AN UAV-BASED PHOTOGRAMMETRIC MAPPING SYSTEM
FOR ROAD CONDITION ASSESSMENT

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ABSTRACT:

We present an Unmanned Aviation Vehicle-based Photogrammetric mapping system in this paper. This work is part of a project monitoring of unpaved road condition using remote sensing and other technology, sponsored by the US Department of Transportation. The system is based on a low cost model helicopter equipped with a GPS/IMU and a geomagnetic sensor to detect the position, attitude and velocity of the helicopter. An autonomous controller was employed to control helicopter to fly along a predefined flight path and reach the desired positions. At the ground station, a computer was used to communicate with the helicopter in real-time to monitor flight parameters and send out control commands. The entire processing system includes camera calibration, integrated sensor orientation, digital 3D road surface model and orthoimage generation, automated feature extraction and measurement for road condition assessment. In this paper, both the project and the system architecture are described, and the recent development results are presented.

1. INTRODUCTION

The unpaved roads are typically low-volume roads linking small agricultural communities to nearby towns and markets. These roads tend to experience seasonal variations in traffic volumes with significantly higher flows occurring around harvest time each year. If periods of wet weather and high traffic volumes coincide, damage to unpaved roads can be very severe. Such roads are also susceptible to damage because of the kind of vehicles that traverse them. Heavy farm machinery and trucks laden with farm produce can do more damage to a road than a series of smaller vehicles of equal net mass.

The construction and maintenance of unpaved roads is usually performed by local townships and county governments. In US, for instance, local transportation departments must conduct field surveys to identify problem areas and schedule maintenance activities. Due to the small funding base of local government, the human and financial resources available for maintaining roads are often inadequate. While state and federal transportation departments often have vehicle-mounted roughometers and other devices to assess road surface conditions, local officials typically rely on visual inspection, intuition and occasional spot measurements in their assessments. Yet the importance of timely identification and rectification of road deformation through loss of crown or damage to the road base cannot be overstated.

The predominant method in conducting road condition survey and analysis is still largely based on extensive field observation by experts. Recent efforts include the development of a pavement survey vehicle coupled with sensor technologies and data-processing onboard. Some such systems have been used by highway agencies (Kenneth, 2004). However, no similar technology or system exists for unpaved roads. Nevertheless, data collection using a moving vehicle still remains an expensive and troublesome survey, while cost and safety considerations require that it be done at regular intervals. Recently, commercial remote sensing technologies have been introduced for pavement assessment. A study has been conducted to find a correlation between spectral reflectance and physical characteristics such as rutting and cracking (NCRST, 2003a). The results show it is possible to describe general pavement age and specific surface defects such as raveling, and to estimate their spatial characteristics. Due to limited spatial resolution (4m), other important pavement quality parameters such as rutting and cracking are undetectable. A further effort was performed using sub-meter (50cm) hyperspectral remote sensing data (Herold et al., 2004). They used image ratios and spatial variance measures and related them with road condition parameters such as the Pavement Condition Index. While the results of this research are promising, the main drawback of this method is that it relies only on spectral information, thus the results are not always accurate. Especially on older roads which might be subject to maintenance, the results usually tend to high levels of uncertainty. This suggests the need for further research to develop a more efficient road condition mapping strategy. First, the road image should contain sufficient spatial detail. High resolution imagery is essential to efficiently detect and measure features on unpaved roads. Aerial imagery can be a choice, but the limited maneuverability of the platform to acquire the image data and the associated high costs are shortcomings. In contrast, UAVs are highly flexible, collecting image data at lower cost, faster and more safely (NCRST, 2003b). Moreover, UAVs are able to operate rather close to the object and acquire images with few centimeter resolution (Eisenbeiss, 2006), providing sufficient detail for identification and extraction of road condition parameters. Second, sophisticated methods should be developed to extract various road features. These methods should include the examination and value of spectral, contextual and edge features, and 3D models of road surface. These information sources can then be fused to derive robust and reliable road condition parameters to meet the operational use in transportation agencies.

2. ROAD CONDITION ASSESSMENT AND MONITORING STRATEGY

This paper explores the potential for applying remote sensing technology to monitoring the condition of unpaved roads. It aims to develop an efficient yet cost-effective method for maintaining statewide information on the condition of unpaved roads. The strategy for monitoring the condition of unpaved roads is a hybrid approach comprising two interrelated systems: UAV-based Remote Sensing of Road Condition (UAVRS), and Predictive Road Condition Modeling using Remote Sensing Data (PRCM). UAVRS will acquire road imagery with high resolution from an UAV platform, and assess roads based on the condition parameters derived through the development of sophisticated algorithms for image processing and analysis. In PRCM, the road condition data are produced by developing a robust road condition model using satellite derived environment data and other road data. The extracted road condition parameters in UAVRS will be directly used in local transportation agencies for road condition monitoring and maintenance. In addition, these data will also be used in the development of the statistical model in PRCM as field data for training and verification. Furthermore, the statistical model that will be developed in PRCM will be constantly updated and improved by the observation data and the derived parameters provided in UAVRS, leading to an operational system for road condition monitoring. The details of the strategy can be found in Zhang (2008).

The UAV-based remote sensing system focuses on acquiring imagery using a UAV and extracting information from the image data.
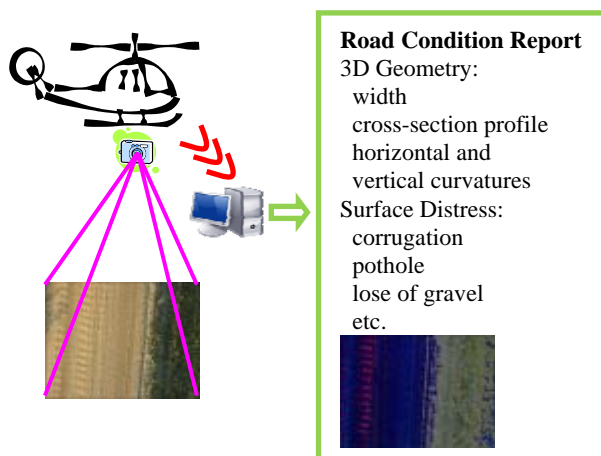

Figure 1. Proposed UAV-based remote sensing system for unpaved road condition assessment.

In addition to operation of UAV for road image collection, the development of the processing will include methods for accurate georeferencing, automated extraction of accurate 3D road surface model, and generation of high resolution orthoimages. Afterwards, a set of image processing algorithms will be developed to detect and extract features related to road surface and condition. The main features include length and size of corrugation, cross section geometry, rutting, potholes, secondary ditches, and road surface roughness, etc. Examples of deteriorate unpaved roads are given in Figure 2. Based on the extracted features, we will derive information about road quality to enable advanced warning of road deterioration.

Figure 2. Ground images of deteriorated unpaved roads. Above: Serious distress with potholes and bad surface drainage. Below: Loose aggregate with corrugation.

3. UAV SYSTEM AND SENSORS

3.1 Airframe

We are currently operating an Airstar International Mongoose airframe helicopter. The airframe is a modified radio controlled helicopter with primary flight systems consisting of the engine and drive train, main rotor and tail rotor assembly, control actuators, and structural components. The airframe is powered by a 26cc, single cylinder, Zenoah G260H engine producing approximately 1940W at 12,000rpm, providing an operating head speed of approximately 1250-1500rpm.

The weight of the Mongoose airframe is approximately 6.1kg dry, and the payload the airframe is capable of carrying is approximately 6.4kg. The fuel capacity is 475cc allowing approximately 45 minutes of flight without payload, and approximately 30 minutes of flight carrying full payload. The battery powering all onboard electronic components will provide approximately 90 minutes of power-on time for the entire system (Raunaq et al., 2007).

3.2 Autonomous Flight Controller

Autonomous navigation and control of the main vehicle is achieved via the combination of the Rotomotion Automatic Flight Control System hardware (AFCS) and custom Mission Control System software (MCS). The combination of these two systems allows for designing and executing pre-programmed waypoint paths, monitoring mission-specific intelligent control software, and maintaining full control of the vehicle at all times.

The MCS software runs on the ground base station computer and manages the guidance and navigation control behavior of the UAV system (Raunaq et al., 2007).

The Rotomotion AFCS consists of an embedded computer running Linux, a WAAS-enabled GPS unit, three accelerometers, three gyroscopes, and a three-axis magnetometer. It utilizes PID controllers to maintain attitude and altitude in translational flight and hover as well as flight during a fast forward flight mode. The GPS unit is primarily used to provide position of the aircraft and maintain course and speed as well as fixed hovering positions.

The AFCS performs the attitude and position control of the UAV. It maintains the stability of the helicopter in hover and translational flight. The UAV will perform an autonomous translational maneuver only when the AFCS is sent a waypoint from the MCS. The AFCS computer can store and execute a way-point stack, allowing the helicopter to follow a pre-programmed path even if it is outside of radio range or line-of-sight. This option is only utilized during specific flight tests or in situations when the MCS is unavailable. As a safety precaution, the AFCS will be sent only one waypoint at a time by the MCS allowing a mission to be halted immediately at any point. In the event that the communication between the AFCS and MCS is broken, the AFCS will stop and hover the helicopter at the most recently received waypoint.

3.3 Imaging Sensor

We currently use a UEye 2220c USB video camera with frame size 768x576. There is also OptiLogic RS-232 laser range finder on board. The UEye camera can provide RGB nature color images. The camera also supports NEMA sentence capturing from external GPS units, thus the time of image capture and the exact position of capture could be recorded into the image header for later review and correlation. A custom camera trigger is made controller by the AFCS. The camera will be triggered at preset GPS waypoints.

4. INITIAL DATA COLLECTION AND PRELIMINARY RESULTS

The first data collection using the above UAV system was conducted in a test site near Rapid City, South Dakota. The UAV flew at an altitude of about 50m above ground, capturing details of the road surface. Figure 3 is an example of the road imagery collected over a road segment with corrugation (washboarding). Ground shots presented in Figure 3a and Figure 3b indicate the very mild washboarding defects with depth around one inch. However, these washboarding features are clearly visible in the UAV image presented in Figure 3c.

Figure 4 is an image of a road segment with more serious distress affecting the entire road cross-section geometry. An overview of this segment is given in the upper part of the Fig 4. The initial low resolution shot of the overall cross section reveals the potential to evaluate potholes, rutting, loss of aggregate cover, drainage issues, and the poor overall cross section. The imagery was acquired early in the morning right after sunrise. Large shadows of trees clearly appear in the image. The details of the distresses are demonstrated in lower part of the figure.
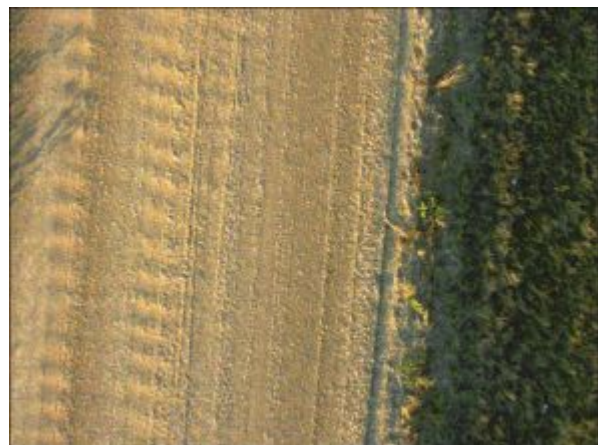
Figure 3. Road segment with moderate corrugation as seen from ground image (top), measurement of the depth of corrugation (middle) and UAV Image (bottom).

We are developing image processing algorithms to detect and extract road defects from the UAV-collected imagery. The development includes detection of various road distresses from 2D imagery, analysis of the inherent 3D geometry information in images using photogrammetric techniques, and the fusion of 2D and 3D information to derive road condition parameters. The current 2D image analysis uses image features (such as color, edges etc.), pattern recognition and image classification techniques, and is powerful as demonstrated in the following example.

Figure 4. An image of a road segment with serious distresses collected from the UAV platform.
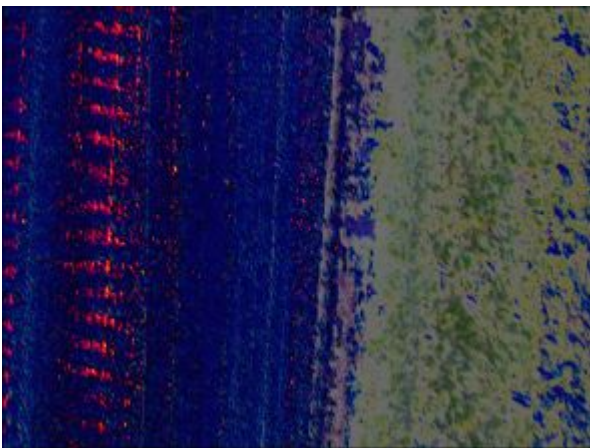

Figure 5. Detection of washboarding in a road segment shown in Figure 3. The washboards are successfully extracted and are presented in red.

The existence and the extent of the washboarding is one of the most important factors in determining the condition of an unpaved road. A cluster of washboarding on the road makes a distinct pattern on UAV imagery (see Figure 3) with closely spaced ridges and valleys at fairly regular intervals. The ridges are perpendicular to the traffic direction. Therefore, the washboards can be detected by pattern recognition and image classification techniques. The result of washboarding detection over the road segment in Figure 3 using pattern recognition technique is shown in Figure 5 where the detected washboarding is presented in red. From the resultant images,

the number of washboading ridges, and the width of the ridges in the direction perpendicular to the traffic can be computed as an indicator of severity of the distress.

5. DISCUSSION AND FUTURE WORK

In this paper, a new strategy for unpaved road condition monitoring has been proposed and presented. In particular, we have introduced an UAV-based remote sensing system for road image acquisition and road condition parameters collection. Initial tests have been conducted where the UAV flew over several test sites to capture imagery of unpaved roads with various defects. The UAV imagery has demonstrated the capability to ascertain the condition of unpaved roads. The preliminary results of 2D analysis of the road imagery has shown the UAV images are suitable for extracting many of the parameters needed for monitoring the condition of unpaved roads.

While the 2D image analysis is under further development and refinement, we are currently focusing on the development of 3D analysis of images by exploring photogrammetry techniques. This includes accurate camera orientation and image geoferencing, automated extraction of 3D road surface model, and generation of high-resolution orthoimages. When 3D road surface models are developed later in the research, the direct detection of improper road cross section and related distresses such as potholes and rutting will be enhanced. Without 3D models, the approaches developed would be limited to identification of areas of distress without estimation of the vertical dimensions of distress. In addition, 3D analysis can provide extremely valuable information on basic geometric aspects of the road, including horizontal curvature, vertical curvature, ditch slopes, and roadway width, etc. This information and the derivative information like design speed and sight distance, are also very important to highway safety and subgrade stability.

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