EVALUATING, MAPPING, AND MANAGING UNPAVED ROAD NETWORKS USING HIGH-RESOLUTION REMOTE SENSING DATA

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ABSTRACT

A significant portion of road networks in many countries are unpaved, and they are critically important to rural communities for providing access, communication, and transporting of people and goods. Being able to manage them effectively requires the ability to inspect the unpaved roads frequently and rapidly to determine their changing condition so the appropriate preventive maintenance or rehabilitation can be implemented. The major challenge with managing unpaved roads is collecting low-cost condition data that can be effectively used to make decisions on maintaining the network. The advent of cheap, reliable remote sensing platforms such as unmanned aerial vehicles (UAVs), along with the development of commercial and open source off-the-shelf image analysis algorithms, provides a revolutionary opportunity to overcome data volume and efficiency issues.

This paper outlines the development of a completed prototype system to detect unpaved road distresses that is compatible with a Decision Support System (DSS), taking advantage of technological advancements. The system uses areal imagery that can be collected from a low-cost remote controlled (RC) unmanned helicopter or multi-rotor UAV to create a three dimensional model of road segments. Condition information on road distresses such as potholes, ruts, washboarding, loss of crown and float aggregate berms are then detected and characterized to determine their extent and severity. Unpaved road condition data are imported into geographic information system (GIS) based decision support system (DSS) software, such as the Roadsoft GIS tool, for use by road managers to prioritize preventive maintenance and rehabilitation efforts.

1. INTRODUCTION

In the United States of America, the Federal Highway Administration (FHWA) stated in 2012 that there are over 2.2 million km of unpaved roads in the United States, over 1/3 of the U.S. total (FHWA, 2012). A study reported in 2000 indicated that over 824,000 km of unpaved roads were on tribal lands, 84% of total tribal roads (Federal Lands Highway Program, 2000). International figures demonstrate a similar large numbers of unpaved roads as a transportation resource. China, in 2011, had over 652,000 km of unpaved roads (CIA World Factbook website); Nigeria had over 164,000 km in 2004 (CIA World Factbook website), Brazil had over 1.3 million km of unpaved roads in 2010 (CIA World Factbook website), and India had over 2.1 million miles of unpaved roads in 2011 (Government of India - Ministry of Roads and Highways, 2013).

Unpaved roads, both gravel and unimproved roads, are a critical transportation resource that provide both rural and suburban transportation networks, including farm-to-table transition of food resources, transport heavy freight, getting children to school, and emergency routing after natural disasters, among many other uses. Unpaved road management is often the responsibility of local governments and transportation agencies, which are in need of rapid, repeatable methods that are cost-efficient and easily deployable in a budget-limited environment, particularly in the developing world. In many cases, agencies do not have an up-to-date or complete inventory of the mileage of unpaved roads, making this an additional pressing need. This paper describes technological advancements made under a cooperative agreement between the US Department of Transportation (Office of the Assistant Secretary for Research and Technology, OST-R) and Michigan Technological University ("Michigan Tech") that have led to the development of a completed prototype system capable of inventory, imaging, and assessment of unpaved road condition for cost-effective management of these critical transportation assets. The current name of the system is the Unsurfaced Road Condition Assessment System (URCAS); a project web page is available at www.mtri.org/unpaved with additional information, including all completed and approved project reports.

2. SYSTEM DESCRIPTION

The Unsurfaced Road Condition Assessment System is comprised of several modular components, consisting of a data collection component to image the unpaved roads of interest to the end user, a software component that creates three-dimensional (3D) data sets of the road surfaces, a customized set of distress detection algorithms to find problems in the roads and create the output road distress data (in a flexible extensible markup language (XML) format), and a GIS-based decision support system component (see Figure 1). The core software of the system are the two components in the center (3D Data Processing and Distress Detection Algorithms) that form the “Remote Sensing Processing System”, which takes in stereographic overlapping digital aerial photos and outputs a data file that records the location, density, and severity of several types of road distresses.

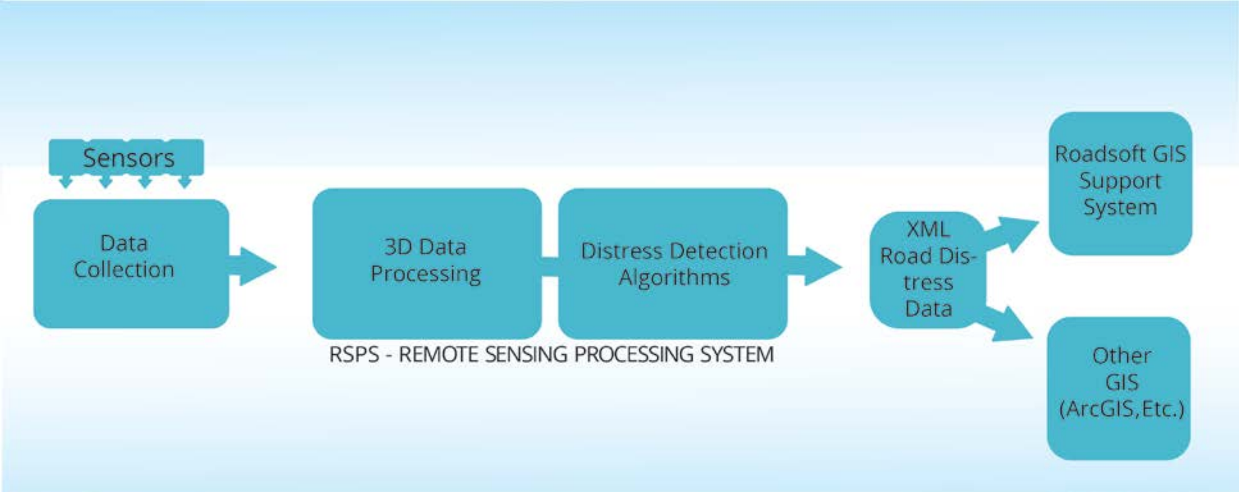

Figure 1: The components of the Unsurfaced Road Condition Assessment System (URCAS) that has been developed to enable the cost-efficient and rapid evaluation of the condition of unpaved roads.

The primary sensor used in the system has been a commercially available, off-the-shelf Nikon D800 digital single-lens reflex (SLR) camera with 36 megapixel (mp) resolution; a 50mm prime lens has been paired with the camera. An initial requirements definition report (Brooks et al., 2011a) had indicated that this resolution would be more than capable of creating 3D models of the road surfaces so that 2.5 cm or better surface defects could be detected and characterized. A State of the Practice review was also completed to ensure that the latest available technologies and assessment were understood by the project team (Brooks et al., 2011b). From this process, the US Department of the Army’s Unsurfaced Road Condition Index (URCI) was selected because it uses measurable distresses in a combined index to indicate road condition for approximately two 30m road segments representing a larger 0.8 to 1.6km road segment (Eaton, 1987; Department of the Army, 1995). Distresses to be measured for the URCI include cross section (crown, in percent), potholes, ruts, corrugations (washboarding), and dust; dust was not included as a tractable metric for airborne remote sensing. As an input layer for mission planning, road networks were also mapped using color infrared aerial imagery (Brooks et al. 2013a).

A platform selection and evaluation process was completed (Roussi and Brooks, 2012), with two UAV platforms demonstrating the capability to lift the Nikon D800 with practical control of the system by a ground agent. In the first year of the project (2012), a Bergen Tazer 800 remote control helicopter was used, collecting 200m of data, flying at 2 m/s at 25-30m in height for up to 15 minutes. In 2013, the project team switched to the easier to control, more flexible Bergen hexacopter (http://www.bergenrc.com/Multi.php - see Figure 2) with flight times of up to 25 minutes, although 4 minutes was sufficient to collect the two 30-m segments per 1.6 km needed to calculate the URCI.

Figure 2: The selected Bergen hexacopter UAV being used to measure unpaved road condition in South Dakota, USA.

The Remote Sensing Processing System's two main software modules imported the stereo overlapping 36 mp imagery collected with the UAVs, created a 3D data set, and used custom algorithms to detect the needed distresses. To create the 3D surface, available open source third-party tools were used, including Bundler, Path-Based Multi-View Stereo, and Meshlab to apply structure-from-motion (SfM) capabilities (Roussi et al., 2012; Lowe, 2004). Potholes are detected using a modified circular Hough-Transform (Rizon et al., 2005), ruts and corrugation using a Gabor filter (Gricorescu et al., 2002), and crown by taking a cut through the surface orthogonal to the road direction in the image. Distress characterization is completed by summarizing the number and severity of distresses into categories; for example, using the URCI, potholes are summarized into low severity (< 5 cm), moderate severity (5-10 cm), and high severity (>10 cm) (Brooks et al., 2011b).

3. RESULTS

Four sites were assessed in Michigan, USA, in 2012; four sites in Michigan, USA, 2013; example data collections were also completed in Iowa and Nebraska in 2013, and South Dakota in 2014. Extensive ground truth reference data was collected to enable comparison of manual methods to automated imagery-based methods. Figure 3 shows two examples of the many stereo images taken from the hexacopter to assess segments of unpaved roads.

Figure 3a and 3b: Example road segment images collected with the Bergen hexacopter UAV and the Nikon D800 camera for calculation of road distresses; 4a (left) shows prominent potholes with field crew markings; 4b (right) shows a prominent rut.

Figure 4 shows an example of the densified 3D point cloud that is created through the Remote Sensing Processing System to create a "water-tight" digital elevation model (DEM) surface. The 3D DEM surface (Figure 5, based on the point cloud in Figure 4) is used to calculate the depth of distresses such as potholes and ruts. Higher values are shown in red and lower values in blue; the locations of potholes are easily observable when shown with the vertical exaggeration present in Figure 5.

Figure 4: An example of the densified point cloud created with stereo overlapping imagery through the Remote Sensing Processing System.

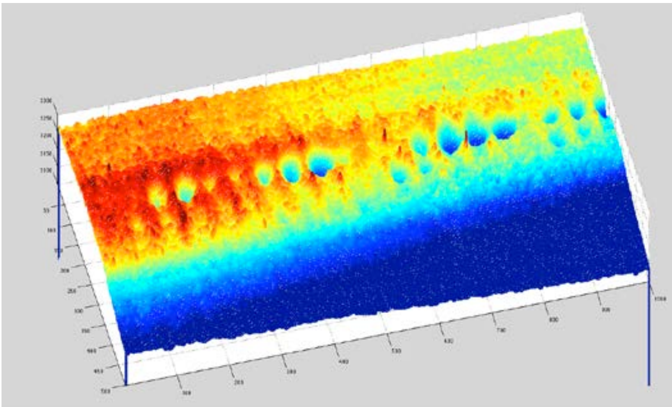

Figure 5: An example of the same stretch of road shown in Figure 4, but as a digital elevation model surface with relief exaggeration; higher areas are in red, lower areas in blue; potholes along the road center can easily be seen.

Processing the images and 3D data into distress measurements produced outputs similar to those in Figure 6; in this case, the location of corrugations (washboarding) were automatically detected, and their area estimated. A minimum threshold could be set, so that smaller areas could be excluded, if desired. An improvement to the algorithm later removed road edges areas so that only corrugation-like features within the roadway were assessed. Overall, potholes were detected with a 96% probability of correct classification, percent crown was measured to better than 0.1% accuracy, ruts had a 67% probability of detection, and corrugations where detected 100% of the time (although they had a relatively high false alarm rate of 38.5%). Overall, the current version of URCAS is best at pothole detection and crown evaluation, with future improvements expected to improve rut and corrugation evaluation through additional algorithm development.

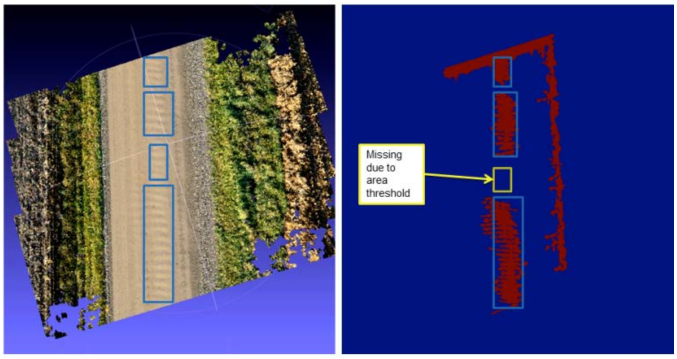

Figure 6: An example of automated distress detection, showing how corrugation (washboarding) was detected, with a minimum threshold area level.

The calculated distress data are output as a documented, flexible XML (Extensible Markup Language) file that can be imported into GIS software to display and query the results on a geographic basis. To support road asset management, the project team demonstrated integration of the distress data into the Roadsoft GIS decision support system, which project partner Dr. Tim Colling oversees the development of at Michigan Tech through the Center for Technology and Training (see www.roadsoft.org). Figure 7 shows an example of URCAS-derived data being integrated into the Roadsoft DSS software. It is designed to allow road segments, and the relevant surrounding network, to be ranked as candidates for rehabilitation or maintenance treatments based on their historical distress ratings and inventory information. For end users in the U.S. and worldwide, it is possible to adapt Roadsoft to local needs, or integrate distress data into existing, more generic GIS setups such as Desktop ESRI ArcGIS.

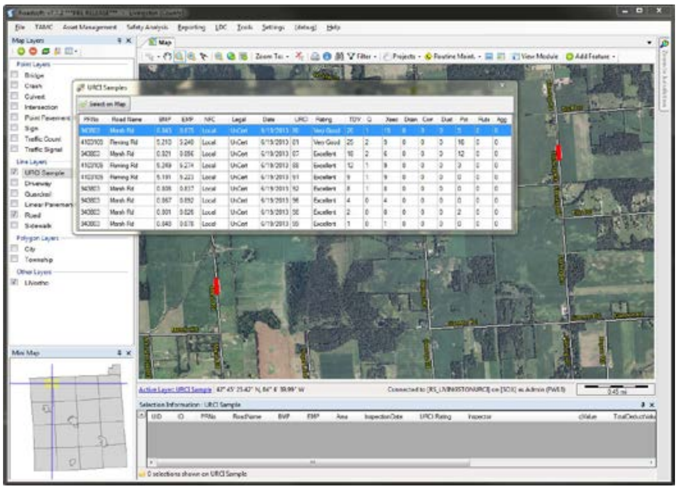

Figure 7: An example of the URCAS-collected unpaved road distress data being displayed with the Roadsoft decision support system for road asset management.

As part of the project funding this work, typical manned fixed wing aircraft such as a Cessna 152 and a Cessna 172 were tested using the same Nikon D800 camera to see if the same sub-2.5 cm resolution 3D data could be derived. A lack of angular diversity, even when using a 200m lens, prevented reconstruction of sufficiently high-resolution data to meet the 2.5 cm or better 3D resolution needed to characterize distresses into URCI severity categories. To gain the resolution needed, only sensors flown at altitudes below 100m will meet all the performance (resolution) and cost-effectiveness requirements using the current sensor setup.

4. IMPLEMENTATION AND NEXT STEPS

A key component of implementation of URCAS is its low cost to acquire and operate. Deliverable Report 7-B, “Performance Evaluation of Recommended Remote Sensing Systems in Unpaved Road Type Condition Characterization” (Brooks et al., 2013b) describes the cost inputs for manual, unmanned aerial, and manned aerial estimation of unpaved road assessment. The Bergen hexacopter cost $5400 US in 2013, including spare batteries and mission planning software. The Nikon D800 with 50mm lens cost $3500 in 2012. An external intervalometer (to control photo frame rate) cost $100. Assuming three years of service from the hardware, operation of the system for 21 weeks a year collecting 120.7 road km a week (2534.7 km a year), processing time of 1 day per week of collection, the total yearly cost to operate would be $30,590 US. Per actual km rated, this would be a cost of $30,590 US / 2534.7 km = $12.06 per km. However, the URCI operates on the concept of two 30-m measured representative segments per 1.6 km (1 mile) of road, so each mile of measured road represents a road network 26 times larger. Therefore the cost is $0.46 US per km, in addition to the cost of a vehicle to transport the UAV to the sampling locations. Costs for completing an equivalent survey using manual methods are in the $100/km range (Brooks et al. 2013b – such as the manual Wyoming URCI cost of $160 per mi = $100 per km).

For the US, implementation of URCAS using a UAV is dependent on new U.S. Federal Aviation Administration (FAA) regulations allowing commercial operations of UAVs. Small UAVs (those under 25 kg) are due to have new operation regulations issued by the end of November, 2014. The first set of commercial operation rules are due by the end of September, 2015, although delays are possible. However, by some point in 2016, commercial operation of a UAV-based URCAS in the United States of America should be possible, with third-party vendors able to offer UAV-based unpaved road assessment services to transportation agencies.

For the project team, next steps involve international outreach, additional outreach to U.S. transportation agencies, improvements to distress algorithms, evaluating platform and sensor advancements, and working with third-party vendors on preparing for commercialization. International outreach could take the form of working with in-country partners to demonstrate and implement URCAS in places such as southeast Asia and southern Africa where large networks of unpaved roads need cost-effective monitoring with rapidly deployable, high-resolution data collection methods.

5. CONCLUDING COMMENTS

The Unsurfaced Road Condition Assessment System has reached a sufficiently advanced status that it can be used to cost-effectively create the type of high-resolution remote sensing data needed to evaluate, map, and manage unpaved road networks. Detection and characterization of road distresses, especially pothole locations and amount of crown, can be rapidly collected and calculated, and made available to road managers for effective road asset management. It is significantly less expensive to collect and process the type of high-resolution data needed for unpaved road management when using a UAV-based system versus equivalent manual methods, which is critical for international adoption.

In the U.S., commercial availability of UAV-based road assessment awaits new FAA regulations that should be in place by 2015 or 2016. Internationally, countries are starting to specifically allow commercial operation of UAVs, and implementation on a practical basis could start even sooner.

6. ACKNOWLEDGEMENTS AND DISCLAIMER

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DISCLAIMER: The views, opinions, findings and conclusions reflected in this presentation are the responsibility of the authors only and do not represent the official policy or position of the USDOT/OST-R, or any State or other entity.

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