CHANGE DETECTION IN PHOTOGRAMMETRIC POINT CLOUDS FOR MONITORING OF ALPINE, GRAVITATIONAL MASS MOVEMENTS

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Commission II

KEY WORDS: Bundle block adjustment, optical images, photogrammetric point cloud, change detection, crevices

ABSTRACT:

This contribution focuses on the assessment of possible accuracies in 3D reconstruction and change detection based on photogrammetric image sets. Photogrammetric results are compared to Geodetic measurements using tachymeter and laser scanner.

1. INTRODUCTION

One of the direct consequences of climate change is the melting of permafrost in alpine areas. In combination with extreme weather especially heavy rain falls gravitational mass movements in the mountains like rockfalls and hang slides are going to be a more frequently and more dangerous hazard (Clague and Stead, 2012). An important task in predicting these mass movements is the classification of the movement type based on a set of indicators. Hung et al. (2014) classifies five different movement types: fall, topple, slide, spread, and flow. This classification needs a detailed observation of movements. Here, observing the movement rate and direction of single points over time is not sufficient to model complex changes. This modeling requires the observation of a number of 3D points for longer time periods and leads to a classification of the movement type and an estimation of possible moving masses.

Different measurement techniques are used for this purpose. Geological systems like extensometers (Malet et al., 2002; Massey et al., 2013) are used to measure changes in the width of crevices. Geodetic measurements are mainly based on tachymeter, GNSS receivers (Squarzoni et al., 2005), radar interferometry or laser scanning (Roberti et al., 2018; Delacourt et al., 2007; Kasperski et al., 2010; Oppikofer et al., 2009). All these devices have in common their high costs compared to cameras and the need of professional personnel. Surveillance of larger areas or all potential risk areas in the Alps is more or less impossible in that way. Using cameras allows handling over the job of data acquisition to non-professionals (Urban et al., 2019; Romeo et al., 2019; Mayr et al., 2019; Peppa et al., 2019; Kromer et al., 2019; Esposito et al., 2017; Hendrickx et al., 2019; Warrick et al., 2016; Piermattei et al., 2016; Eltner et al., 2016; Stumpf et al., 2015; Kääb et al., 2014; Westoby et al., 2012).

This contribution focuses on the assessment of possible accuracies in 3D reconstruction and change detection based on photogrammetric image sets. Photogrammetric results are compared to Geodetic measurements using tachymeter and laser scanner.

2. MEASUREMENT AND PROCESSING STRATEGY

The evaluation of the accuracy and reliability in 3D reconstruction and change detection and deformation analysis is split in two parts. In the first part, the accuracy of the 3D point generation is evaluated. The second part focuses on the change detection between two point clouds.

A set of ground control points defines a local coordinate system. Camera orientations are unknown beforehand and the image set is oriented based on the ground control points. Two different sets of ground control points are used. Set one is fixed longterm ground control points defining the local coordinate system for registering the different epochs. Set two is ground control points that were individually measured for every epoch. The interior orientation of the camera is given and assumed to be fix for one epoch.

2.1 3D reconstruction

The 3D reconstruction is based on the well-known two step process of bundle adjustment of the image based on tie point and ground control points (Förstner and Wrobel, 2016) followed by a semi-global matching for dense point cloud generation (Hirschmuller, 2008). Measurements of crevices are taken with an image overlap of at least 80%. The camera is moved...
The bundle adjustment uses variance components to model the different accuracy levels of measured image points and measured ground control points. Random Sample Consensus (RANSAC) (Fischler and Bolles, 1981) removes outliers in the tie point search before the bundle adjustment is performed. The resulting exterior orientations are the input for the semi-global matching (Hirschmüller, 2008).

### 2.2 Change detection and deformation analysis

Change detection consists of three major steps: i) coregistration; ii) noise detection; iii) detection of significant changes. As all image sets are oriented based on the same set of ground control points, one can assume the resulting point clouds to be already registered. An additional coregistration by distance minimization like Iterative Closest Point (Besl and McKay, 1992) would falsify the change detection as it minimizes the distances of all points and thus would also include moved points in the registration.

The bundle adjustment calculates the inner quality of the resulting adjusted equation system. 3D points are only generated for the tie points and the ground control points. An absolute accuracy of the dense 3D point cloud is not calculated neither in the bundle adjustment nor in the semi-global matching. Estimating the noise level is very important to distinguish noise and real changes.

The proposed strategy uses the Multiscale-Model-to-Model-Cloud method (M3C2) (Lague et al., 2013) to find for every point in one point cloud the corresponding neighbor in the other point cloud and the distance between this point pair. M3C2 is used both for noise level estimation and change detection.

Given the exterior orientation of the images from the ground control points, the registration accuracy is limited to the measurement accuracy of the ground control points. To refine the registration we assume the area with the ground control points defining the local coordinate system to be stable without changes. If so, a coregistration using Iterative Closest Point (ICP) (Fischler and Bolles, 1981) leads to a refined registration of the point clouds. However, small geometric changes caused by the works on the summit like changed position of equipment or small stone falling down during walking reduce the coregistration accuracy. These points are removed by an iterative process that generates a histogram of M3C2 distances of corresponding points in the two point clouds. The five percent points with the highest distances are cut out from the data set as points that either are wrong point pairs or regions with unexpected small geometric changes. ICP is repeated for the new reduced data set and the M3C2 distances are recalculated. This is repeated until all distances of the stable part of the summit are below a threshold. The remaining point cloud gives the parameters for the coregistration of the second point cloud to the first. These transformation parameters are now applied on the original second point cloud including all points.

To estimate the noise level in this work, the next step compares the two point clouds generated from two image sets of the same day taken with several hours difference. These point clouds include changes in lighting conditions and slight differences in the orientations of the images. As no geometric changes around and in the crevice are expected for such a short period, both point clouds should show M3C2 point distances in the level of the noise of the point cloud generation quality. The median M3C2 distance is the threshold of the noise level. The change detection uses the M3C2 distance with this threshold to remove noise and detect the geometric changes.
3. EXPERIMENTS: THE HOCHVOGEL CREVICE

The mountain Hochvogel (Fig. 3) is situated at the border between Germany (Bavaria) and Austria. Hochvogel is the highest mountain in the Allgaeu alps with 2592 m. Hochvogel is characterized by its steep rock slopes and fast erosion processes caused by a very choosy limestone (Scholz and Scholz, 1981; Krautblatter and Funk, 2010). The reduction of permafrost in the last decades destabilized the summit region of Hochvogel. This geologic behavior causes big mass movements and several rock falls. The summit is crossed by a big crevice of up to seven meters width and visible down to 10 meters of depth. The deeper parts of the crevice are invisible due to the debris. It has a total length of 35 meters through the whole summit from north east to south west and several narrow crevices in the south west of the summit (Fig. 4). The outer part of the summit that is separating by the large crevice is moving in a gravitational movement to the south (Leinauer et al., 2019) with approx 2 cm per year. The 3 dimensional complex movements in the summit of the Hochvogel should be estimated.

In addition to the given ground control points used for defining the local coordinate system and for the geodetic measurements (Fig. 5), additional ground control points have been placed in the scene to have more points for the initial orientation estimation.

Images have been taken during three measurement campaign on 2018-07-09 (one image set in the morning, one image set in the afternoon for the noise level estimation), 2018-09-27, and 2019-07-19. A Sony Alpha 7RII with 42 megapixel and 15 mm focal length was used to take the images. The camera was mounted on a stick stand with a maximum length of 7 m (Fig. 6). The camera records the scene with at least 80% overlap in parallel views moving along the crevice.

Table 1 lists the number of images, visible ground control points and manually added TIE points for the three measurement campaigns.

| Campaign   | images | GCPs | manual TIE |
|------------|--------|------|------------|
| July 2018-A| 183    | 32   | 20         |
| July 2018-B| 106    | 32   | 20         |
| July 2018  | 407    | 32   | 20         |
| Sept 2018  | 645    | 55   | 47         |
| July 2019  | 510    | 74   | 55         |

Table 1. Different measurements: July 2018-A and B: Same day measurements for noise level estimation. July 2018, Sept 2018, July 2019: Change detection measurements.

4. RESULTS AND DISCUSSION

During the measurements, several groups from geology, geodesy and photogrammetry were working on the summit and installing ground control points and equipment. This leads to small geometric changes and changing occlusions by person during the recordings.
Table 2. Standard deviation of July 2018 measures of Ground Control points Geodesy (Geo XY/Z in [m]) compared to Photogrammetry (X,Y,Z in [m]) and reprojection error of ground control points in [pixel].

| Geo XY/Z | X   | Y   | Z   | error |
|----------|-----|-----|-----|-------|
| R1       | 0.004/0.002 | -0.003 | 0.002 | 0.001 | 0.432 |
| R2       | 0.004/0.002 | -0.001 | 0.001 | 0.001 | 0.364 |
| R3       | 0.004/0.002 | -0.000 | -0.000 | 0.000 | 0.425 |
| R5       | 0.004/0.002 | 0.001 | 0.001 | 0.000 | 0.502 |
| R4       | 0.004/0.002 | -0.001 | -0.001 | -0.000 | 0.431 |
| R6       | 0.004/0.002 | 0.001 | -0.002 | 0.001 | 0.546 |
| R7       | 0.004/0.002 | -0.001 | -0.002 | -0.000 | 0.526 |

4.1 3D reconstruction

The results for the 3D object coordinates estimated in the bundle adjustment shows that the standard deviation of the points is below 1 cm in the center of the image set and gets worse to the borders of the set (Fig. 7 and 8). This is mainly caused by the lower number of images that see these points and by the configuration of the ground control points. The ground control points are aligned along an axis due to the formation of the crevice and accessibility of the different parts of the summit. This makes the orientation unstable to a certain point. The reprojection error for the three image sets for July 2018, September 2018, and July 2019 are 0, 225pixel, 0, 119pixel and 0, 162pixel.

Looking at figure 9, one can see the M3C2 distances of the photogrammetric point cloud from September 2018 to the corresponding point cloud taken with a terrestrial laser scanner. The standard deviation of the scanner σ is about 2mm. The mean M3C2 distance of the point clouds is 0.94mm with a standard deviation of 5.6mm. As seen in the figure 9, the main difference is in a small area where different occlusions of scanner and camera may cause changes. Similar reasons are the small high differences which are mainly in the shadow areas of rocks.

4.2 Noise level estimation

The noise level estimation uses the two image sets July 2018 A and B taken during the first measurement campaign and compares the two generated point clouds. As we assume that there is no change in the geometry of the summit, the point clouds are coregistered using ICP to remove possible errors from the limited accuracy of the ground control point measurements. M3C2 calculates the distances of point pairs of the two point clouds. The mean distance µ of the points is $5.35 \times 10^{-4}$m. The standard deviation σ is 0.013m.

4.3 Change detection

In change detection, two comparisons are done. The first compares the point cloud from epoch one (July 2018) to the second (September 2018) where no movements have been detected neither by geological nor geodetic measurements. In fact, using the estimated noise level, almost no significant changes are detected in the photogrammetric point clouds (Fig. 10). The left images shows the detected changes. Small rocks have moved during the summer, but no movement of the whole crevice is visible. The right images shows the cleaned point cloud with stable points only that have been used for the fine coregistration.

The mean value µ of the M3C2 distances is $9.5 \times 10^{-5}$m and the standard deviation σ is 0.0015m. This is below the estimated noise level and thus no movement is detected.
If we have a look at the distances of the point clouds from September 2018 to July 2019 (Fig. 11), the results look totally different. On can see M3C2 differences of up to 3 cm in the left part of the crevice and that more or less all parts of the crevice are moving. If one looks at the histogram of the M3C2 distances (Fig. 12, one can see three peaks at -1.4 cm, +8 mm, and +1.6 cm. If the points are segmented using a histogram based threshold around these three peaks, one can see, that all three peaks belong to a certain characteristic (Fig. 13). The 8mm peak is more or less only on horizontal plains that are going down, whereas the 1.6 cm peak is located on more or less vertical surfaces that are moving away from the stable part of the summit. This distances and their locations describe movements of the sliding part of the summit. The peak at -1.4 cm belongs to objects that are falling into to crevice. The movement in total seems to be stronger on the left side (Fig. 9). Characterising the type of movement, the results indicate a combination of topple and slide which fits to the geologic reference measurements.

An interesting observation can be made at the smaller crevice that is perpendicular to the big crevice. Here, we see a movement along the crevice, more or less in the same direction as the movement in the main crevice. The distances in the point clouds of September 2018 to July 2019 (Fig. 15) at first show an unstructured change. But, if one adds virtual connection lines of objects in the September 2018 data set and compares this to the July 2019 data set one can see a displacement of these characteristic structures.

If we compare our measurements and the interpretation with the geodetic measurements (Fig. 14, we can see that the changes of the control points on the moving part of the summit support the
results of the photogrammetric measurement and interpretation of the point cloud differences. The mean value of the movement is 2cm which fits to our estimation of the movement of the vertical surfaces away from the stable part of the summit. Table 3 shows the comparison of the geodetic measured movement and the estimated movement from the point cloud differences.

5. CONCLUSION AND OUTLOOK

The image acquisitions in this project were done with a terrestrial camera system. It is possible to replace this terrestrial camera by a UAV/RPAS mounted camera system. This would most likely speed up the recording process that was quite complex due to several groups working at the summit at the same time and thus generating artificial changes from persons and material that had to be removed before processing. A second limitation is the possible ground control points configuration. As the summit and crevice have an elongated shape and the moving part is hardly accessible, the ground control points for the coordinate system are also elongated which makes the registration unstable at the ends of the image sets. Nevertheless, it is possible to reach high geometric accuracies for the photogrammetric point clouds. If one considers the real noise level instead of the inner accuracy of the bundle adjustment and dense matching, it is clear that relevant movements are not detectable, whether this accuracy in combination with the noise removal and an point based coregistration can reach the same absolute accuracy as the method based in ground control points.

The interpretation of changes as specific movements can be improved by adding a segmentation to the point cloud and group points by radiometric and geometric features and detected edges as well as similar estimated movement vectors. This way, it would be possible, to track objects instead of assigning points of two point clouds to each other that show not necessarily the same object.

Future steps include the use of UAV/RPAS systems for carrying the camera. This has the advantage that exterior orientation parameters are measured for every image and can be used as initial values in the bundle adjustment. Nevertheless, using only these orientation will only lead to an optimized inner accuracy. It has to be investigated, whether this accuracy in combination with the noise removal and an point based coregistration can reach the same absolute accuracy as the method based in ground control points.

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