SfM-MVS based Haar Wavelet Decomposition as a tool to examine mixed grain size sedimentary outcrops

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Introduction

Outcrop is arguably the most important source of data to study subsurface geology and geomorphology. Despite being a traditional technique, outcrop analysis has recently seen a methodological regain of interest, with the application of spatial remote sensing techniques, such as close-range hyperspectral imagery for mapping mineral content (Buckley et al., 2013), and terrestrial laser scanner to retrieve millimeter to centimeter scale features (Bellian et al., 2005), or a mix of both approaches (Buckley et al., 2013). When these techniques can be very cost-prohibitive, the application of a 3D photogrammetric low-cost method has been developing very rapidly in the last 5 years: Structure from Motion (SfM) and Multiple-View Stereophotogrammetry (MVS).
For this contribution, the authors aim to (1) present the usage of Structure from motion associated with Multiple-View Stereophotogrammetry - a method that can achieve results comparable to terrestrial laser scanner for almost no-cost – and its application to outcrop analysis; and (2) test the use of wavelet decomposition to surface roughness analysis and by then the development of semi-automated analysis.

In 1979, SfM was first developed in the field of computer-vision engineering (Ullman, 1979). It has since developed into a valuable tool for generating 3D models from 2D imagery (Szelinski, 2011). This development has then in turn benefited the fields of geomorphology and geomorphometry, from hand-sample sizes (Westobuy et al., 200x), using either purposely taken photographs or existing archives (Gomez, 2014; Gomez et al., 2014) either from handheld cameras (XXX, Morgenroth and Gomez, 2014) or cameras mounted on flying vehicles (Obanawa et al., 2014a,b). The success of the method is based the limited necessary parameters, which makes it very polyvalent. Indeed, traditional photogrammetry requires a series of identifiable points identifiable in at least two photographs and, perhaps more importantly, known values of camera projection, distortion, position, and orientation (Robertson and Cipolla, 2009). By contrast, SfM uses algorithms to identify matching features in a collection of overlapping digital images, and calculates camera location and orientation from the differential positions of multiple matched features (Fisher et al., 2005; Quan, 2010; Szeliski, 2011). Based on these calculations overlapping imagery can be used to reconstruct a 3D model of the photographed object or scene. Where relative projection geometry and camera position are known, the values can be integrated into the SfM reconstruction to improve the calculation productivity and accuracy of the model (Agisoft

Photoscan-PRO Users Manual, http://downloads.agisoft.ru/pdf/photoscan-pro_0_9_0_en.pdf).

A number of desktop (e.g. Bundler; Snavely *et al*., 2006; Snaveley, 2010) and browser-based (e.g. Microsoft Photosynth; photosynth.net) SfM software packages are freely available for generating 3D scenes from digital photographs. However, this study used a commercial software program, Agisoft Photoscan-Professional, which has been used in several of the published studies in geomorphometr (http://agisoft.ru/products/photoscan/professional). Although the procedures described in this study are achievable using the freeware options, the decision to use Photoscan-Professional software was also made, because it also includes MVS algorithms, meshing the produced pointclouds. Using the combination of SfM and MVS, the software can then retrieve an initial set of sparse points from matching features (SfM), increase the point-cloud density, and then mesh the pointcloud into a surface using the MVS algorithm (Agisoft Photoscan-PRO Users Manual; James and Robson, 2012; Verhoeven *et al*., 2012).

Data collection and creation methods such as laser scanners or photogrammetric methods have multiplied the amount of measures possible by at least 6 digits compared to previous manual collection methods, and consequently one arising issue that had to be addressed is how to process effectively large datasets and also what extra-information can be extracted from it - as increasing the size of datasets for its own sake isn't a goal for geoscientists.
One of the possibility to extract information from large morphometric datasets comes from the broad field of 'data mining', with different statistical and analytical tools, like Fourier transforms and wavelet analysis that can be adapted from time-series to topographic features (Gomez, 20XX), the later we used for the present contribution.
During the last 10 years, the use of wavelet analysis in Earth-sciences has increased concomitantly with the increasing availability of numerical data. It has especially benefited the study of time-series for the determination of different frequencies and momentum (e.g. Andreo et al. 2006; Partal and Küçük 2006; Rossi et al. 2009). Analyses of space-scale data with wavelet - although more scarce in earth-sciences – are also on the rise (e.g. Audet and Mareschal 2007; Booth et al. 2009; Lashermes et al. 2007), eventually following the influence of research in medical imagery, which has been widely using wavelet for topographical analysis for instance (e.g. Langenbucher et al. 2002).
Wavelets allow the decomposition of a signal into a set of approximations, which is hierarchically organized in a combination of different scales. Wavelet analyses use a short-term duration wave as a kernel function in an integral transform. There are several types of wavelet, which are named after their 'creators': e.g. Morlet wavelet, Meyer wavelet. Based on the shape of the series/function that needs to be analyzed, the appropriate mother wavelet is scaled and translated (daughter wavelet), allowing the detection of the different frequencies of a signal at different time (Torrence and Compo 1998; Schneider and Farge 2006). Wavelet is a well-fitted tool for separating spectral components of the topography (i.e. working on the different scales of a single object), because it returns both the spatial and the spectral resolution.
The present contribution, therefore uses a method based on the combination of (1) SfM-MVS based data collection and creation and (2) wavelet decomposition.

Location

The dataset used in the present contribution is an outcrop peel conserved at the University of Niigata and that has been retrieved from deposits produced by Numazawa Volcano, Honshu, Japan (FIG LOCATION). Numazawa Volcano erupted last 5,000 years ago, emplacing at least 4 km^3 of ignimbrites confined in valley around the volcano, reaching tens of meters thickness in the Agano and the Tadami rivers (Kataoka et al., 2008). In this publication, the authors demonstrate that the eruption also resulted in floods that impacted the Tadami River, from which the peel of the sediment outcrop has been retrieved. The peel is part of a 15 m thick hyperconcentrated-flow deposit that lied on top of debris-flow deposits, and which is made of coarse sand to pebble size material.

Method

For the present study, a sandy to gravely material from Numazawa Volcano (Japan) has been digitally acquired and analyzed. The sedimentary peel from Numazawa volcano is 85 cm wide and 290 cm high. It is mainly displaying a matrix of coarse sands with intercalated layers of coarser material ranging from sands to pebbles. The digital data has been collected using a point and shoot digital camera (Canon cybershot), by 'hoovering' over the outcrop taking 170 photographs from a distance of 10 to 40 cm. To reach the best results, the favoured image retrieval to conduct SfM on a dataset varying over a horizontal plane, is to reproduce the movement of an imaginary aircraft flying to take aerial photographs (Agisoft Photoscan-PRO Users Manual). Therefore, the photographs were taken following this method and in such a way that it allows sufficient overlap to display features on multiple photographs. The SfM processing was carried out using the software Photoscanpro® created by Agisoft®. From the created dense pointcloud, a surface was then extrapolated before being exported into Matlab as a Tiff file representing the surface variation from a hypothetic vertical wall. In Matlab, the surface was transformed into series of vertical and horizontal signals, decomposed into '7 scales' signals using Haar wavelets (Fig. Method). From the decomposed signal, the general trend of outcrop-scale slant was subtracted in order to only keep the variations at the millimeter to pluri-centimeter scale.

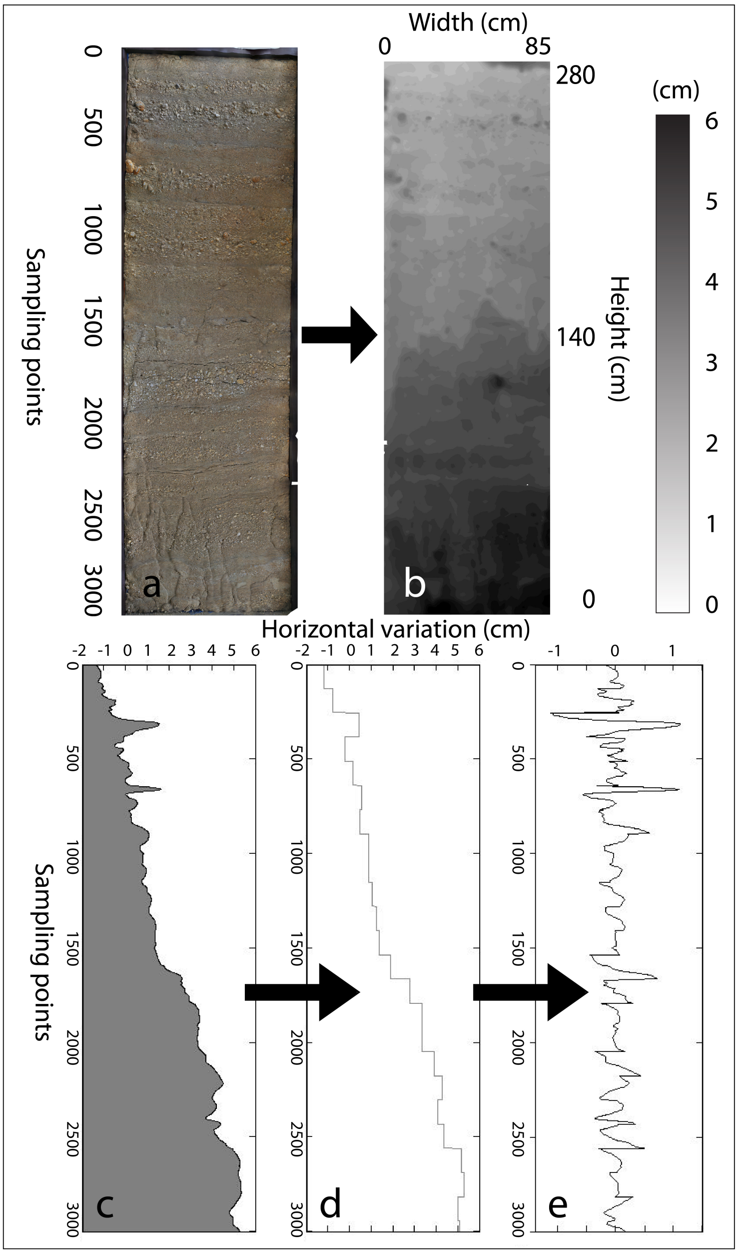

Fig. Method Transformation of the surface 'topography' obtained from Structure From Motion. (a) Orthophotograph constructed from Structure from Motion; (b) Surface variation, the 0 being the perfect vertical; (c) Surface extraction of the vertical transect at the centre of the outcrop; (d) 'topographic' general trend as extracted by Haar wavelet decomposition (Level 7 of a 7 scales decomposition); (e) Combination of the 4 lowest level of wavelet decomposition minus the main trend at level 7 (e = L1+L2+L3+L4-L7).

Results

The conserved peel is dominated by a series of horizontal sandy layers with intercalations of coarse sands to pebble size material, which have generated on the SfM-MVS created surface variations usually referred to as surface roughness, and which can be associated to topographic variations for a horizontal surface. The high-density of points (more than 10 millions for a surface of 290 cm x 85 cm, i.e. > 4 millions points per square meter, allows a precise reconstruction of the peel-surface roughness (cf. b in fig. method and right-hand side of fig. x).

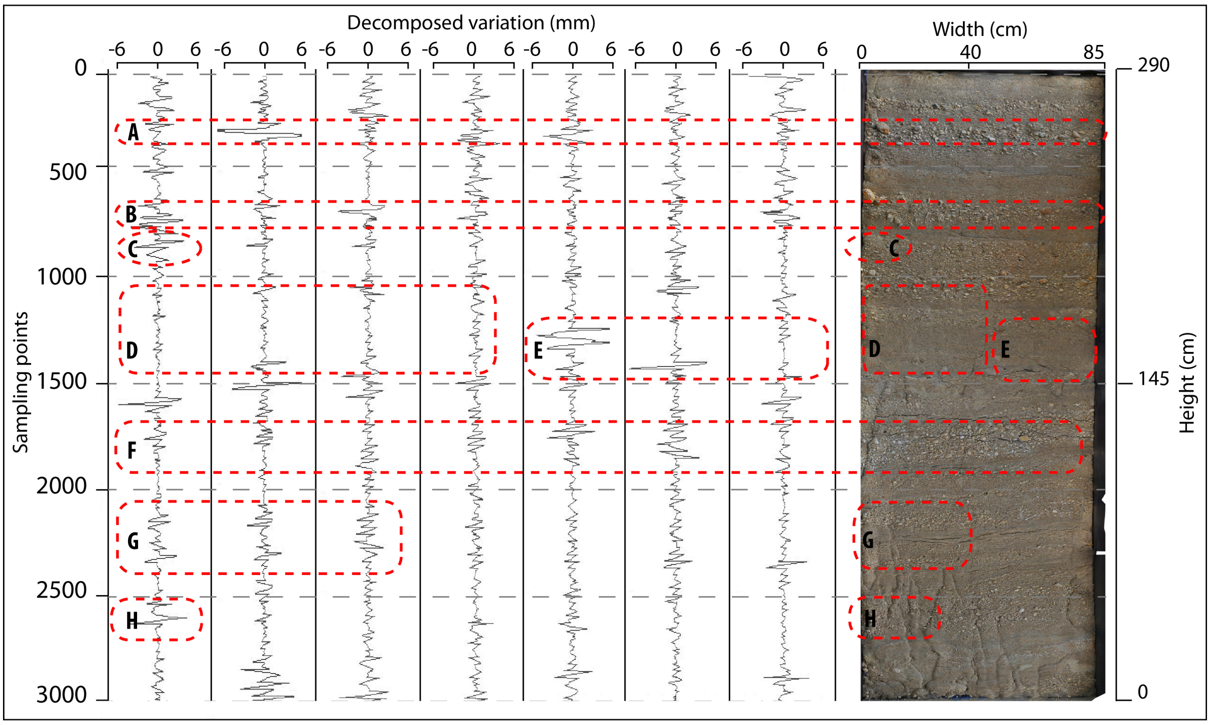

Fig. Reconstruct_signalLevel1

3D reconstruction of both outcrops with SfM-MVS shows the capacity of the method at different scales

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