LOW-ALTITUDE DIGITAL PHOTOGRAMMETRY TECHNIQUE TO ASSESS EPHEMERAL GULLY EROSION

J.R. Frankenberger, C. Huang and K. Nouwakpo

USDA-ARS National Soil Erosion Research Lab, W. Lafayette, IN.

ABSTRACT

Recent development in digital imaging makes it feasible to employ photogrammetry procedures to delineate landscape and erosion features. We evaluated the feasibility of using low-altitude photogrammetry to assess ephemeral gully erosion at agricultural fields. We tested an unmanned aerial vehicle (UAV) and a ground based technology to acquire low-altitude surface images to create digital elevation models (DEM). Collaborators at Wuhan and Yangling in China also used the LIDAR technology on a steep slope for DEM acquisition. We found 1) current DEM's derived from airplane flights are not accurate enough to delineate ephemeral gully channels; 2) a ground-based LIDAR system is capable of generating an accurate DEM and gully channels at steep hillslopes; and 3) at gentle slope situations, low altitude photogrammetry has the potential for acquiring DEMs. Nevertheless, proper deployment of a camera at a suitable height to have sufficient aerial coverage while maintaining the resolution at the Z (elevation) scale to assess rill ephemeral gully development is still a challenge.

Index Terms— erosion, ephemeral gully, photo-grammetry.

1. INTRODUCTION

Ephemeral gully erosion is the main source of sediment from the agricultural landscape, unfortunately, it has been overlooked in traditional soil erosion assessment. Since an ephemeral gully, by definition, can be easily alleviated or filled by normal tillage, the difficulty in making the ephemeral gully erosion assessment is the lack of well-defined channel morphology such as classical gullies and river channels. The width and depth of the ephemeral gully are too small (+/- 0.5 m) to be detected by general topographic surveying and mapping. The intermittency of ephemeral gullies, i.e., the removal by tillage operations, adds to the difficulty in its quantification.

The analysis of time lapsed aerial photos or digital elevation models (DEM) to quantify gully erosion has been well documented, especially aided by geo-spatial data processing techniques in recent years [1]. These studies are mainly conducted on well-incised gullies with depths in the order of 1 to 10 meters or greater. There is still a need to develop an accurate and rapid tool to assess rill or ephemeral gully erosion in the order of 0.5-1.0 m wide and 0.1 to 0.2 m deep in cultivated fields. In other words, we seek to develop a close-range DEM technology that can be deployed at the field scale to assess rill and ephemeral gully development.

2. RESEARCH OBJECTIVES AND PLAN

Using low cost digital cameras to acquire 8 to 10 mega pixel images has made photogrammetry a much more feasible technique to generate DEMs for gully erosion assessment. Although a remote controlled blimp has been successfully used to acquire low-attitude photo images, it is not a technique that can be easily adopted [2].

In this research, we are using modular open-source software components as well as the commercial Leica Photogrammetry Suite to merge overlapping digital photos with ground control points to estimate DEMs. We first tested the photogrammetry software by comparing a generated DEM with a laser scanned DEM in meter size areas in the laboratory. We then conducted two field trials: the first test conducted at a relatively flat farm field using an unmanned aerial vehicle (UAV) to acquire photographs at approximately 100 m altitude and the second test performed at a steep, i.e., 30 degree, loess hillslope with the camera suspended 8 m above ground. A ground-based Light Detection and Ranging (LIDAR) system was also deployed during the second test.

3. IMAGE ACQUISITION AND PROCESSING

Two different camera configurations are supported. The first uses two cameras mounted on an aluminum beam. The distance between the cameras can be changed depending on the scale of work. This configuration is primarily for laboratory work. The second configuration uses a single camera to capture multiple overlapping images. The fixed dual camera system is advantageous at the laboratory scale to provide quick depth maps. This requires more initial calibration and care in positioning the cameras. The dual camera system is more suitable for close range work (1m-

2m). For outdoor field assessment the single camera approach of taking multiple pictures of the scene from different perspectives has the advantage of being able to vary the camera placement based on the scale of the area.

After the images are captured, a point location in the actual space can be determined by identifying the corresponding points in two image frames. The distance from the camera to the object point is related to the amount of pixel shift between the images – closer points have a larger shift.

The open source OpenCV image processing library [3] and custom software written in C++ are used to calibrate the cameras, perform image rectification, generate disparity images and re-project pixels to three-dimensional coordinates. Algorithms from computer vision, including KLT feature tracking[4] and scale invariant feature tracking [5][6] are used to predict initial matching points between images. A bundle adjustment [7] is used to refine the camera positions and 3D point coordinates. After the images have been rectified searching for corresponding points is done along rows of the images using the method described by Birchfield and Tomasi [8]. Dense stereo is achieved by matching as many pixels as possible from the overlapping images.

Using the disparity map, internal camera parameters and camera orientations, the actual 3D location of the pixels can be determined. This involves transforming the points from the camera reference plane to the ground reference plane. The resulting point cloud of X-Y-Z data can be exported to be used by other software.

Accuracy is determined by several factors during the processing. The most common source of error is inaccurate or unsuitable camera positions with respect to the ground control points. A related source of error is inaccurate camera calibration The second most common source of error is inaccurate point matching. This can be the result of sharp changes in elevation or occlusions which prevent points from being identified in both images. Since the point matching is based on grayscale intensity values the scene lighting can also be a cause of incorrect point matches.

4. ASSESSMENT OF CLOSE RANGE DEM TECHNOLOGY FOR EPHEMERAL GULLY DELIENATION

Two field trials were conducted to evaluate the feasibility of the using the low-altitude photogrammetry technique to assess ephemeral gully development.

4.1 UAV Image Acquisition

The test of using a remote control airplane (or UAV) to acquire overlapping ground surface images was conducted over a farm field with ephemeral gullies at Indiana (Figure 1). The field is approximately 150 m long and 50 m wide and there are numerous rills and shallow, ephemeral gullies. Aerial images were taken with a Sony DSC-V1 5 mega pixel camera from a height of approximately 100 m.. Because the airplane was flown under an operator visual control mode, image acquisition was performed in a somewhat ad hoc fashion. Therefore, multiple images were taken to ensure a good set of overlapping images for photogrammetric processing.

Figures 2 shows an aerial image with predicted channel initiation points (red dots) from a topographic threshold model based on the photogrammetry derived DEM at 0.1 m by 0.1m grid. Although our initial trial of the UAV technique shows its potential for acquiring suitable images for ephemeral gully delineation, several challenges still remain. The main challenge of using the UAV technology is the cost associated with the plane and piloting skills

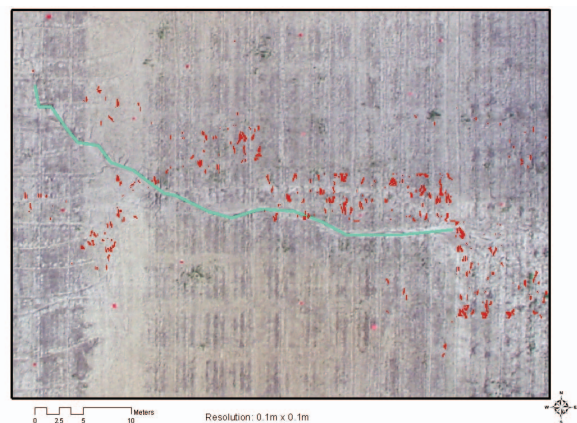Figure 1: A farm field with ephemeral gullies.

Figure 2. The aerial image of the farm field showing the main gully channel and potential channel initiation points from the photogrammetry derived DEM analysis.

required to control the vehicle. The low-cost hobby type unit, which we used in the initial trial has a limited payload, hence can only carry a lightweight camera. Additionally, the hobby-type airplanes are generally flown manually, hence timing and location of image acquisition can not be controlled. UAVs that can be flown with autopilot program are generally much larger, and expensive, despite the advantages of a larger payload and the capability of using an autopilot program to preset the fly path and locations of image acquisition. Another issue associated with the UAV technology is the relation between flight height, aerial coverage and relative ground speed. At low flying altitudes, i.e., in our case 50 m or less, the relative ground speed can easily blur the image. Seeking a good balance among a reasonable cost, easy to operate and being able to produce clear ground images at low flying heights is a challenge in the UAV technology for ephemeral gully erosion assessment.

4.2 Comparison Between Photogrammetry and LIDAR

The second trial of the photogrammetry technique was conducted at the Ansai Field station located at the Loess Plateau of China. Inside the station grounds, there is a 3.5 m wide by 12 m long soil box at slopes varying from 28 (bottom) to 5 (top) degrees. A sequence of six simulated rainfall events were applied to this soil box, and as a result, created a surface with deep incisions as it would have occurred on the natural loess slope of similar steepness.

Cooperators from Wuhan and Yangling used a ground based LIDAR system. The Leica HDS3000 3-D Scanner was used after each rainfall event to digitize the surface topography. The photogrammetry procedure was tested after the last rain event using a Canon EOS Digital Rebel Xt 8-mega pixel digital camera mounted on top of an 8-meter pole. The locations of the ground control points were surveyed using a Trimble RTK 5700 GPS system.

Figure 3 shows the images of the soil surface as well as LIDAR acquired DEMs after first and last (sixth) rain events. It is obvious that the LIDAR technology can deliver high resolution surface topography data for assessing erosion feature development. Figure 4 is the DEM generated from the photogrammetry procedure after the final rain. Comparing the two DEMs derived from two vastly different technologies, we believe the digital photogrammetry technology has the potential for delineating detailed surface erosion features.

Although at a much greater cost, the LIDAR technology can quickly deliver a scanned surface DEM as compared to photogrammetry which requires more human interaction to analyze the intermediate photogrammetric results and perform post-processing No doubt that the ground-based

LIDAR scan is a very powerful tool for quantifying minute topographic changes at steep slopes, as we have shown here. In fact, cooperators at Wuhan and Yangling have successfully field tested the LIDAR system on actual steep loess slopes in the range of 100 to 200 meters in China. However, for shallow slopes such as the farm field example shown in Figure 1 at Indiana, the ground-based LIDAR will not be useful unless elevated on a platform to provide a more direct view of the surface. Aircraft-based LIDAR scanning will also not be able to deliver a DEM with the proper resolution needed to delineate ephemeral gullies at the field scale.
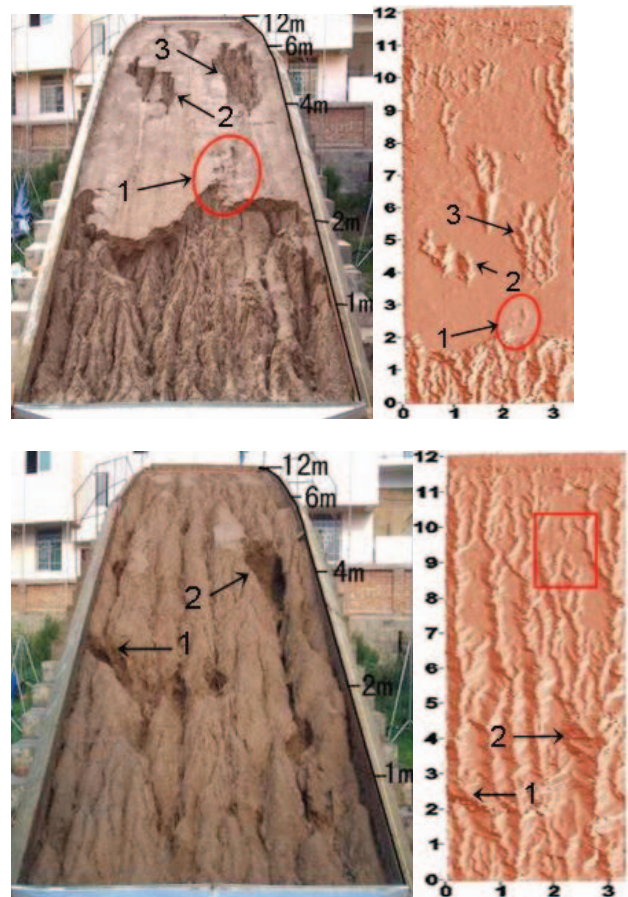

Figure 3. Images of the soil surface and LIDAR acquired DEMs after one (top) and six (bottom) rainfall events at the Ansai Station, China.

4.3 Challenges in Low-Altitude Photogrammetry for Ephemeral Gully Assessment at Shallow Slopes

We have discussed the technological challenges in deploying a digital camera at low altitudes for image acquisition with the UAV technology in Section 4.1. There is still an inherent scale issue that has yet to be resolved in

low-altitude digital photogrammetry. The issue is the need to have similar resolutions on all three coordinates to be able to delineate rills and ephemeral gullies at shallow slopes. Unlike steep slopes such as the Chinese Loess Plateau, ephemeral gullies formed at 5 to 10 % shallow slopes are usually 10 to 30 cm deep and 30 to 100 cm wide. To capture the shallow rill and channel geometry in a hectare sized area would require DEMs in ~5 cm spatial (X and Y) resolution and probably even better in elevation (Z) accuracy. For a pair of stereo images, the Z resolution improves as the camera separation increases and camera height decreases. How to optimize the spatial coverage to maintain a relative high Z resolution without patching together many small scale DEMs is yet to be resolved.
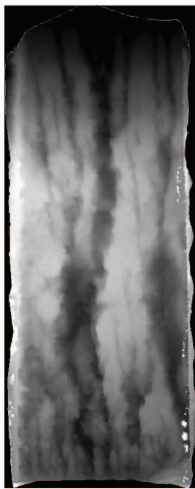

Figure 4. Photogrammetry derived DEM from a soil box after six rainfall events at Ansai Station, China.

5. REFERENCES

[1] J.A. Martınez-Casasnovas, "A spatial information technology approach for the mapping and quantification of gully erosion", Catena, 50:293– 308, 2003.

[2] J.B. Ries and I. Marzolf, "Monitoring of gully erosion in the Central Ebro Basin by large-scale aerial photography taken from a remotely controlled blimp", Catena, 50:309-328, 2003

[3] OpenCV Software and Documentation: http://www.intel.com/technology/computing/opencv/

[4] B.D. Lucas and T. Kanade. "An Iterative Image Registration Technique with an Application to Stereo Vision". International Joint Conference on Artificial Intelligence, p. 674-679, 1981.

[5] D.G. Lowe, "Distinctive image features from scale-invariant keypoints," International Journal of Computer Vision, 60(2): 91-110, 2004.

[6] A. Vedaldi, "An open implementation of the {SIFT} detector and descriptor", UCLA CSD Tech. Report 070012, 2006.

[7] M.I.A. Lourakis and A.A. Argyros, "The Design and Implementation of a Generic Sparse Bundle Adjustment Software Package Based on the Levenberg-Marquardt Algorithm", Technical Report 340, Institute of Computer Science - FORTH, 2004.
http://www.ics.forth.gr/~lourakis/sba/

[8] S. Birchfield and C. Tomasi, "Depth Discontinuities by Pixel-to-Pixel Stereo", International Journal of Computer Vision, 35(3): 269-293, 1999.