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Very high resolution DEM acquisition at low cost using a digital camera and free software

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This paper explores the use of an new technique for acquiring low-cost very-high-resolution DEMs. *Photosynth* is a relatively new application from Microsoft that allows hundreds of photos to be collected and processed into a 3D model in a relatively short time.

We explore the use of *photosynth* to derive a very high resolution digital elevation data set covering a 1 m^2 area. Previously the plot has been measured manually at varying intervals over a 23 year period to examine soil erosion and deposition as a starting point for quantifying physical processes such as erosion/deposition and the links between scale and resampling intervals.

A previous paper, presented at MODSIM07, investigated some of the challenges making DEMs at this resolution and inferences about processes that can and can't be made through various scales. It was acknowledged that a major limitation was the cost involved to obtain the DEM manually and that improved (automated) sampling methods could increase the study areas to interesting proportions, or to a representative number of calibration quadrats in a much larger area.

The results show that using only a modest digital camera, *Photosynth* and some post processing, a higher resolution DEM can be obtained faster and more reliably than the manual methods previously used. Importantly the method is very low cost compared with other manual or automated methods

While this paper studies a small well quantified plot the technique should scale well to cover larger area such as a small catchment by capturing photos from a aircraft through to detailed gully erosion modelling or 3d models of undercutting stream banks.

Keywords: *High Resolution DEMs, Hydrological Modelling,, Erosion modelling*

1. INTRODUCTION

This paper follows from a previous paper presented at MODSIM07 (Dowling et al., 2007). That study focused on the comparison of an erosion rate experiment at 50 x 20 m resolution and a very small, very fine resolution alternative measurement (microDEM) of 1 x 1 m. Long term erosion measurements were planned to investigate the different erosion rates in the fine sandy topsoil and the heavy yellow clay subsoil. With changes in rainfall amount and pattern due to extended drought this has not been achieved. When the project ended the monitoring was sustained in the interest of science, as opportunities permitted, resulting in a useful long term dataset for erosion and geomorphological studies.

The datasets from Yarralaw provide an opportunity to compare a large area of spatially sparse point measurements with a very small area with spatially dense measurements, the 1 x 1m DEM. Elevation accuracy is important since total erosion has been in the order of 20cm over 20 years while differences between sampling times can be 0 mm, or even several mm of deposition. However, it was acknowledged that the manual acquisition method was inadequate for regular monitoring and improved, i.e. automated, sampling methods could increase the study areas to interesting proportions, or to a representative number of calibration quadrats in a much larger catchment. To be effective they needed to be low cost and more time efficient.

In the interim a new web based software application called *Photosynth* was released by Microsoft that had the potential to provide both.

The main objective of this work is to explore the processing issues and usefulness of the Photosynth technology for obtaining microDEMs to replace the existing manual method. The specific objectives are to:

- Investigate the potential of *Photosynth* for obtaining high resolution elevation data cost effectively.

- assess the benefits of this method compared to the existing manual method.

2. STUDY AREA

The Yarralaw study site is a 4.3 ha salt scald in a 37.8 ha subcatchment situated ~60 km northeast of Canberra (-34^{o} 16’ S 149^{o} 53’ E) in New South Wales, Australia (Fig. 1). Elevation ranges from 605m to 635m with a well defined N-S valley through the centre of the area. Geology is predominantly porphyritic monzonite intruded through ordivician sediments. Soils, yellow duplex or texture contrast with a strongly bleached A2 horizon, are thixotropic when saturated – a normal occurrence in winter. The fine sandy topsoil is highly erodible when the vegetative cover is removed. Mean annual rainfall is approximately 670mm with an even distribution throughout the year. Natural vegetation was *Eucalyptus rossii*, *E. melliodora and E. macrorhyncha* that has been cleared to less than 1% cover prior to 1941. Sheep and cattle grazing has been the major land use. Research into salinity and erosion was well advanced on the site through a number of studies including extensive mapping of topography, geology, electromagnetic conductivity, soils, vegetation and groundwater level surveys as part of ameliorating erosion and salinity. Evidence of salinity appeared between 1952 and 1962 (4 ha salt scald) with relatively little expansion since.

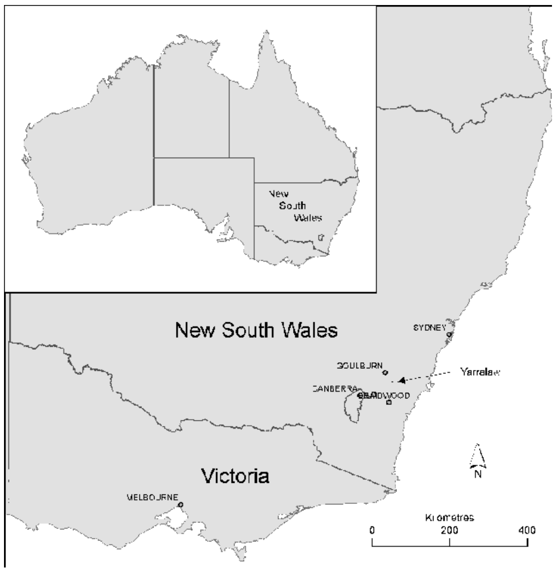

Figure 2. Location of the Yarralaw study site in southeastern Australia.

The microDEM is situated below the upper boundary of a severe salt scald and next to an actively eroding watercourse. The ground surface bounded by the quadrat has varying sized patches of fine powder, fine sand, pea gravel and bare compact smooth soil. Vegetation cover is absent. Star pickets used for measuring at the coarser spatial resolution are situated about 120m down stream (Fig. 2).

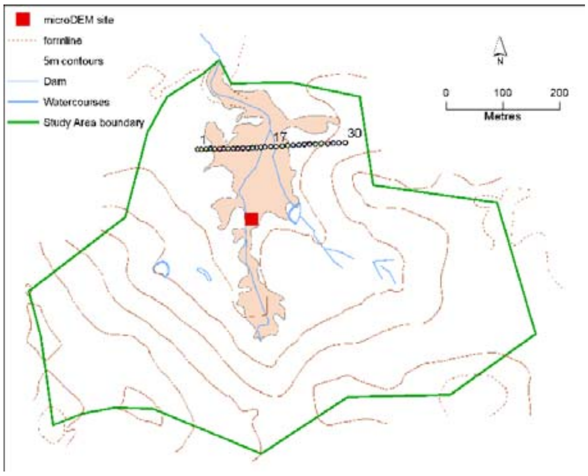

Figure 3. Location of the microDEM and erosion pins (1 to 30) in the study area. The erosion pins provide a cross section through the salt scald while the microDEM is within the scald (pink), close to an upper boundary.

3. METHOD

3.1. MicroDEM

The DEM for this work has historically been measured manually using a 1 x 1m steel quadrat that mounts on four corner posts that are permanently fixed at the site (Fig. 3). Holes at 2.5 cm spacing on opposite sides of the quadrat allow repeatable alignment of a movable cross bar on the N-S axis while 2.5 cm spaced holes on the cross bar allow a measuring pin to be lowered to the surface across the E-W axis. Data points are imported from a spreadsheet directly into Arcinfo GRID with no interpolation. Since heights are measured from above they are subtracted from a datum of 400mm to give a surface elevation.

Figure 3. The instrument for measuring the microDEMs manually. (from the west).

3.2. Photosynth

Photosynth (Microsoft corporation, 2009) is a web application that was developed as a tool for photo tourism allowing users to supply a set of photos of an object that is then automatically arranged in 3 dimensional space. The photo reconstruction techniques applied within photosynth produce a large number of points that represent features that can be identified in multiple photos. The combination of all these points forms a 3 dimensional cloud of points that sit on the surface of the objects visible in the photos. The point cloud is visible in the photosynth internet viewer interface.

There is no point cloud export option but it can be captured when creating or viewing a synth (the name of the output of photosynth) (Binarymillenium, 2008). The captured point cloud is then reformatted for importing into ArcGIS for analysis.

When the micro DEM was routinely resurveyed using the manual method in October 2008 the quadrat was also photographed using a modest Panasonic Lumix 9 megapixel camera to trial *Photosynth*. Any photos greater than 2 megapixels are resampled by *Photosynth* to its working resolution of 2 megapixels. A total of 273 photos were taken in several minutes by circling the area at varying distances between 2 and 15m and taking photos in burst mode. After downloading, the *Photosynth* application took a few hours to process the model.

The coordinate system and orientation of the resulting model is arbitarily determined by photosynth and needed to be transformed into real world, i.e. the quadrat, coordinates to allow comparisons with the manual measurments. This was accomplished by first clipping out just the frame coordinates by successive reselections and estimating the position of the corner points from the point cloud. This is the most difficult part of the process and more reliable methods are being considered. With the control points established in both coordinate systems a transformation matrix was developed in the Microsoft Excel Solver module and based on the quarternion rotation transformation as described in Wikipedia (2009). Once the model parameters were established in Excel they were applied to the dataset points that were cropped approximately to the inner dimensions of the quadrat frame to reduce processing and eliminate additional noise. *There was considerable noise within the point cloud* of the quadrat which was reduced in a staged process. Firstly, the transformed points were interpolated at 2.5cm resolution using the inverse distance weighting (IDW) command in ArcInfo Grid where any points deviating from this surface by more than 2mm were discarded. Secondly, the retained grid was converted to points and the procedure repeated. Thidly, the filtered points were interpolated using ANUDEM (Hutchinson, 1989) in a revised version developed to handle dense noisy data (Hutchinson *et al*., this conference).

Figure 4. Photosynth output (from southeast) showing the relevant photo for that view with the point cloud (that is underneath) evident at the sides.

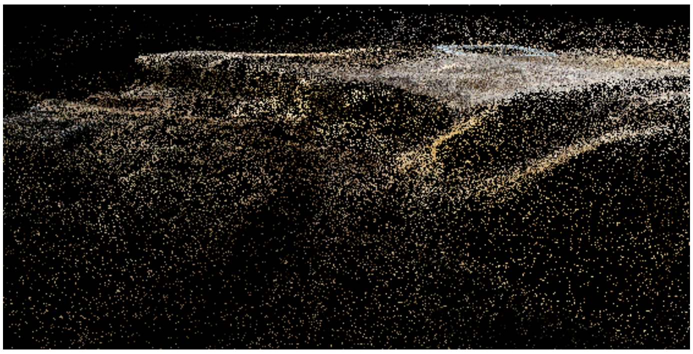

Figure 5. Photosynth point cloud (from southeast) illustrating the potential for detailed erosion modelling of overhangs.

4. RESULTS

The results are presented in 2 steps: a) the *photosynth* products b) comparison with the manual collection method. Figure 4 shows the *Photosynth* output from one of the more distant photos used in the model, draped over the 3D model. Figure 5 is essentially the same view showing only the point cloud and highlighting the challenges for 3 dimensional GIS in the form of undercut banks. Figure 6 is a close up of the microDEM site from several metres illustrating the ability to see underneath the frame, and the problem in isolating appropriate control points on the frame. While the ground and quadrat surfaces are quite coherent significant noise is evident above and to the right of the frame.

The point cloud for the entire model consisted of over 600,000 points which was reduced to 115,135 when clipped to the inside of the frame. After the noise filtering 52,014 points were read in Anudem of which 48,461 were accepted into the grid at 2.5 cm resolution.

Figure 6. Photosynth point cloud (from northwest) illustrating the 3D depiction of the quadrat frame that was used to obtain the control points for the transformation.

Figure 7 illustrates the amount of noise in the raw (pointgridded) photosynthDEM (clipped outside the frame) compared to the manually sampled microDEM (only sampled inside the frame) in Figure 8. Figure 9 shows the photosynthDEM after the filtering steps and overlayed on the microDEM (grey). Figure 10 is the difference grid (photosynthdem – microDEM) with the minimum value of -12mm, maximum 10mm, mean of -.005 mm and standard dev. 2.4 mm.

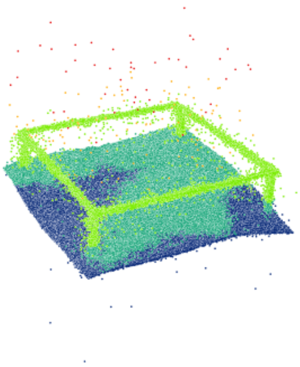

Figure 7. Raw *Photosynth* points (from northwest) before being clipped, transformed, gridded and interpolated

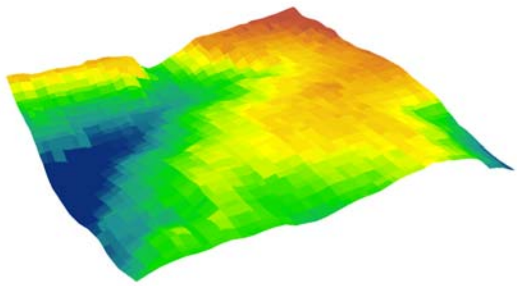

Figure 8. Manually sampled microDEM (from northwest) which is simply imported into grid at final resolution of 2.5cm.

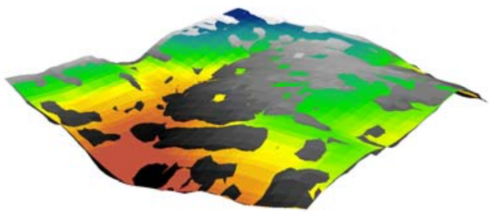

Figure 9. Final *Photosynth* DEM (from northwest) in colour (red low; blue high) overlayed on the manually collected microDEM (greyshade).

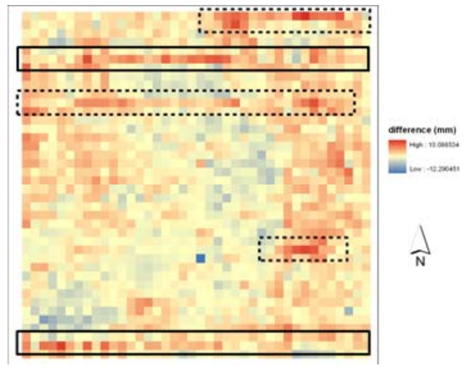

Figure 10. Difference surface (Photosynth – Manual)**.** Solid rectangles indicate where field notes were made about adjustments to the quadrat; dashed ones were not

5. DISCUSSION

While there is a good agreement between the methods (Fig. 9) a quantitative analysis is reliant on good observed data. In this study the difference grid (Fig. 10) raises some doubt about the accuracy of the manually collected DEM. The black rectangles indicate adjustments made to the quadrat frame and/or measuring-pin alignment during recording and distinct changes in height differences between rows are evident. A number of similar artefacts (in dashed rectangles) are also evident, where unintentional adjustments appear to have been made without the operators' knowledge. This suggests that there are significant errors in the manual sampling that may compromise its use as a reliable ground truth comparison.

Point cloud conversion to world (microDEM frame) coordinates is straight forward and cost effective. Deriving the transformation parameters currently involves manually selecting appropriate control points coinciding with the top surface of the frame as close to the corners as possible. This step is the most difficult and time consuming given the point distribution and noisy nature of the data. An alternative is to attach appropriate markers on the corners that can be readily identified in the point cloud. This and a method to accurately capture GPS coordinates of the camera at exposure time are being investigated to enable the camera locations (also available in model coordinates from *photosynth*) to be used as more reliable control points.

The number of photos that are necessary and the distance range from the area of interest are important in deriving data for particular resolutions and need to be understood. This and other factors such as the pattern detail that *Photosynth* has to work with can affect the density and noise of the point cloud and thus the resolution of the DEM that can be supported. These are also being investigated.

Noise in the photosynth point cloud is most likely attributable to pattern mismatches in *photosynth*, caused by photo quality, detail, pattern complexity and shadowing. Although visually this is a major consideration in the raw DEM derived by pointgrid-ing the transformed points (Fig. 7), the coherence of ground surface points makes filtering straightforward. With the large number of points per 2.5 cm cell compared to one manually sampled point the photogrammetric method has the potential to provide even finer resolution DEM.

It is likely that photosynth internally has a measure of quality of fit for each point and if this was made available it could improve noise removal techniques.

6. CONCLUSIONS

The *Photosynth* DEM is useful in dramatically reducing the data collection time and cost while producing a finer resolution DEM. The results show good agreement between very fine resolution microDEMs obtained by manual and automated methods, although discrepancies that do occur between them point more towards inadequacies in the manual sampling methods.

Photosynth is a more cost effective technology that opens the door to capturing a larger number of representative sites (landscape positions) in a catchment rather than just the one used for this long term erosion study. The advantage of using a microDEM because it averages many elevation changes over a reasonable area, ie is data rich, can easily be extended to a large number of sites in a catchment further helping to reduce uncertainty. Selected representative microDEMs could be targeted to provide more useful information in appropriate sites and selected point surveys could target other less appropriate landscape / landcover sites.

A potential disadvantage of using *Photosynth* is that data is retained on the *Photosynth* site and could be problamatic if privacy was a concern. The Photosynth engine is available commercially but it appears to be prohibitively expensive for this type of application. There are alternatives like Bundler (Snavely, N., 2009) which photosynth is based on and we would like to investigate this.

The study has shown that with minimal post processing Photosynth can be used to capture a DEM for a small area in a minimal time. The DEM produced is of a high quality. Further work to test this method over larger areas is likely to indicate the usefulness of the technique for capturing DEMs of small study sites.

With the ability to adjust the distance from camera to target or select appropriate photos there is potential to generate a point cloud that has a variable density of points this opens up possibilities for multi-resolution analyses rather than the degradation or smoothing of a single DEM. These are interesting areas that are currently being investigated.

ACKNOWLEDGMENTS

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