# The Application of Photogrammetry for Process Quantification in Geomorphology – Examples of Modern Applications

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## Summary

Photogrammetry is a well established tool in the earth sciences for retrieval of qualitative as well as quantitative information from imagery. In the past, analysis was predominantly performed on publicly available or archival imagery taken by trained photogrammetrists. In this case mission planning, image acquisition, camera calibration, and image orientation were often readily available to earth scientists at the start of their analyses. The photogrammetric products that are of interest to earth scientists are typically digital elevation models (DEMs) or orthophotos that are processed for analysis. Monitoring of changes in the landscape, or tracking the course of a laboratory experiment requires data for different time steps for quantification of processes. Although earth scientists apply well-established photogrammetric techniques for data acquisition, workflow and hardware setup can pose challenges to the users with little experience. Expectations regarding accuracy in object space are often close to the theoretical limit of a given setup and are difficult to meet under field conditions or during short breaks of experiments for data capture. Therefore, the workflow for data acquisition must be streamlined and the hardware optimized to yield optimum accuracy under these conditions. In this paper we will present some geomorphologic experiments where digital photogrammetry was employed for data capture. Special attention was given to uncommon or novel solutions of camera setup and hardware easing data capture or image processing for analysis in the earth sciences.

## 1 Soil Erosion Experiments in the Laboratory

### *1.1 Small format digital camera*

A laboratory rainfall experiment was performed to quantify the effect of slope shape and rill network development in a 4 m x 4 m soil bed (Rieke-Zapp and Nearing, 2005a). As many of the processes involved in soil erosion act on the millimetre scale, DEMs with millimetre (3 mm grid spacing) resolution were generated from imagery taken during short breaks of the experiments. The faster the images were acquired, the sooner the experiment could continue. For this experiment a 6 megapixel Kodak DCS 1 monochrome camera was employed. Stereoscopic coverage of the soil box was accomplished with 16 images in a block (Figure 1). Control points were signalized only around the flume (Figure 1).

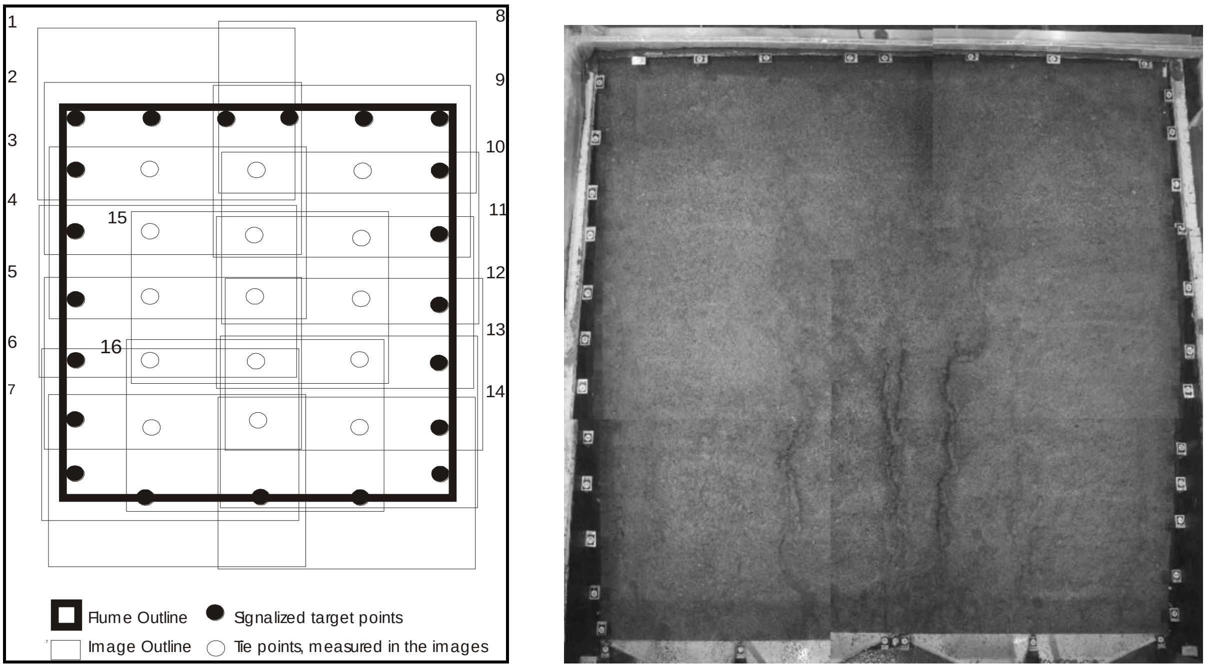

*Figure 1. Coverage of a 4 m x 4 m flume with a block of imagery (left). Image mosaic of the flume (right).*

While control points were measured semi-automatically, natural points on the soil surface were chosen as tie points and had to be measured manually. The DEMs for analysis were calculated by image matching using DPCOR software (DPCOR, 2000). Sub-millimetre accuracy for control points was accomplished for the control and tie points based on the results of the bundle block adjustments. Comparing overlapping stereo models to estimate the precision in Z-direction of the DEMs, yielded a standard error of 1·26 mm (Rieke-Zapp and Nearing, 2005b).

This experiment has shown that DEMs with mm precision can be accomplished for soil surfaces, but further automation of the workflow was needed to generate DEMs in a timely fashion. Furthermore, the digital sensor inside the camera had to be fixed to increase the stability of interior orientation.

## *1.2 Digital shift camera*

For a subsequent laboratory rainfall experiment the size of the plot size was reduced set to 1 m x 2 m, because the resulting DEM with 3 mm grid spacing was to be used in a software model that would not support more cells. Stereo coverage of the box was accomplished with two nadir images taken with a single Alpa TC medium format camera and a digital camera back mounted to the camera. Nadir images were assumed to be most suitable for image correlation software because of little variation in scale compared to oblique imagery. A stereo overlap of 60 per cent would have resulted in a reasonable base length between camera station in order to utilize more than just 60 per cent of the sensor a lens with 8 mm displacement of the principal point was used. Keeping the base length fixed, a stereo overlap of approximately 80 per cent was possible (Figure 2). Keeping the cameras parallel to the experimental surface was also advantageous to keep the whole surface in focus which is more difficult when working with an oblique camera setup. Calibration of cameras with such asymmetric field of view poses no major problem and the gain in coverage and resolution outweighs slightly worse calibration results (Rieke-Zapp and Peipe, 2006). The displacement of the principal point is a very useful tool for terrestrial applications (i.e., Meydenbauer, 1912)

*Figure 2. Setup with two camera stations above the soil surface (left) Stereo image pair of the flume surface.*

## 1.3 Field applications

While laboratory experiments are typically well controlled and problems with the setup may easily be solved during experiments or in the next replicate, field applications usually require quick setup in the field, establishing a reference frame, and covering a fairly large object with high precision. InSAR was used in a research project to predict soil water content in a small watershed upstream of the River Elbe near Dresden, Germany. Ground truth information for analysis of the InSAR flight required among other things input of soil surface roughness which was calculated from terrestrial photogrammetric measurements on fallow. Images for DEM generation were acquired on two fields at two locations. The surface area was staked out in 5 m x 1 m areas that overlapped in a cross like pattern oriented along and across the flight track of the airplane (Figure 3). Within one day four plots had to be staked out and images were taken to generate DEM with a grid spacing of 1 mm and a desired accuracy of 1 mm to calculate soil surface roughness. Control points were signalized and scale bars were distributed around the plots (Figure 3). In a first step, images for camera calibration were acquired. Interior geometry of the camera was calculated in a bundle block adjustment along with coordinates of control points. Then images for DEM generation were taken from a step ladder covering the soil surface with two strips of imagery pointing the camera straight down.

*Figure 3. Photogrammetric setup for soil surface roughness measurements in the field (left). Digital elevation model generated from images (right).*

### *1.4 Mono image adjustment*

Provenience analysis of marble in antique buildings or statues is a field of activity for historians, chemists as well as geologists that can help to figure out whether statute is authentic or fake, where it came from, or where to find the marble for restoration. Grain size distribution and shape of calcite crystals in marbles can be one important factor – among others – for defining the provenance of marbles. The size of the crystals for marbles from the island of Naxos, Greece, was too large to collect a statistically significant sample using electron or light microscopy to measure grain sizes. Therefore, photogrammetry was chosen. Polished specimens of 0·2 m by 0·2 m were prepared. Illumination of the specimen had great influence on the perceptibility of grains in the images. Light source and camera had to be tilted for best perception of grain boundaries (Figure 4).

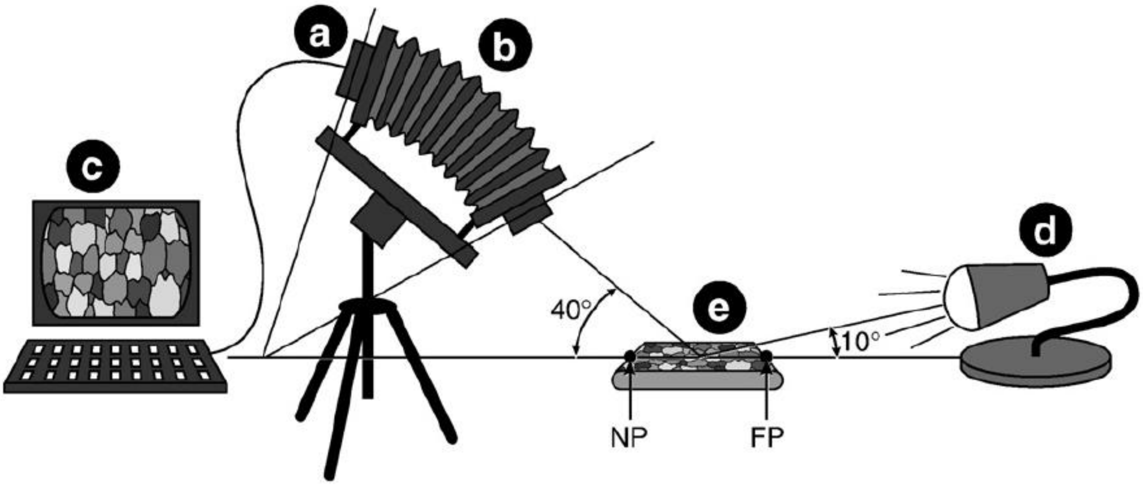

*Figure 4. Scheimpflug setup for coverage of marble samples (e). Camera (b), sensor plane (a), computer screen for image control (c), light source (d).*

A Scheimpflug (tilt) angle of 20° was necessary for best perceptibility of the grains and to keep the whole sample in focus. The sample was rotated to four different positions (Figure 5) to make all grain boundaries visible. Single image photogrammetry was suitable for this problem. One pixel represented approximately 0·036 mm in object space. Control points in a common coordinate system were marked on the surface of the samples before the experiments. Images were rectified in Rollei Metric Single Rectification software. The rms error estimated in the Rollei software was 0·05 mm and thus surpassed the accuracy of hand digitizing grain boundaries. Grain shape and grain size distribution parameters derived from the images were similar to the parameters derived from established methods (Figure 6) and had the additional advantage that larger grain sizes could be included in the analysis (Ebert *et al.*, 2009).

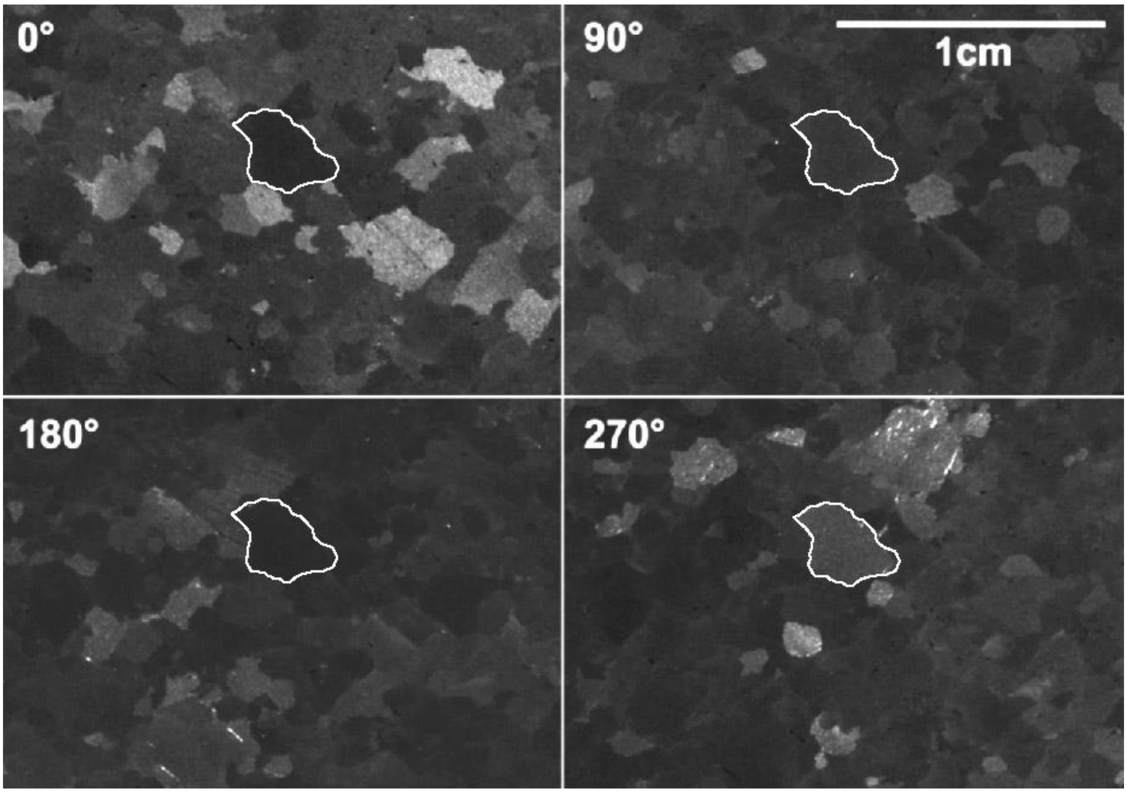

*Figure 5. Reflectance of the sample surface for different orientations towards the light source.*

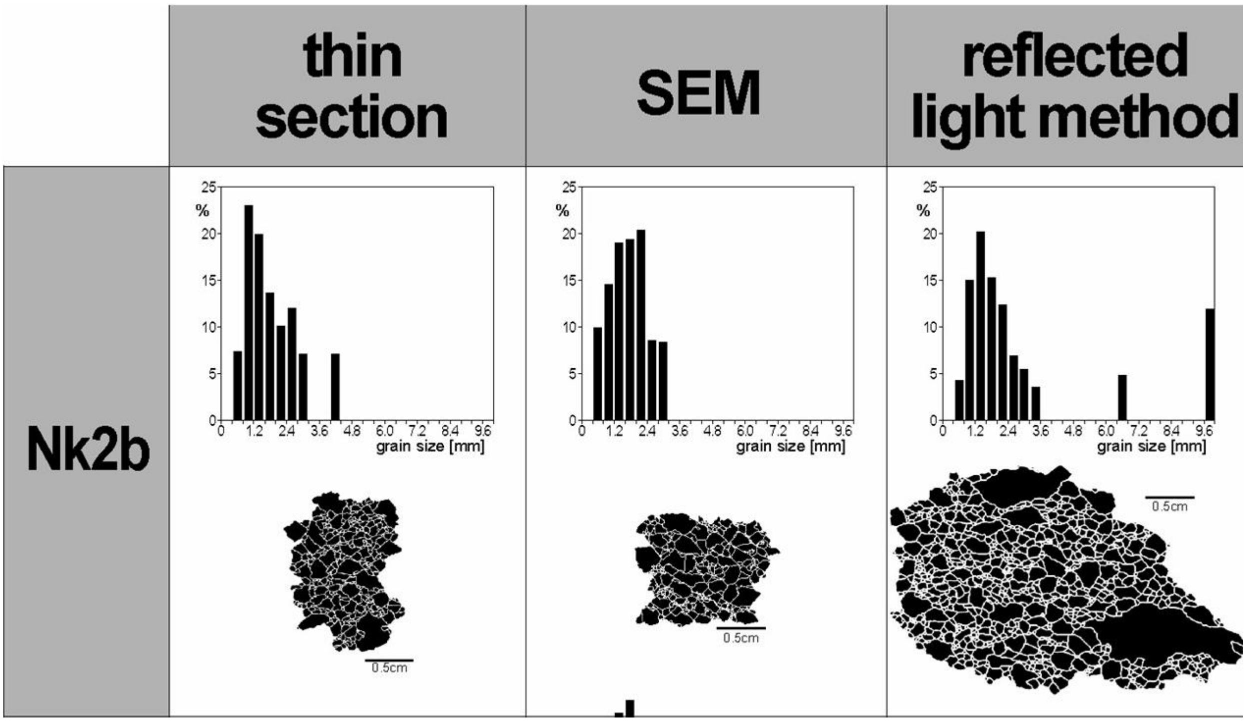

*Figure 6. Comparison results of three different methods for quantification of grain size distribution in marble specimens (sample Nk2b). Comparing light microscopy on thin section; Scanning Electron Microscopy (SEM), and photogrammetry with reflected light.*

# 2 Accuracy

## 2.1 Metric camera

Considering the amount of detail required for generation of dense DEMs from imager as well as the expectations on accuracy in object space, the ideal camera for application in earth sciences is a camera with stable interior orientation and large pixel count. The largest pixel count is available in digital medium format backs. These backs typically use larger sensor areas with wider pixel spacing than cameras based on the 35 mm format and a complete range of high-resolution digital lenses is available for medium format cameras. The major drawback of digital medium format systems was that both, lens and digital back have to be mounted to the cameras, which represent two sources of camera instability. At the same time lenses and backs for medium format cameras are heavier than 35 mm equipment aggravating stability problems. Consequently, a fairly rigid digital medium format camera should be chosen to fully exploit the accuracy potential of the large digital sensor. Identification of cameras with stable interior geometry that can be used for photogrammetry poses a perpetual challenge (Peipe and Schneider, 1995; Chandler *et al*., 2005; Rieke-Zapp *et al*., 2009a). The accuracy in object space of the Alpa 12 Metric with Leaf Aptus 75 digtal camera back, and a Schneider Kreuznach Apo Digitar 35 mm L where the focusing tube was fixed to a distance of 3·5 m was tested on a 2 m x 2 m x 1·5 m volume according to VDI/VDE 2634 (1) (2002). The maximum length measurement error in the volume was 0·043 mm calibrating with Aicon 3D Studio software (Figure 7) calibrating the interior orientation of the camera as well as additional parameters (A1, A2, A3, B1, B2, C1, C2). The rms error of the object coordinates calculated in the calibration was estimated to be approximately 0·008 mm in object space.

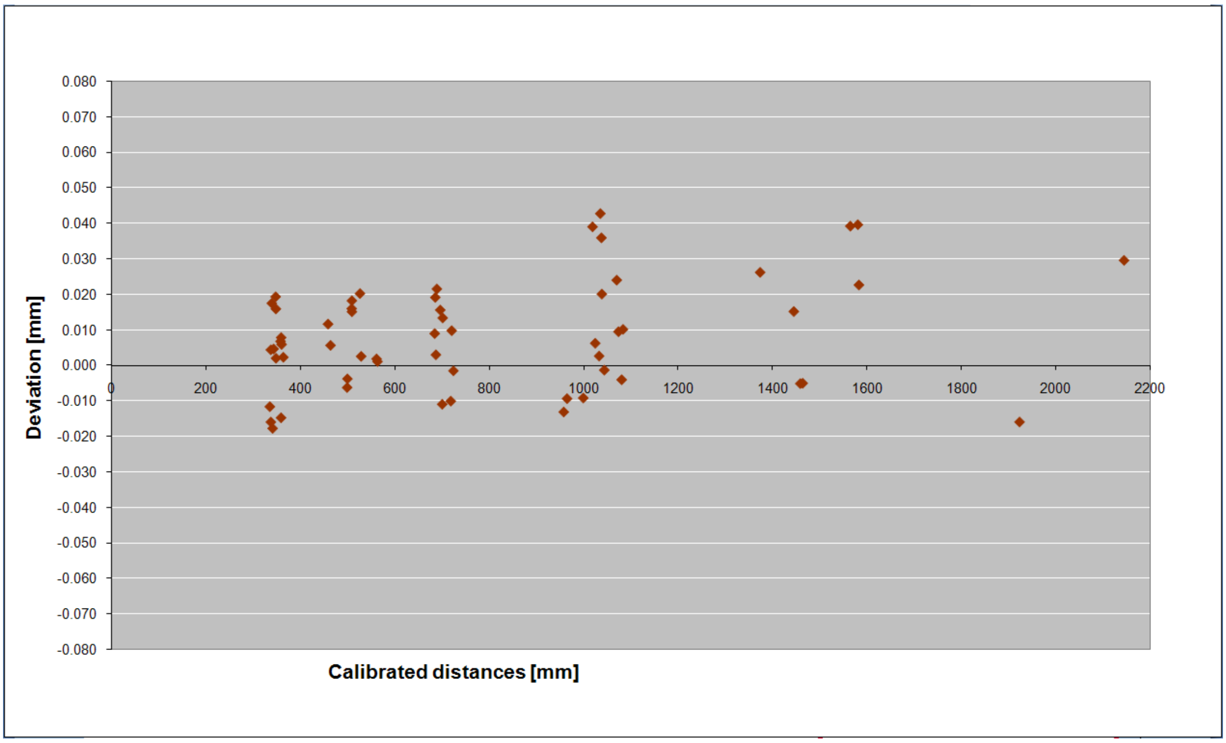

*Figure 7. Calibrated length measurement error of the Alpa 12 Metric camera with 35 mm lens calibrated on a 2 m x 2 m x 1·5 m volume.*

### *2.2 Field applications*

In order to find an easy to use photogrammetric setup that does not add much weight to the backpack of field scientists, a photogrammetric method was developed yielding optimum accuracy in object space with minimum equipment. A very lightweight setup for field surveying consists of a laser distance meter, three ping pong balls and a small digital camera (Rieke-Zapp *et al*., 2009b). The ping pong balls mark reference points on the object of interest and serve as omni-directional target points. The laser distance meter was used to measure scale distances between the balls. The ping pong balls appear as circular targets in the images. Recent laser distance meters offer an inclination sensor that allows calculation of a level coordinate system with adequate accuracy for measurements of strike and dip which refer to the orientation of a geologic feature in the stereo model. Recently, tests were undertaken on an 11 m x 14 x 3 m volume. The accuracy in object space of this setup was tested for several cameras (Bommer, 2009). Distances between signalized points were calculated after the photogrammetric adjustment of five images and compared to distances independently calculated from a total station survey. A Sigma DP1 camera revealed a maximum length measurement error of 38 mm. The rms error of all lengths was 12·5 mm. The camera also revealed a reasonably stable interior geometry despite the fact that the lens was retracted when the camera was shut down. Comparing results of five calibrations performed over a time span of two month revealed that the position of the principal point moved by approximately ±1 pixel. Camera constant and radial symmetric lens distortion also showed very little variation between calibrations. The Sigma camera in combination with a recent laser distance meter and ping pong balls weighed less than 0·4 kg. Software for analysis requires a least squares adjustment program for calculation of 3-dimensional coordinates from distances and angles measured between the ping pong balls and a digital photogrammetric workstation for image orientation and analysis. Adding camera calibration software suitable for non-experts makes for a complete system.

## 3 Hybrid Sensor

Hybrid sensors try to combine the advantages of different surveying tools to increase productivity and accuracy. One such sensor is an image assisted total station (IATS) (Reiterer, 2007). Placing a digital frame sensor in the image plane of a total station allows using both, the positioning accuracy of the total station as well as the mass point detection in photogrammetric images taken from two or more different stations (Figure 8). Because the total station turns around the perspective centre of the of the frame camera in the focal plane, an image mosaic combining several images with different rotation angles can be calculated to cover larger areas than in a single image. Two IATS have been calibrated in the laboratory and software was developed to calculate an image mosaic from several images taken from a single station. Matching algorithms will be employed to detect interest points in the images and to monitor rock fall areas and landslides. In a second project, the same IATS will be used to measure bedrock erosion at close range. In the latter case mm accuracy is required to capture the expected annual erosion rate in a debris flow channel.

## 4 Conclusions

Photogrammetry serves as a valuable tool for earth scientists who want to quantify processes, measure dimensions in imagery or who just want to shift the measurement task from an outdoor location inside the office. The presented application show common and uncommon setups used for experiments in the earth sciences. Straight forward applications designed for non-experts or students help to introduce new users to the concepts and methods of photogrammetry.

*Figure 8. Image assisted total stations with frame sensor in the focal plane of the telescope.*

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