data sets to be displayed spatially in a geographic information system (GIS) for a complete view of surface and subsurface distresses.

RESULTS

Traffic Monitoring

The Traffic monitoring blimp was set up along US-23 in Ann Arbor, MI and at the ITS World Congress event on Belle Isle in Detroit, Michigan in 2014. The blimp has a Samsung 4G digital camera slung underneath it, with the built-in Verizon 4G providing the capability to transmit the video over the cell phone network. This video was sent to the Ustream web-based image streaming service using the USTREAM app that was installed on the Samsung 4G camera. With a small delay of 10-15 seconds, the Ustream service then makes the video available for access via their web page, with secure (password-protected) access possible.

The video from US-23 was used to show traffic patterns of the freeway as the blimp was on station for several hours at a time. Figure 4 is an extracted frame from the collected video. The three-axis gimbal not only stabilized the imager but it was also able to keep the camera pointed in the same direction independent of the movements of the blimp. The gimbal was also controlled by a standard RC controller which allowed for the cameras viewing angle to be changed while in the air.

![Figure 4: Views of US 23 and Plymouth Road looking North (A) and South (B) from the blimp (altitude approximately 36m) during a test flight.](image)

Confined Space Inspection

Both micro-UAVs were deployed to multiple pump stations in the Detroit region to collect imagery. They were successful in flying through small openings and though the pump stations. Figure 5 shows the Heli_Max 1 Si being flown through an opening which was approximately 1m wide. Once in the pump station video was collected from the Heli-Max 1 Si while the Walkera QR 100S demonstrated the video being transmitted back to the operator’s cell phone (Figure 6).
FIGURE 5: The Heli-Max 1Si passing through the opening (A) and into the lower section of the pump station (B).
There were some difficulties encountered with flying into and through small spaces. The first is the turbulence created from the micro-UAV’s rotors which could disrupt the air around it while flying through a small opening. This effect can lead to the UAV becoming unstable and difficult to fly. This is easily avoided by passing through the opening quickly so that the turbulent air does not have a chance to affect the UAV. Another issue is if the UAV gets too close to the wall or a large object. In this case the turbulence will actually pull the UAV towards the wall or object. This leads to the UAV hitting the wall and potentially losing control. When “sense and avoid” technologies reach small inexpensive UAVs, the authors anticipate this being less of an issue as they will be able to remain a specified distance from the obstacle.

**Bridge Deck Assessment**

Imagery was processed through Agisoft Photoscan to create sub-centimeter 3-D models of the bridge deck to help locate distress features such as spalls (potholes). The merged product is a high-resolution (2.5 millimeters) orthorectified image, with visible spalls and patchwork. Likewise the DEM is also a product of the Agisoft Photoscan processing and has a resolution of 5mm. The reduced resolution is due to the processing level selected. Agisoft Photoscan has the capability to produce DEMs at the same resolution as the input imagery but this also requires significantly more time. A dense point cloud processing of “Medium”, which is roughly half the input imagery resolution, is usually selected as it is a good compromise between output resolution and time required for processing. A hillshade representation of the DEM was also created using ArcGIS. The hillshade displays the DEM in 3D so that it is easier for the user to visualize the output. This creates a visual height difference output that aids in quick differentiation between the bridge deck and spalls. The orthoimage and hillshade representation of the DEM for Merriman East U-turn Bridge are shown in Figure 7.
FIGURE 7: Orthoimage (A) and hillshade (B) of the Merriman East U-turn Bridge.

The DEM is processed through the spall algorithm to detect minor (defined) differences in elevation, which was created to automatically detect and quantify the amount of spalling on the bridge deck, and to produce a GIS shapefile output. For the Merriman East U-turn Bridge, it was determined that a total area of 14.0 m² of the bridge deck was spalled, which equates to 4.4 percent (Figure 8). The algorithm does not detect all of the patching on the bridge’s surface, resulting in a lower spalled area than if this was included – but as patched areas are not usually included in spalling amounts, this is the correct result.
FIGURE 8: Automatically detected spalls on the Merriman Road East U-turn Bridge.
These totaled 14.0 m² of the bridge deck, or 4.4% of the total deck area.

The high resolution and georeferenced orthophotography was used as the base layer to georeference the individual thermal image frames, captured by the Tau2 camera during the UAV flight. Georeferencing of the thermal images was done in ArcGIS, using reflective duct tape marks located on the bridge deck for that purpose. This enabled the thermal data to be laid directly on top of the optical bridge photos, enhancing image interpretation and usefulness of the data. The reflective tape marks are...
easily distinguishable in both the visible and the thermal images, and therefore can be used as tie-points between both datasets. Other distinctive and naturally occurring features that could be identified in both datasets were used in addition as tie-points for the georeferencing process.

Figure 9 shows the coverage of thermal imagery for the Merriman Road East U-turn Bridge overlaid on the visible orthophoto mosaic. Although the majority of the bridge is covered, due to a lack of real-time first-person-view for UAV operation of thermal image capture, led to parts of the bridge deck not being covered by the thermal imagery. The thermal imagery shows the complex and patchy structure of the bridge deck surface, caused in part by the many patches of repaired pavement and by pot holes and other surface discontinuities. Differences in patching material are reflected as differences in radiance values at the sensor, and although some may correspond to actual differences in temperature (some materials will absorb more radiation and heat up more by the solar radiation), some of the differences are likely to be mainly due to differences in the surface emissivity (11). This complexity provides a challenging testing ground for the delamination classification methods, but subsurface thermal anomalies can still be detected, especially when compared to bridge deck surface optical imagery (10).

FIGURE 9: Georeferenced thermal imagery acquired through the Tau2 and ThermalCapture camera system mounted on a UAV, overlaid on high resolution orthophotos, also acquired from the same UAV platform for Merriman East U-turn
CONCLUSION

An applied research project was completed in collaboration with the Michigan Department of Transportation to evaluate how unmanned aerial vehicles could help with meeting the data collection and condition assessment needs of the Department. This paper reviews example results of the main focus areas, which were traffic monitoring, confined space inspection, and bridge deck assessment. Additional details are available at http://www.mtri.org/mdot_uav.html and in a detailed project final report (9), including LiDAR data collection via UAV, an automated sign inventory example, and other project results.

MDOT has found the results useful for potential use in operations, maintenance, and asset management, and has funded a second phase of the project, entitled “Implementation of Unmanned Aerial Vehicles for Assessment of Transportation Infrastructure”, under the continued direction of program manager Steve J. Cook, P.E. This second phase includes implementation of first-person capabilities for thermal data, integration of UAVs into two to three business functions, deploying near-real-time data collection communication tools, development of an operation guidance document, a return on investment cost/benefit analysis, and operations under updated FAA UAV “Part 107” rules.

REFERENCES


