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Unmanned Aerial Systems and DSM matching for rock glacier monitoring

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ABSTRACT

Among other techniques, aerial and terrestrial photogrammetry have long been used to control the displacements of landslides and glaciers as well as for the detection of terrain morphological changes. Unmanned Aerial Systems (UAS) are today an efficient tool to perform data acquisition in rough or difficult terrain, both safely and quickly, avoiding hazards and risks for the operators while at the same time containing the survey costs. Since 2012 ARPAVdA (the Regional Environmental Protection Agency of Aosta Valley, Italy) periodically surveys with UAS photogrammetry the Gran Sometta rock glacier, the Agency main monitoring site for the climate change impacts on high-mountain areas and related infrastructures.

A Digital Surface Model (DSM) and an orthophoto of the rock glacier are produced after each survey flight. In order to accurately georeference them in a stable reference system, a Global Navigation Satellite System (GNSS) campaign is carried out at each epoch, to update the coordinates of signalised Ground Control Points (GCPs), since they partly lay in unstable (moving) areas. In late August 2015 a survey flight has been executed with a senseFly eBee RTK, with differential corrections sent from a ground reference station. The block has been adjusted without GCP using, as control information, only the projection centres coordinates encoded in the images. The RMS of the differences found on twelve Check Points were about 4 cm in horizontal and 7 cm in elevation, i.e. practically the same accuracy found using GCP. Differences between the DSMs produced at the same epoch with block orientation performed with GCP and with GNSS-determined projection centres were also investigated.

To evaluate the rock glacier displacement fields between two epochs, corresponding features were at first manually identified on the orthophotos by a trained operator. To avoid the manual time-consuming procedure and increase the density of displacement information, two automatic procedures, the former using Least Squares Matching (LSM) and the latter a proprietary implementation of Semi-Global Matching (SGM) have been implemented. Both techniques were applied to pairs of orthophotos as well as to pairs of DSMs at different epochs. A discussion of the characteristics of the implemented methods is provided and the results of the comparison of the two methods with manual measurements are illustrated. Overall, results using DSM matching provided higher completeness of the displacement field than orthophoto matching, especially if long-term (year-to-year) comparisons are considered. At the same time, SGM in both cases produced less mismatches and more smooth and reliable displacement fields than LSM.

1. Introduction

Periodic control of displacements in landslides or glaciers as well as the detection of morphological changes (as in coastline erosions or in gully dynamics) must cope with a large variety of cases and situations. Indeed, the behaviour of different phenomena (in the time domain as well as in the space domain) depends on very

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many factors, which present the geologist and the surveyor each time with different challenges.

Besides the accuracy needed to assess, with a given probability, the magnitude of the expected displacement, a number of other issues influence the choice of the best monitoring system to use, see (Scaioni et al., 2014) for a review. To cite a few: the size of the area to control, the frequency of data acquisition, the time to deliver the results (alert time), the stability of the reference system, the influence of atmospheric parameters on measurement accuracy or operation, the site constraints, etc.

Photogrammetry has been used since long to periodically control the evolution of landslides, either from aerial images (Casson et al., 2003), as well as from ground (Cardenal et al., 2008). In (Mora et al., 2003) the same technique has been used in combination with GNSS surveys on the landslide body. In some cases, fixed monocular (Travelletti et al., 2010; Motta et al., 2013) or stereo (Roncella et al, 2014) photogrammetric systems have been installed, to ensure daily or even higher frequency updates on displacements. Today photogrammetric surveys carried out with Unmanned Aerial Systems (UAS) (Eisenbeiss and Sauerbier, 2011) are in many cases an efficient alternative to other techniques in the periodic survey of landslides or other movements. With fixed costs lower than aerial photogrammetry and very high Ground Sampling Density (GSD), UAS are both economically and technically well suited for the survey of most landslides (Rau et al., 2011), potentially allowing higher monitoring rates. The performance of UAS photogrammetry in Digital Surface Model (DSM) production has been deeply investigated in the last years (Rock et al., 2011; Küng et al., 2011; Vallet et al., 2011; Harwin and Lucieer, 2012; Niethammer et al., 2012; Haala et al., 2013; Mancini et al., 2013; Naumann et al., 2013; Santise et al., 2014). With appropriate ground control, accuracies in the range of 3–10 cm in 3D can be expected, making UAS photogrammetry extremely appealing also for monitoring applications.

However, empirical investigations on DSM accuracy (Rosnell and Honkavaara, 2012; Javernick et al., 2014) found that systematic decimetre-level errors might arise. Effects of inaccurate camera modelling, a likely error source especially with consumer-grade cameras, might be avoided by taking convergent images (Wackrow and Chandler, 2008) or improving GCP distribution (James and Robson, 2014).

Measuring GCP for UAS block adjustment may prove difficult in areas around or on the landslide body. Therefore, efforts to improve on-board navigation data by using Real Time Kinematic (RTK) positioning and dual frequency receivers are of particular interest, since they might allow to get rid of GCP altogether.

Monitoring the surface creep and basal gliding of mountain permafrost is important to understand the effect of climate fluctuations and on-going changes on slopes dynamics. Rock glaciers are widespread landforms that can show rapid acceleration and destabilization (Delaloye et al., 2013). In heavily anthropic areas like the Alps, the accelerating creep of perennially frozen talus/debris with high ice content will probably become an increasing problem, notably for human infrastructures (Haeberli, 2013). However, traditional techniques (e.g. topographic surveys) cannot be easily applied in such scenarios to study the evolution: for example, the rock glacier surface is rough and presents hazards like block instability and rock falls. Only an operator with adequate training is able to carry out the survey, often with some risks to his safety. Therefore, though tracking with GNSS is also used (Delaloye et al., 2013), digital photogrammetry from aerial images (Kaufmann and Ladstädter, 2003) might be preferable to cover larger areas and/or to provide higher monitoring rates. Surface motion of glaciers has been traced using terrestrial, aerial and satellite images (Maas et al., 2010; Delacourt et al., 2004; Berthier et al., 2005). The advent of Digital Image Correlation (DIC) has provided a very flexible tool for measuring deformation and displacement fields, including glaciers and landslides (Heid and Kääb, 2012; Debella-Gilo and Kääb, 2011, 2012). Though in the past only 2D displacements larger than several meters could be highlighted in satellite images, today high resolution satellites and sub-pixel techniques pushed the limit well below the meter level.

Since 2012 ARPAVdA (the Regional Environmental Protection Agency of Aosta Valley, Italy) periodically surveys with UAS photogrammetry the Gran Sometta rock glacier, the Agency main monitoring site for the climate change impacts on high-mountain areas and related infrastructures such as ski resort. In the period 2012–2015, seven survey flights were executed; a GNSS campaign was carried out at each epoch, to update the coordinates of permanent signalised Ground Control Points (GCPs), since they partly lie in unstable (moving) areas.

After evaluation of the displacements by manual identification of features on orthophotos for the first two campaigns, four flights were executed in summer 2015 to investigate the seasonal velocity changes. In order to improve the overall efficiency and to reduce the cost of the process, minimizing the time spent on field operations and on manual measurement of the displacement field, GNSS-assisted block orientation has been tested in one of the flights. Moreover two change detection techniques, the former using Least Squares Matching (LSM) (Gruen, 1985) and the latter a proprietary implementation of Semi-Global Matching (SGM) (Hirschmüller, 2005), have been implemented and validated to evaluate automatically the displacements.

The paper is organised as follows. Section 2 first illustrates the test site characteristics and compares the block orientation procedure with GCP and with projection centres determined by on board GNSS. Then the two image matching methods implemented to evaluate the movements are presented in detail and discussed. Section 3 reports on the results of the application of the two methods to pairs of orthophotos as well as to pairs of DSMs of the rock glacier at different times. The pro and cons of the methods and the advantages of using the DSM with respect to the orthophotos are discussed, based on the validation provided by manual measurements. Section 4 presents prospects and future work.

2. Materials and methods

2.1. Test site description

The study area is located in the south-western Alps at the head of the Valtournenche Valley (Valle d'Aosta, Italy) on the south side of Matterhorn. The body of the rock glacier is composed by two lobes, spanning an elevation range between 2600 and 2750 m. It is nearly 400 m long, between 150 and 300 m wide and has an apparent thickness (based on the height of the front) of 20–30 m. The debris originates from an overhanging rock wall, mainly composed by green schists with prasinites (dark rocks), with insets of bands of dolomite and marbles (clear rocks). It displays morphological features typical of active landforms: longitudinal ridges in the central steep part and a succession of transverse ridges and furrows in the compressive part of the tongue. An overview of the area is shown in Fig. 1.

In the framework of a regional study on the impact of climate change (global warming and precipitation regime changes) on such high-mountain areas, since 2012 the surface movements of the rock glacier, which juts on a ski slope of the Cervinia resort, requiring maintenance works every year, are being monitored by ARPAVdA in order to understand its dynamics. The current dataset of observations consists of seven UAS flights (October 2012, August and October 2014, July, August and September 2015 and an