Determining gully volume from straightforward photo-based 3D reconstruction

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1. Introduction

Digital elevation models (DEMs) can be derived by conventional photogrammetry approaches, but this usually requires aerial photographs or stereo pairs, specialist software, expertise, and extensive manual measurement of control points or features.

Here, we use a computer vision technique (a combination of structure-from-motion[1] and multi-view stereo[2], **SfM-MVS**) that automatically constructs 3D models using images from consumer cameras[3]. Key advantages of this approach are:

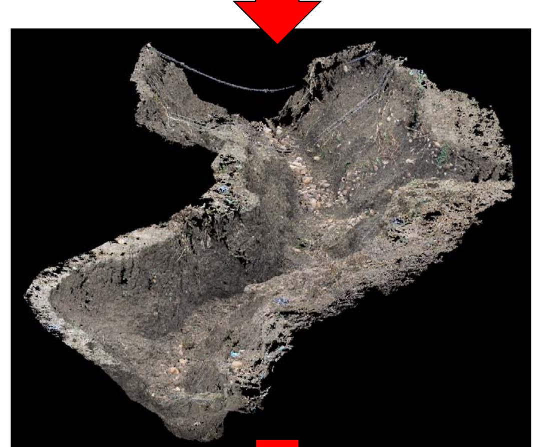
- automatic image processing and model generation
- oblique (ground-based) or aerial images
- significantly reduced control-point requirements
- free software with automated camera calibration

We explore the practicalities and accuracy of SfM-MVS for volume estimation of erosion gullies, comparing the results with equivalent data collected with a terrestrial laser scanner (TLS).

2. SfM-MVS method

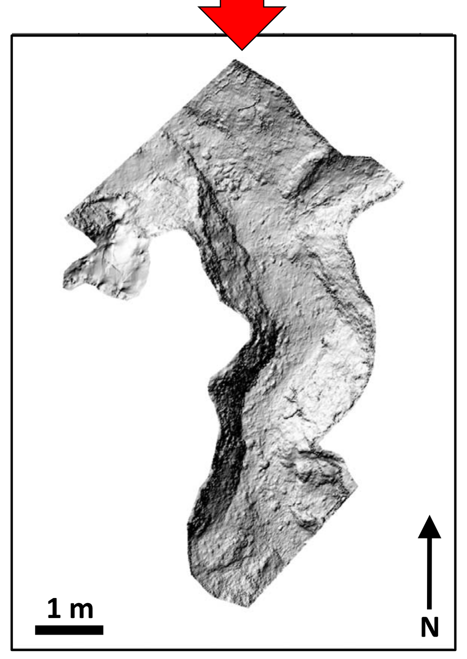
image collection using a digital SLR camera from different positions

automated 3D reconstruction[a]



3D coloured point cloud (without scale or orientation)

define scale and georeference[b]



interpolate point cloud into DEM surface

3. Study site[4]: La Conchuela, Cordoba, Spain

- olive farmland in Campina landscape around the Guadalquivir River
- 7.1 m long gully section in Vertisol soil; average width, 2.4 m, average depth 1.2 m

4. Data collection and processing

Terrestrial laser scanner (TLS)

- data collected by an independent contractor, using a Riegl LMS-Z210i (accuracy ~10 mm)
- two scan positions, two scanner orientations at each, georeferenced using control targets and differential GPS (dGPS)
- data collection ~ 1 hr, data processing ~1 hr.
- contractor interpolated point cloud onto a 2-cm grid

SfM-MVS

- 191 photos taken with a Canon EOS 450D digital SLR camera and 28 mm lens, walking round the gully (~10 minutes, example photos given in panel to left)
- automatic processing on a laptop (a few hours)
- resulting 3D model scaled and georeferenced using 6 control targets (RMS error on control = 32 mm for control measured by dGPS, 11 mm for control measured by total station)

Software and References

[a] **Reconstruction pipeline:** http://blog.neonascent.net/archives/bundler-photogrammetry-package
[b] **Georeferencing:** http://www.lancs.ac.uk/staff/jamesm/software/sfm_georef.htm

[1] Snavely et al (2006), Photo tourism: Exploring photo collections in 3D, *ACM Trans. Graphics*, 25, 835-846, doi: 10.1145/1141911.1141964.

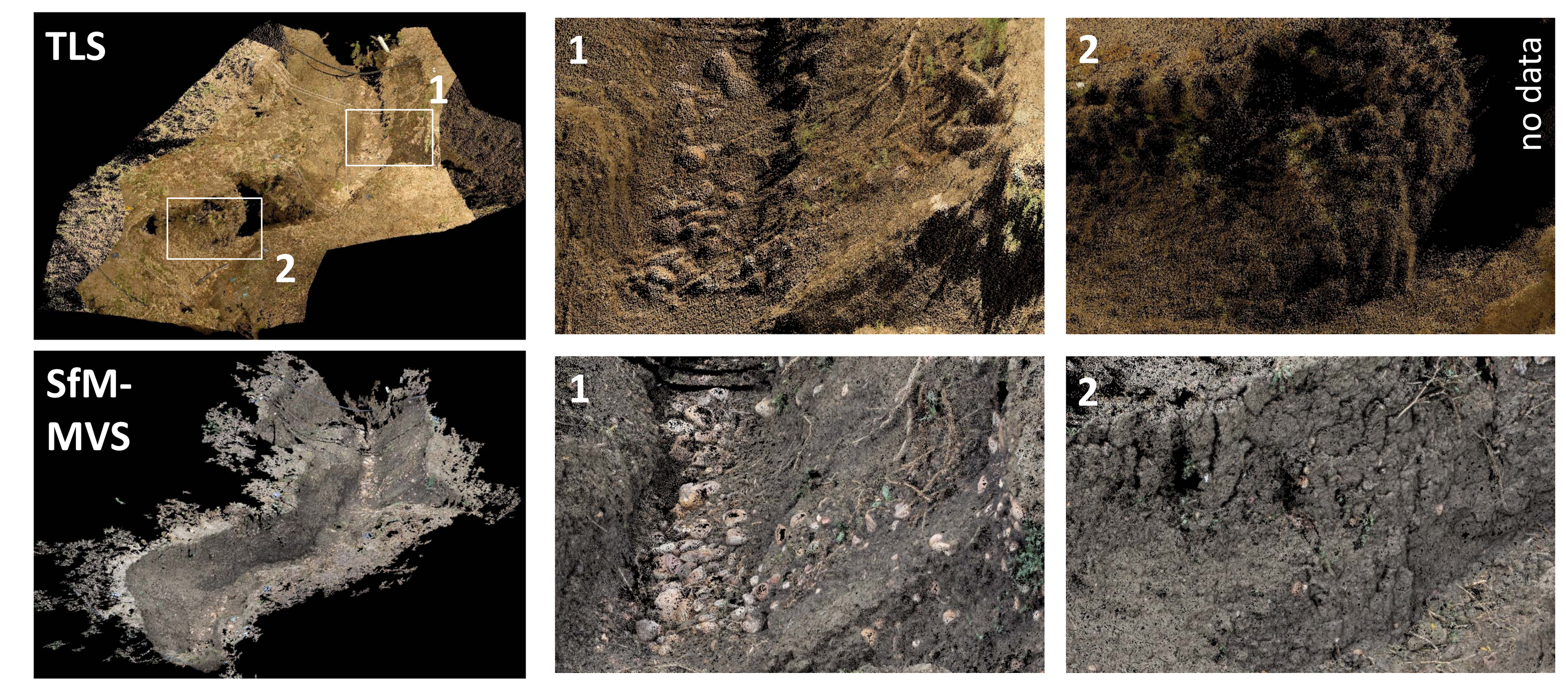
[2] Furukawa & Ponce (2010), Accurate, dense, and robust multiview stereopsis, *IEEE Trans. Pattern Anal. Mach. Intell.*, 32, 1362-1376, doi: 10.1109/TPAMI.2009.161.

[3] James & Robson (submitted to *J.Geophys. Res.*, Nov. 2011) Straightforward reconstruction of 3D surfaces and topography with a camera: Accuracy and geoscience applications.

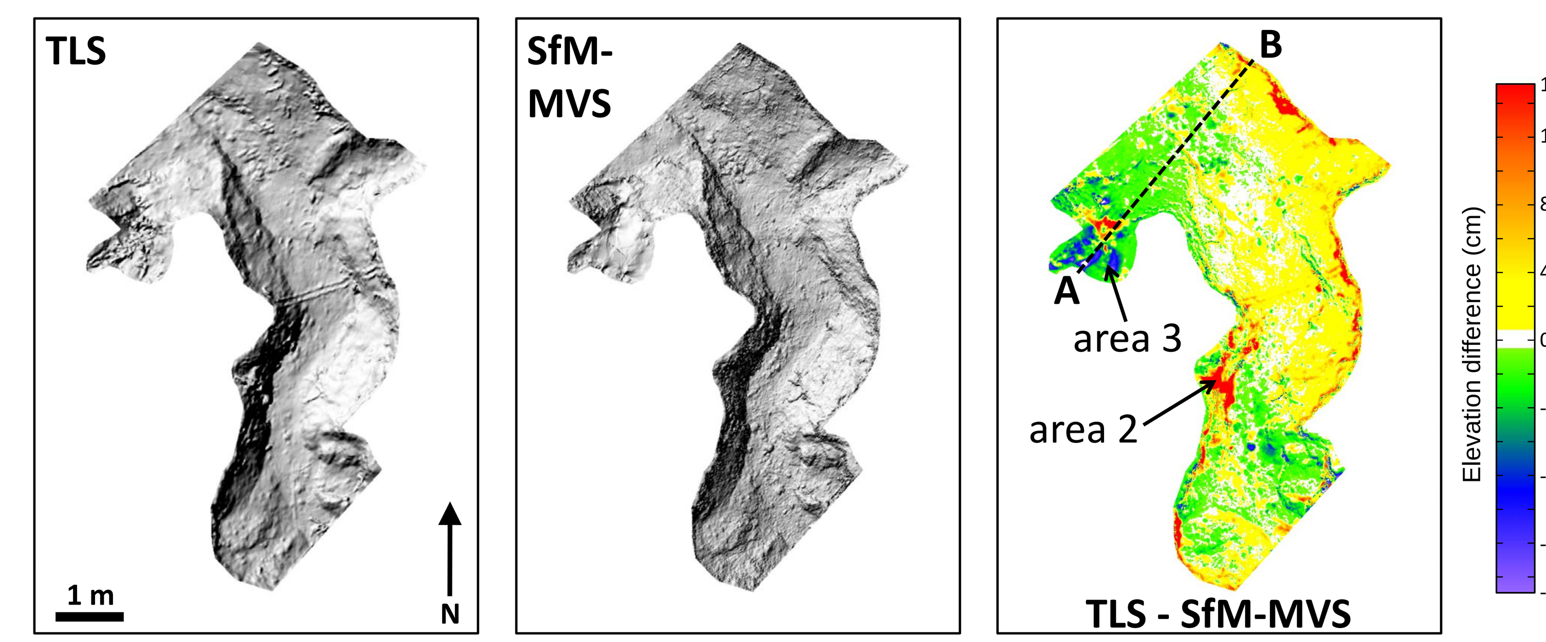
[4] Castillo, C., Pérez, R., James, M. R., Quinton, J. N., Taguas, E. V. and Gómez, J. A. (submitted to *Soil Sci. Soc. Am. J.*, Nov. 2011) Comparing the accuracy of several field methods for measuring gully erosion

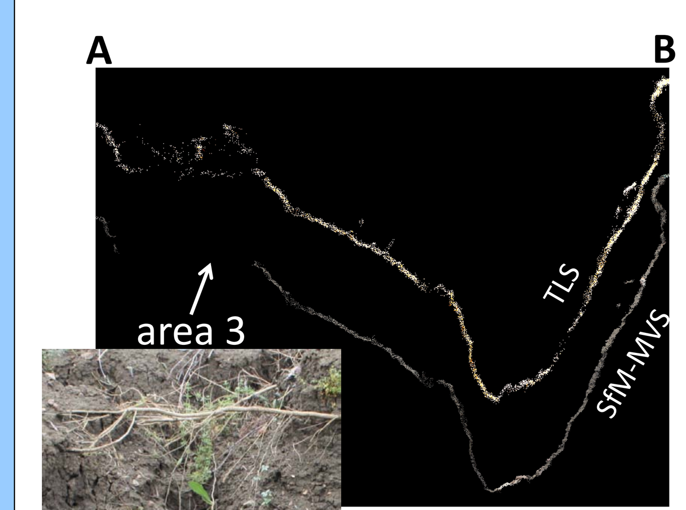
5. Comparisons

Point clouds: For the gully region, both TLS and SfM-MVS point clouds contained ~5×10^6 points. Overviews are given below (left panels) with close ups of labelled areas 1 and 2 for comparison. Note that no colour balancing has been attempted. Area 1 illustrates the comparable data quality and area 2 shows data captured by SfM-MVS in an area that was occluded from the TLS.



DEMs: Shaded relief models of the DEMs, with elevation differences given in the right panel (white areas are within ±5 mm).





Above: Section A-B through the point cloud data. Sections are vertically offset for clarity. In an area of dense root network, TLS data are noisy and SfM-MVS does not reconstruct the surface

Elevation differences due to:

- overall georeferencing errors ~ ±2 cm
- missing TLS data (area 2 above)
- areas covered in root networks that are not reconstructed by SfM-MVS and give complex laser data (see left)

6. Conclusions

Gully volumes

TLS:	12.73 m^3
SfM-MVS:	12.88 m^3
difference:	1.2 %

- SfM-MVS can be used for easy and cheap DEM generation from photos
- precisions can approach those of terrestrial laser scanners

Also see: Castillo et al. (EGU2012-11321 - Comparing the accuracy of several field methods for measuring gully erosion) and James & Robson (EGU2012-4550 - The accuracy of photo-based structure-from-motion DEMs)