Terrestrial and UAS-borne Imagery for Quarry Monitoring with Low-Cost Structure from Motion

MARTIN HÄMMERLE, FABIAN SCHÜTT, BERNHARD HÖFLE

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Abstract

Detailed and quickly available geodata of quarries as, e.g., breaklines or dump volumes are highly important for quarry operators because they are needed, e.g., for planning and monitoring raw material extraction, calculating extraction costs, and fiscal purposes (FUGMANN 2009). Low-cost methods for gathering such data are thus of high interest for quarry operators in order to increase extraction efficiency. By having complementary methods at their disposal, operators may also overcome restrictions of traditional methods such as total station or GNSS surveying which deliver relatively sparse point measurements, often expose the survey personnel to risks, may capture inaccurate measurements in case of inaccessible areas, and are time- and cost-intensive.

A low-cost remote sensing method for deriving geodata is structure from motion (SfM),. With SfM, 3D point clouds of objects can be reconstructed from collections of photographs taken with consumer-grade cameras that capture objects from different perspectives. It is increasingly used to analyse natural or anthropogenic processes which change the Earth surface topography (e.g., RAGG et al. 2013, FONSTAD et al. 2013, SIEBERT & TEIZER 2014).

In this study, we examine the potential of SfM to deliver high-quality geodata important for quarry operators. The study site is an active limestone quarry near Heidelberg. We derive 3D point clouds of a dump and a terrace in the quarry from images taken (i) with consumer-grade cameras from the ground (terrestrial SfM, tSfM) and (ii) by a fixed-wing unmanned aerial system (airborne SfM, aSfM), using a combination of the SfM software packages VisualSfM (WU 2013) and SURE (ROTHERMEL et al. 2012). Reference data were captured with terrestrial laser scanning (TLS), total station and GNSS surveys. The parameters used as indicators for SfM data quality comprise:

- Ratio of cells of a raster which contain at least one point (completeness; ROSNELL & HONKAVAARA 2012)
- Number of points within a raster cell (point density; KRAUS et al. 2006)
- Vertical deviation of SfM-based digital terrain models (DTM with two model types raster and triangulated irregular network, TIN) from survey-based ground control points (accuracy; AGUILAR & MILLS 2008)
- Distance of SfM point clouds to the respective TLS point cloud (M3C2 distance; LAGUE et al. 2013)
- Deviation of SfM-based digital terrain models (raster DTM) from a TLS-based reference DTM in X, Y, and Z direction (least square matching LSM; RESSL et al. 2008)
- Scaling via a comparison between distances measured in the TLS and corresponding SfM point clouds (RUMPLER et al. 2013)
- Dump volume (raster and TIN-based)
- Accuracy of breakline detection (RUTZINGER et al. 2012)

It was found that the main factors influencing completeness are perspective and the distribution of capturing locations: The aSfM data reach 100% coverage and thus capture even very steep walls, whereas TLS reaches 100% coverage only when including several scan positions and tSfM does not achieve 100% coverage at all. The comparison between DTMs and ground control points shows that in case of the raster DTM, the elevation deviations show no distinct differences between TLS and SfM. Comparing TIN and GCPs, however, leads to lower vertical deviations in case of the terrestrial methods (minimum of TLS: 0.026 m, tSfM: 0.025 m) compared to aSfM (min. 0.101 m). Similar to precision, lower SfM resolutions lead also to lower accuracy. The examination of the M3C2 distance exhibits that the two terrestrial datasets correspond well with mean M3C2 distances of -0.037 m between the reference TLS point cloud and the tSfM point clouds derived from 4 or 482 images. However, the aSfM point clouds reach mean M3C2 distance values of up to -0.277 m. Also regarding LSM values, the tSfM data are closer to the TLS reference. Scaling differences between SfM and TLS show very low deviations between 0.04% and -0.33%. Dump volume calculations show larger deviation ranges, strongly depending on volume calculation method (based on raster or TIN), platform, and point density. Finally, the quality of breakline detection shows differences for lower and upper edges, indicating advantages of aSfM for lower edges and inversely better results for upper edges using tSfM.

From the findings it can be concluded that the low-cost SfM approach provides valuable 3D geodata which can be used as input for deriving parameters important for quarry management. The quality of SfM datasets are most influenced by the number of images, perspectives, image overlap, and the density chosen for point cloud reconstruction. SfM can be used as an on-demand survey method which can be applied complementary to traditional high-end surveying.

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Addresses of the Authors:

MARTIN HÄMMERLE & FABIAN SCHÜTT, Heidelberg University, Institute of Geography, GIScience Research Group, Berliner Straße 48, D-69120 Heidelberg, Tel.: +49-6221-54-5562, Fax: +49-6221-54-4529, e-mail: haemmerle@uni-heidelberg,de, fabian.schuett@stud.uni-heidelberg.de

BERNHARD HÖFLE, Heidelberg University, Institute of Geography, GIScience Research Group, Berliner Straße 48 and Heidelberg Center for the Environment, Im Neuenheimer Feld 229, Tel.: +49-622154-5594, Fax: +49-6221-54-4529, e-mail: hoefle@uni-heidelberg.de

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