Deliverable 10-A: Commercialization Report on AURA for Day-to-Day Operations

Michigan Technological University

Characterization of Unpaved Road Condition Through the Use of Remote Sensing Project

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Table of Contents

List of Figures

Section I: Introduction

This report describes advancements made by the research team to commercialize the Aerial Unpaved Road Assessment (AURA) system. The project team has been actively engaging with aerial services companies who would offer AURA as a third-party service to transportation agencies and others needing high-resolution road condition assessment, such as mining companies wanting to monitor haul roads. Woolpert, Inc., a project partner, has shown considerable interest in licensing the AURA system and has been important in helping provide input from a commercial firm on practical day-to-day operations. Woolpert team members coordinated a commercialization field test at a gravel mine site near Sidney, OH with a company interested in site and road monitoring. Woolpert has been the logical partner for demonstrating and evaluating operational potential because they have a blanket Certificate of Authorization (COA) from the Federal Aviation Administration (FAA) under one of the country's earliest Section 333 commercial unmanned aerial vehicle (UAV) exemptions that covers most of rural Ohio.

Section II: Commercialization Field Test

Site Details

The two commercialization field test sites were located in Sidney, OH (Figure 1) at the site of a gravel mining company interested in commercial UAV applications such as volumetric calculations of gravel piles and assessment of road condition. Both sites contained aggregate mining haul roads that were unpaved. We chose these sites for several reasons:

1. The mining industry uses heavy machinery that requires haul roads to be well-maintained and rebuilt often. This stood out as a high-potential commercialization opportunity.

2. The heavy machinery used on the haul roads creates prominent and visible stresses (potholes, trenches, bank failures, etc.).

3. The site was within Woolpert's blanket COA. The site was a closed construction sight and non-participants were a not an issue.
4. A successful demonstration here could be used to help offer commercial services that include AURA system capabilities for gravel mining companies and similar opportunities in Ohio and elsewhere.

The northern gravel mining site was approximately 0.2 miles (east-west) x 0.3 miles (north-south). The site contained several haul roads and also contained several aggregate piles. These piles were beneficial to the collection because they lend themselves to a secondary commercialization opportunity that can be derived from the same imagery used to analyze haul road conditions. This secondary commercialization opportunity is the volumetric measurements of the aggregate piles – countless hours are spent monitoring inventory as new material comes in from the dredge or quarry and goes out to paving and other aggregate customers. These unmanned aerial data collects will provide the mining industry a better safer workflow for asset management and inventory tracking, as well as indisputable visual records for insurance purposes.

Figure 1: An overview of the commercialization test field sites near Sidney, OH.

The southern site contained a haul road that was approximately 0.5 miles in length. This section of haul road contained “control potholes” to allow for objective measurements in the three-dimensional image products produced by each of the platforms (Figure 2). The smallest pothole measured 6” (diameter) x 3” (depth). The second pothole measured 12” x 6”. The third pothole measured 18” x 6”. All potholes were dug to be cylindrical in shape.

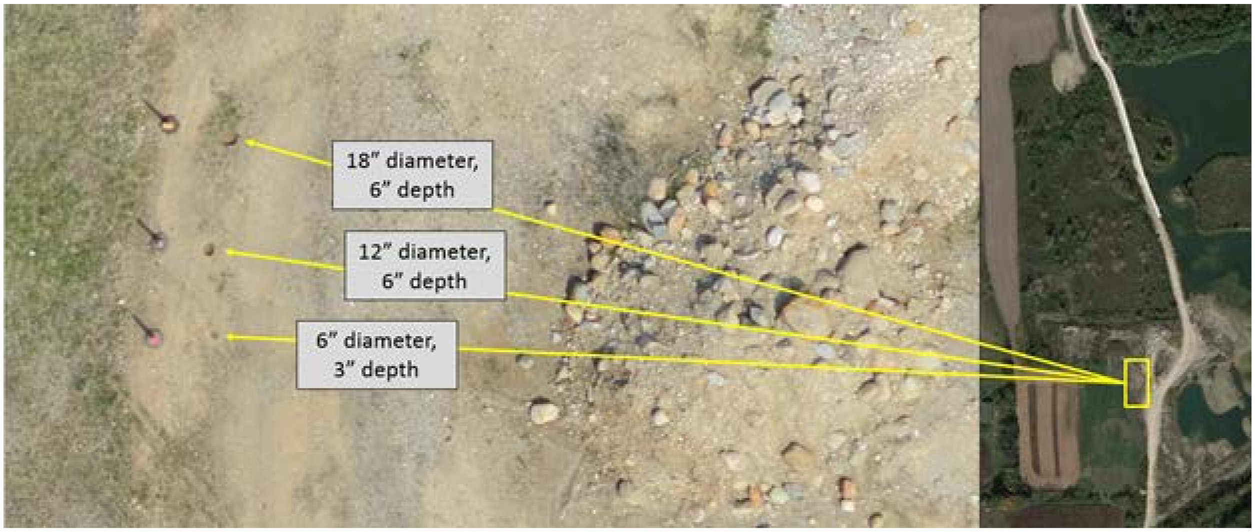

Figure 2: Overview of control potholes made at the southern test site.

Field Collection & Data Processing

Collection Platforms

1. Kespry (multi-rotor system owned by Woolpert, with similarity to the AURA system's Bergen hexacopter):
    a. Platform and Sensor: The Kespry is a small-medium sized quad-copter with an integrated Sony Alpha SLR natural color camera (Red/green/blue RGB-only).
    b. Logistics: There are two cases for the complete Kespry system – one for the platform, and one for the ground control station (GCS). Both are person-portable and are easily transported for deployment to any location.
    c. Workflow:
        i. Planning: Flight planning for the Kespry is done on an iPad. The user draws a perimeter around the area of interesting (AOI) and selects a Ground Sample Distance (GSD). The flight planning software takes care of the rest, such as the planned flight path.
        ii. Collection: Collection is fully automated. Once the flight planning is complete, the user executes the flight plan with the push of a button on the iPad. The Kespry unit operators autonomously, with an operator at the controls prepared to take over in case of unexpected issues.
        iii. Processing: When the collection is completed and an internet connection is available, the Kespry unit uploads the imagery to the Kespry Cloud and the 3D image products and 2D orthomosaic are automatically created and delivered to the user. This is advantageous in its simplicity, but disadvantageous because the user does not have the ability to influence processing (manually tie points between images, add ground control, move seam lines, refine color balancing, etc.).
        iv. Data Delivery: The data is delivered to the Kespry Cloud. Users access the data via browser with a username and password.
    d. Results: 3D image products and point clouds, and 2D orthomosaics are complete. Detection of road distresses using the AURA system's Remote Sensing Processing Software (RSPS) is ongoing.

Figure 3: Kespry quadcopter hovering.

2. Vireo (Woolpert-owned system):
    a. Platform and Sensor: The Vireo is a small, fixed-wing, single-prop unmanned aerial system. The Vireo has a swappable payload. A Sentera Quad, 10.5 MP CMOS camera sensor was used to collect RGB imagery.
    b. Logistics: The Vireo was the most difficult system to deploy, as it required significantly more equipment to operate.
    c. Workflow:
        i. Planning: The flight planning of the Vireo was done on a laptop. The software was not as robust as the Kespry software, and was not equipped to satisfy the flight planning requirements for imaging of unpaved roads. Most notably, the flight planning software did not allow the user to adjust the frame rate of the camera. Thus, forward-lap was insufficient to process the imagery as altitude was decreased (altitude was decreased to increase GSD).
        ii. Collection: The insufficient forward-lap between images prohibited the Vireo imagery from producing a useful 3D imaging product.
        iii. Processing: n/a
        iv. Data Delivery: n/a
        v. Results: The Vireo, in its current state, proved to be a poor candidate for high-resolution corridor mapping. Other than some standalone JPG images of the site, no other data products were created.

Figure 4: Vireo fixed-wing UAV being hand launched.

3. Surrogate Unmanned Aerial System (SurrUAS):
    a. Platform and Sensor: The SurrUAS is a small, manned-aircraft (Cessna 182) equipped with a sensor pod. The sensor pod contained a Nikon D800E SLR – a sensor that is very common among a wide-range of UAS platforms, including with the AURA system’s Bergen hexacopter.
    b. Logistics: The logistics of the SurrUAS were very simple and required only one person for collection (the pilot). No ground station was required, and the data collection was completed in less than two hours. No personnel were required on-site to support the SUAS.

    c. Workflow:
        i. Planning: The planning was completed using open-source QGIS software on a laptop. The planning was done prior to deployment and was loaded into the Cessna's Garmin navigation system.
        ii. Processing: The processing was completed using SimActive's Correlator 3D processing suite.
        iii. Data Delivery: The quantity of data captured by the SurrUAS required imagery to be delivered via hard drive.
        iv. Results: 3D image products and point clouds, and 2D orthomosaics are complete. Detection of road distresses using the AURA system's Remote Sensing Processing Software (RSPS) is ongoing.

Figure 5: Surrogate Unmanned Aerial System with sensors mounted below the aircrafts fuselage.

4. Bergen Hexacopter
    a. Platform and Sensor: The Bergen Hexacopter is a heavier-lift hexacopter with a two-axis gimbal capable of carrying multiple payload types, used as the primary system in AURA system development. For unpaved roads data collects the Hexacopter is mounted with a Nikon D800 digital SLR camera with 36 mp resolution.
    b. Logistics: The Bergen Hexacopter has folding arms which makes it easy to transport in any vehicle.
    c. Workflow:
        i. Planning: Flight planning software is not necessary as the Hexacopter is flown manually for data collection missions. It is capable of autonomous flight as well.
        ii. Collection: The Hexacopter was flown manually down the unpaved roads with one operator and one spotter. The spotter also monitored the First Person Viewer (FPV) screen to ensure the road was within the cameras field of view, check battery voltage, altitude and UAS speed.
        iii. Processing: Imagery processing was completed in the AURA system's Remote Sensing Processing System (RSPS), and in the commercial Agisoft PhotoScan and Correlator3D software tools for comparison.
        iv. Results: Raw imagery or point clouds from other software are run through RSPS.

Figure 6: Bergen Hexacopter ready for data collection at the southern mine site.

Data and Processing Results

All of the collected imagery was processed through commercial Structure from Motion (SfM) software for comparison except for the Vireo fixed-wing UAS that did not produce data meeting AURA system requirements. Imagery from the Vireo was not processed as it was not able to obtain sufficient overlap of the imagery for SfM processing. Figure 7 shows a comparison of the orthoimagery from the southern mine site. All three data products are of similar resolution and quality. The collected imagery resolution from the Bergen Hexacopter is 0.3 cm, Kespry is 1.6cm and the Surrogate Unmanned Aerial System is 2 cm. Based on the assessment conducted in Deliverable 5-B: “Review and Update on AURA System Requirements, Sensors, and Platforms – Supplemental Report” each of these three UAS are capable of capturing imagery with sufficient resolution for making high resolution distress characterizations developed in Phase 1 of this project. With the requirement of a minimum DEM resolution of 2.5cm (1 inch), imagery from the Kespry and the Surrogate Unmanned Aerial System can be processed through commercial SfM software such as Agisoft to produce point clouds at the resolution of the input imagery.

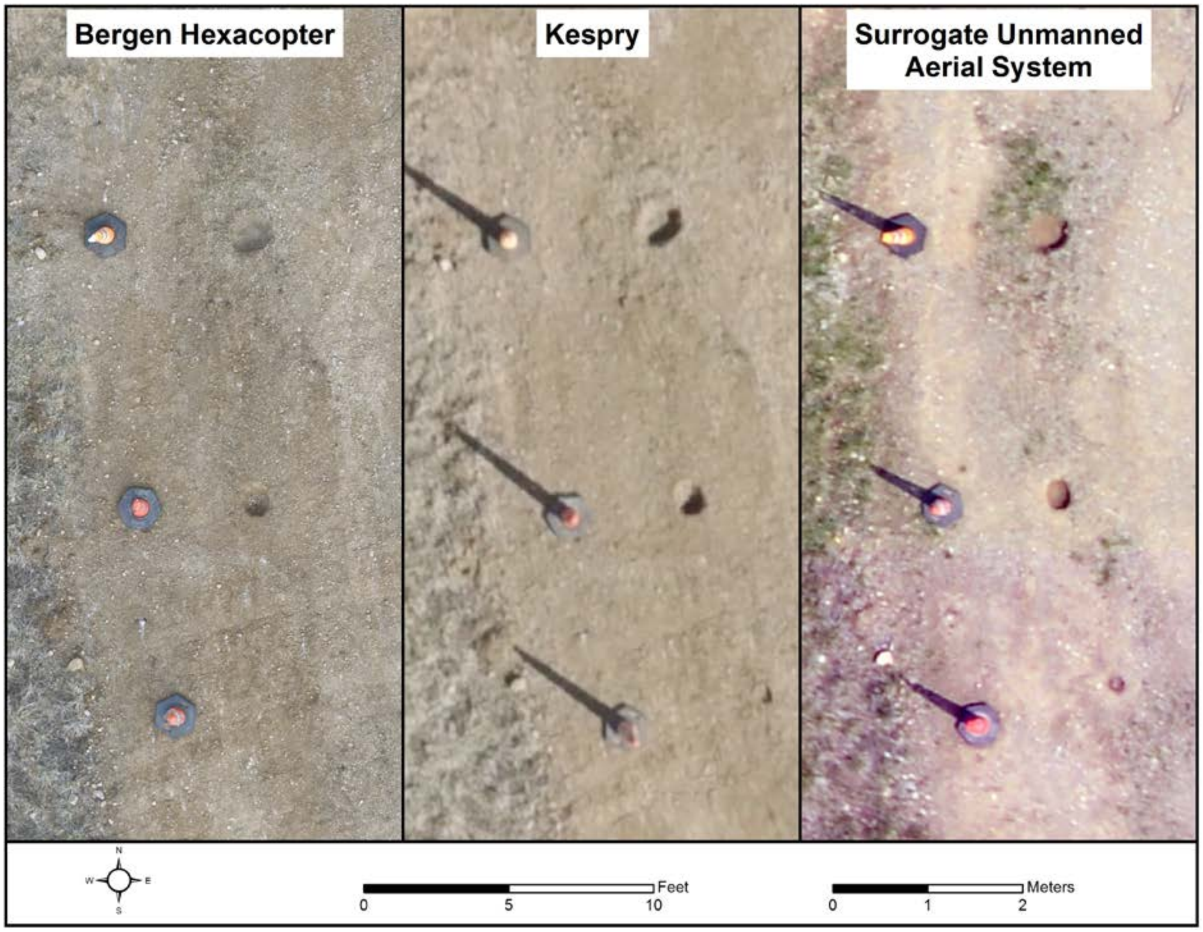

Figure 7: A comparison of the output orthoimages from the Bergen Hexacopter (Left), Kespry (Center), and the Surrogate Unmanned Aerial System (Right).

Section III: Outcomes of Commercialization Field Test

Target Markets

Several target markets exist for the characterization and analysis of unpaved road conditions. The industries that will benefit most from the AURA system technology are, not surprisingly, the industries that are affected monetarily from poor road conditions. This includes the mining, forestry, and oil and gas industries. Those responsible for rural and residential roads, such as local and state transportation agencies, are also potential beneficiaries of this technology, especially when a mandate exists to collect road condition data as part of an asset management strategy. The amount of time that transportation agencies spend fielding road condition complaints, searching for problem areas, and making repairs can be extremely costly.

UAS combined with AURA system technologies represents a significant potential cost savings, as previously discussed in Deliverable 7-B (“Performance Evaluation of Recommended Remote Sensing Systems in Unpaved Road Type Condition Characterization”, http://geodjango.mtri.org/unpaved/media/doc/deliverable_Deliverable_7_B_PerformanceEvaluation_Final_2013-11-27_updated_1.pdf). This report found that using the AURA system for unpaved road condition assessment could cost as little as $0.74 per mile if using the representative road segment concept, and

$19.42 / mile for evaluating every part of a one mile road stretch, still far below the cost of equivalently detailed data (at least $66.10 per mile).

Barriers to Commercialization

1. FAA Restrictions: See above; the ability to operate longer distances and over non-participants is needed for more widespread commercialization.
2. Processing Time: The sheer amount of data from a single collection makes data processing the current workflow bottleneck. As the clientele grows, it will be imperative to have a cloud-based storage and processing solution that is scalable to meet demand. This will also allow for a multitude of custom processing offerings as well. For example, if a customer requires a quick-turn processing solution, more processing power can be allotted to their job - for an appropriate price. Processing on local computer workstations, even with 20+ CPUs and 128-gigabytes of memory can still take two to three days of processing time. Processing in the cloud, where CPU power and memory can be added as needed, takes the process down to a few hours for large data collections.
3. Cost:
    a. Autonomy: As FAA restrictions ease, UAS autonomy will be the key to keeping operating costs low. With the requirement for an observer and licensed private pilot no longer present, the manpower costs for long-distance corridor mapping will be drastically reduced. The proposed FAA small UAS rules, due out by the end of June, 2016, should change the current licensed pilot requirement to a UAS operators permit instead that the FAA estimated as having only a $300 cost.
    b. Hardware: In order to scale the business model, a low-cost, widely available UAS is recommended. Multi-rotor systems such as the Kespry quadcopter and Bergen hexacopter meet this need for camera payload requirements (AURA requirements are for at least a 24-mp camera, with 36-mp preferred).
    c. Data Storage and Processing Costs: A cloud-based solution will likely be required to keep data storage and processing costs low and processing times reasonable. Processing within a single day is the new expectation for many end users. The multiple cloud storage options provided by Amazon Web Services have proven cost-effective for Woolpert’s large-scale mapping storage and processing needs. The Michigan Tech is investigating cloud-based processing for its larger data analysis needs.

Strategies for Commercialization Success

In each of these industries, the strategy for AURA system commercialization needs to be prevention of having poor road conditions impacting operations. For example, the AURA system algorithms should be utilized to detect potholes of a size that have not yet impacted operations at a mine site. For the transportation agency market, the AURA system would need to detect potholes of a size that have not yet caused transportation delays or customer complaints. By detecting smaller irregularities, necessary repairs can be made before money is lost as part of asset management methods.

A second strategy for commercialization needs to be data organization and prioritization. As restrictions ease, UAVs has the potential to cover vast areas in a small amount of time. This will, no doubt, produce very large amounts of data. It will be critical for the provider of this information to organize and prioritize the areas that require repair in some way, and to store data locally in a reasonable way (such as finished products). For example, if thousands of miles of roads are analyzed monthly, it may be prudent to prioritize and organize repairs based on condition severity, traffic density, degradation potential (high-traffic and high-moisture areas, for example), etc.

Section IV: Path to Commercialization

For commercialization of the AURA system there are two major components, 1) the UAS platform and 2) the RSPS that itself contains two major components: A) the 3D data processing using SfM and B) the distress detection and severity rating algorithms. The type of UAS used impacts the sensors available for the data collection due to weight and payload size limits on different platforms. This in turn impacts the quality and resolution of imagery to be collected for analysis. The RSPS is currently able to process imagery from any camera but resolution is a key factor in making the detailed measurements (1” resolution) of road distresses as defined in Deliverable 1-A: Requirements for Remote Sensing Assessments of Unpaved Road Conditions. For this reason multiple UAS was assessed for the commercialization field testing.

AURA UAV System

Platforms: The platforms used in this effort can be grouped into three distinct categories:

- a. Fixed Wing UAS
- b. Rotary Wing UAS
- c. Surrogate (manned) UAS

The Fixed Wing UAS has inherent disadvantages for commercializing the AURA system developed by MTRI. First and foremost, a fixed-wing platform requires significant forward velocity (relative to a rotary wing) in order stay aloft. This is ideal for larger, rectangular collections where the UAS can utilize its speed to “mow-the-lawn” efficiently. However, for ultra-high-resolution corridor mapping and 3D modeling, a slower, more agile system is ideal. A fixed-wing also requires a cleared (and soft) area for landing. Unpaved roads are often located in areas surrounded by dense tree lines or other unsuitable terrain where this is not possible.

A multi-rotor UAS is better suited for high-resolution corridor mapping. Although the run-times are half that of a fixed-wing at about 20 minutes, the stable, agile, and heavier-lift nature of the platform make up for this shortfall. Having additional battery packs helps limit the impact of this battery life. The image products produced from the Kespry, Bergen Hexacopter, Vireo, and Altavian (used in previous collects) confirm this.

In general, until the FAA eases UAS restrictions, both fixed-wing and rotary-wing platforms have significant limitations in their commercialization potential. The non-participant, pilot-only operation, and beyond-line-of-site restrictions must be changed in order to scale the technology in a way that allows industry to operate at a profit. Until that time, we recommend a hybrid approach for the commercialization of the AURA system technology:

1. Utilize a multi-rotor UAS when the terms of current FAA rules permit effective data collection (based on the specifics of Section 333 exemptions), and when the non-participant and beyond-line-of-site restrictions do not slow acquisition time.
2. When it is impractical or not possible to fly UAS, utilize a Surrogate UAS platform to acquire the imagery. As the FAA restriction ease, the technical and financial benefit of flying multi-rotor UAS over Surrogate UAS will increase, providing simpler, less expensive operations.

AURA RSPS

The Remote Sensing Processing System (RSPS) was developed by project team during the first phase of the project. This software was originally designed to process overlapping imagery captured by a UAV and provide an XML file which characterizes the detected unpaved road distresses in a “damage report”.

Processing is completed in two parts, first a 3D model is reconstructed using Structure from Motion (SfM) algorithms and second the model is then run through a series of distress detection algorithms developed by the Michigan Tech team. As mentioned in recently submitted Deliverable 5-B-Supplemental report evaluating fixed wing options, UAS (such as the Kespry) can be purchased with a variety of often tightly-integrated commercial SfM software or the aerial services firm may already have SfM software with their easy to use interfaces. Because of this the project team is working to separate the two parts of the RSPS so the distress detection component can operate as a stand-alone software and can process any 3D point cloud generated from other software.

Many UAS manufacturers have tightly integrated software (Kespry and Sensefly eBee systems, for example) that creates a 3D image product automatically for the user. If burdened with another image processing solution, this may detract from the AURA system from an end-user perspective. For commercialization, we have recommended that the AURA system accept industry-standard 3D image products (LAS and PLY files, for example), and produce actionable intelligence from them with its distress algorithms. As part of closing project activities, the Michigan Tech team is developing examples of how 3D point cloud outputs from SimActive's Correlator3D, ESRI's new Drone2Map software (which uses Pix4D), and Agisoft Photoscan can be run through the RSPS distress detection and severity algorithms.

These steps are designed to improve the opportunities for commercialization by enabling a third-party service partner to use their own SfM software, but then use the RSPS distress algorithms through a software licensing agreement. Software licensing is designed to produce a small revenue stream to the Michigan Tech inventor team who would dedicate the funds to answering questions from AURA system users (i.e., providing support) and help enable future improvements to the software, such as developing a user-friendly interface to the distress algorithms component.

Comparison of Agisoft and AURA system RSPS point clouds

As a step in demonstrating that the distress detection algorithms can work with any point cloud with suitable resolution, Figure 8 shows the same stretch of a Phase I study site (Piotter Hwy in southeast Michigan) processed with the AURA system's Structure from Motion implementation (top) and via the commercial AgiSoft Photoscan (bottom). Both software solutions produce a sufficiently dense point cloud appropriate for analyzing with the RSPS distress algorithms that can then be used to produce the XML "damage report" of that road segment. This is a significant advancement towards commercialization.

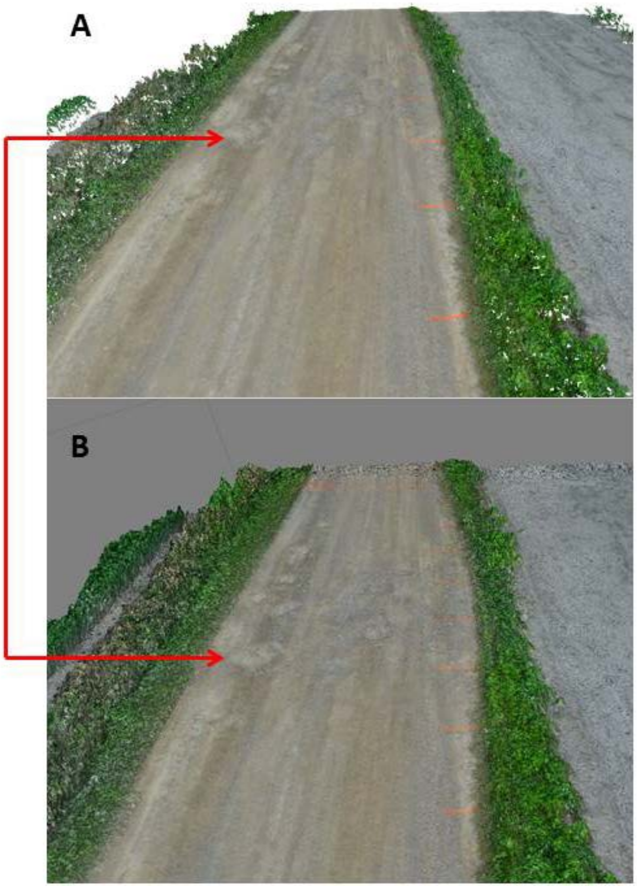

Figure 8: A comparison of the point clouds generated by the RSPS (A) and Agisoft PhotoScan which is a commercially available SfM software (B). The red line identifies the same pothole on each point cloud.

RSPS Distress Detection

Since the point clouds generated from other SfM software is similar in quality to those produced by RSPS, the distress detection portion of the algorithm characterizes the distresses with the same accuracy. Figure 9 shows an example XML “damage report” output from the section of Piotter Hwy shown above. As noted, the project team is currently working on separating the RSPS software so the distress detection portion will function as a stand-alone software able accept 3D point clouds from any commercial SfM software, which should help with commercialization efforts.

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        <Units>count</Units>
      </Type>
      <!--potholes-->
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        <Quantity>0</Quantity>
        <Units>count</Units>
      </Type>
      <!--potholes-->
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        <Quantity>0</Quantity>
        <Units>count</Units>
      </Type>
      <!--potholes-->
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        <Severity>N</Severity>
        <Quantity>1</Quantity>
        <Units>count</Units>
      </Type>
    </DistressTypes>
  </inspection>
</inspections>
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Figure 9: An example of the XML output from RSPS run on the Piotter Highway point cloud and categorizing detected potholes into severity categories. For example, one high-severity ("H") pothole was detected in this stretch.

Section V: Other Commercialization Efforts

The project team has also been pursuing commercialization of the AURA system with other businesses both within and outside the United States. These business contacts have come from either presenting the AURA system at conferences or through outreach and demonstration activities in South Dakota and Kansas. To date, there have been two companies (beyond Woolpert) that have shown strong interest and started discussions with Michigan Tech for licensing the AURA system. Two other companies from South Dakota demonstrations and one from Kansas also expressed interest, but did not select to move forward as far as licensing discussions. After the recent AURA system e-mail "blast" to UAV services companies that was organized by Valerie Lefler, two additional companies (one in Nevada and one in Arizona) have expressed interest in using AURA system technology on a commercial basis and are currently looking opportunities to use it as part of project bids.

RDO Integrated Controls (Bismarck, ND) - http://www.rdointegratedcontrols.com/

The project team first met with representatives of RDO Integrated Controls at the 30th Annual Regional Local Road Conference in Rapid City, SD in September of 2015. An AURA system demonstration was held the day prior to the conference and as well as a presentation and a vendor booth during the conference. With outreach professional Valerie Lefler helping to enable regular communications, a series of discussions were held to talk about how to commercialize the AURA system. RDO Integrated Controls is more interested in selling software, rather than providing services. The parties mutually agreed that if the AURA system distress detection software could be packaged as commercial stand-alone software, then RDO Integrated Controls would be able to sell the software, which is closer to their business model, rather than providing road condition assessment services. The Michigan Tech team plans to follow up if funding is found that can create a more user-friendly graphical user interface (GUI) version of the distress algorithm tools, which currently use a command-line interface.

Grupo Engemap (Assis, São Paulo, Brazil) - http://www.grupoengemap.com.br/

Representatives from the Brazil's National Department of Infrastructure of Transportation (DNIT, "Departamento Nacional de Infraestrutura de Transportes", part of the Ministry of Transportation) saw Rick Dobson present on the AURA system at the 2015 TRB Annual Meeting during the Sensing Technologies Sunday workshop. They shared our project's progress with their service providers in Brazil, and representatives from Grupo Engemap, an engineering services firm contacted PI Colin Brooks shortly thereafter. The Engemap company is interested in providing automated unpaved road assessment services to DNIT and state transportation agencies in Brazil, and potentially elsewhere in South America. Working with Michigan Tech's Office of Innovation and Industry Engagement, Engemap and Michigan Tech have agreed to licensing terms so that Engemap would provide AURA system services, starting in their home market of Brazil. Final details of the licensing agreement are awaiting formal signatures from the parties within the next month (May/June 2016).

Section VI: Conclusions

With the help of Woolpert, Inc. the project team was able to collect high resolution data of the unpaved roads with multiple UAS platforms of a gravel mine site near Sidney, OH that represented a commercial deployment of the AURA system. Though this field test and other previous efforts outlined in supplemental report Deliverable 5-B (Fixed-wing evaluation), fixed-wing UAVs have not been able to collect the high resolution imagery necessary for making detailed measurements of unpaved road distresses. However, flexible multi-rotor systems can meet data needs, and are ready for initial commercialization, even within the limits of current FAA rules. Rules that would enable longer-distance aerial assessment, combined with the need for only an UAS operator's permit instead of an expensive pilot's license, will greatly increase the commercial potential of the AURA system. Woolpert and Michigan Tech will continue to actively pursue commercial customers in Ohio, and Michigan Tech is actively seeking partners elsewhere in the country and internationally.