LANDSLIDE ACTIVITY MONITORING WITH THE HELP OF UNMANNED AERIAL VEHICLE

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ABSTRACT:

This paper presents a practical example of a landslide monitoring through the use of a UAV - tracking and monitoring the movements of the Potoska Planina landslide located above the village of Koroska Bela in the western Karavanke Mountains in north-western Slovenia. Past geological research in this area indicated slope landmass movement of more than 10 cm per year. However, much larger movements have been detected since - significant enough to be observed photogrammetrically with the help of a UAV. With the intention to assess the dynamics of the landslide we have established a system of periodic observations carried out twice per year – in mid-spring and mid-autumn. This paper offers an activity summary along with the presentation of data acquisition, data processing and results.

1. INTRODUCTION

The current activity of Potoska Planina landslide is presumed to be a slow motion slip that may eventually change into a debris flow. The area of the landslide is approximately 2000 square meters and is located at the altitude of 1200 meters. Relative altitude of the landslide is approximately 600 meters above the village of Koroska Bela, which makes the landslide quite remote and hardly accessible.

Five consecutive measurements have been performed so far. In this paper we focus on describing the results and the landslide dynamics assessment of the first measurement as methodology has not changed.

Determination of landslide dynamics is of great interest to geologists studying landslide activity. With this in mind we have introduced a system of periodic observations involving two independent survey techniques: a UAV photogrammetry based on standard photogrammetric approach enhanced with automatic change detection and a classic tachymetry. Due to its easy, cheap and fast deployment a UAV photogrammetry offers the ability to systematically monitor landslide movement over time with tachymetric geodetic measurements providing an accurate control of photogrammetrically assessed displacements.

In the area around the landslide we stabilized a geodetic network of stationary points used to determine the positions of photogrammetric ground control points during each measurement. A hexacopter UAV was used to record overlapping aerial images of the landslide area. A network of tachymetric control points moving with the landslide was stabilized and measured each time as well. This offered an independent control of photogrammetric observations of landslide activity.

2. HARDWARE USED FOR DATA ACQUISITION

A hexacopter UAV – an in-house designed Survey Drone was used to record overlapping aerial images of the landslide area. It carried an Olympus E-P2 camera with an 18 mm 12 Megapixel sensor and a fixed length camera lens with a focal distance of 17 mm.

Figure 1. SurveyDrone UAV

Georeferencing was done through the use of ground control points. They were signalized by black circular targets on a white background. A tachymetric total station was used to determine positions of ground control points and to perform tachymetric control measurements of landslide dynamics. Some of tachymetric control points were stabilized as tachymetric reflector mounts drilled into larger boulders on the landslide, others as reflector mounts mounted onto steel rods and stabilized into the landslide mass.

Figure 2. Tachymetric control point – reflector mount mounted onto steel rods and stabilised into landslide mass

3. DATA ACQUISITION

3.1 Photogrammetric data acquisition

A UAV was used to record overlapping aerial images of the landslide area during each of the periodic measurements. Images were recorded from an elevation of 40 meters above ground level with a horizontal overlap of 75% and a vertical overlap of 66%. Camera was set to a low ISO value, typically ISO 100, and a high shutter speed (1/1250). Ground control points used for photogrammetric data georeferencing were signalized by recognizing black circular targets on a white background. Wooden stakes with targets attached to them are hammered into the landslide in order to completely stabilize the control points.

Figure 3. Ground control point

3.2 Tachymetric data acquisition

A geodetic network of stationary points was set up in the area around the landslide. It was used to determine the positions of photogrammetric and tachymetric control points when performing periodic measurements.

For each periodic measurement 9 photogrammetric ground control points and 6 tachymetric control points were used. Positions of all the control points were then determined following a standard tachymetric land surveying technique.

4. DATA PROCESSING

4.1 Standard photogrammetric workflow

First part of the data processing workflow reflects those of any modern digital photogrammetric techniques. In-house developed software 3Dsurvey is used for processing. Sift

keypoints are identified in aerial images and Sift descriptors are computed for images recorded during each periodic measurement. These are then matched between all the images in a set. False matches are removed with the help of fundamental matrix determination for each image pair. Incremental bundle adjustment is performed taking advantage of a sparse Levenberg-Marquardt algorithm. Georeferencing is provided by the positions of ground control points. Results of sparse Levenberg-Marquardt algorithm are parameters of inner and outer camera orientations and a sparse point cloud of 3D tie points. Sparse point cloud is then densified following a multiview stereo approach. Non-terrain points are excluded from the point cloud, and digital terrain model is calculated. Digital orthophoto calculation serves as the final step.
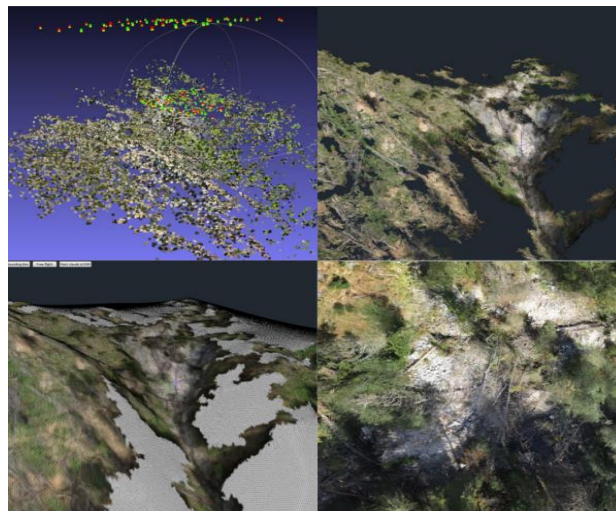

Figure 4. Results of standard photogrammetric workflow (upper left – sparse pointcloud, upper right – point cloud of points belonging to terrain, lover left – digital terrain model, lower right – digital orthophoto)

Accuracy assessment of generated data is performed based on ground control point errors and through comparison between independent tachymetric control measurements and photogrammetrically generated data.

4.2 Displacement vectors

In order to assess the landslide dynamics subsequent photogrammetric measurements need to be compared. Our proposed method is based on automatic Sift descriptor matching of subsequent photogrammetric measurements. We take advantage of the sparse point cloud calculated in incremental bundle adjustment. 3D points belonging to the sparse point cloud have multiple Sift descriptors - the exact number depending on the number of cameras the point is visible in. In order to calculate 3D displacements between first and second photogrammetric measurement the following procedure is used: take first and second photogrammetric measurement sparse point clouds and perform point by point matching. Then take the first point of the first point cloud – query point – and continue by selecting from the second point cloud only those points whose distance to the first query point is less than a certain threshold (2 meters in this case). These points are called train points. Perform descriptor matching between the query point and train points. For each pair (query point and train point) the shortest distance between the Sift descriptor of the query point and Sift descriptors of train points is calculated. The

goal is to find the pair with the shortest distance - if less than 200 it is added to possible displacement vectors (as the Sift descriptor has dimension of 128 – distance of 200 means that descriptors will only differ about 1.5 on average in each dimension – 1.5^128 roughly equals 200).

This process yields approximately 1280 displacement vector candidates. Landslide area of 2000 square meters in this case gives an average of 0.6 displacement vector candidates per square meter. These will still contain false displacement vectors. In order to filter out false positives we check how well the vector direction agrees with weighted k-nearest neighbours.

Figure 5. Displacement vector candidates prior to filtering. Generally we place ground control points on the same positions for each of the consecutive measurements, therefore most false matches are found at ground control points.

Figure 6. Displacement vectors after filtering

Take a look into how well each candidate agrees with its nearest 10 neighbours. For shorter vectors focus on checking how well a candidate vector length agrees with neighbourhood and for longer vectors focus on how well a vector direction agrees with its neighbourhood. If a candidate vector agrees with six or more neighbouring vectors the candidate is accepted as a displacement vector. There are 930 displacement vectors left after filtering – roughly 4.5 displacement vectors per square meter.

Based on these displacement vectors a regular grid of displacements can be interpolated and displayed over a digital

orthophoto. Contours of vector magnitude are also very useful when it comes to landslide dynamics visualization and can effectively complement the vector grid. This data enables a very clear representation of landslide dynamics for both large and extremely small displacements and is most useful to geologists who then use it to calculate and assess both the area and the mass of the sliding material.
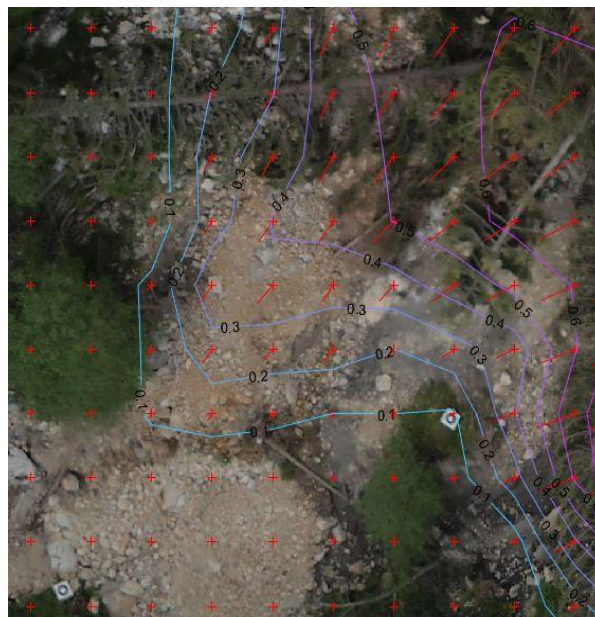

Figure 7. Subset of regular grid of vectors drawn over digital orthophoto with contours marking the magnitude of vectors. Contour equidistance 0.1 m.

4.3 Accuracy analysis

Standard photogrammetric workflow for periodic landslide measurements of Potoska Planina landslide yields ground control point RMSEs (root mean square error) of 2 cm. This value is obtained during bundle adjustment following sparse Levenberg-Marquardt algorithm for each of the periodic measurements. Ground pixel size of an aerial image is roughly 1 cm. 9 photogrammetric control points are placed across the landslide with an area of approximately 2000 square meters.

In order to assess the displacement vector accuracy the safest and most elegant approach is to compare two independent measurements. Comparing classically determined displacement vectors measured at tachymetric control points to photogrammetrically determined displacements requires an interpolation of the photogrammetric displacement vectors for the classic tachymetric control points positions. Results of the comparison are presented in tables 1, 2 and 3.

Point no.	X[m]	Y[m]	Z[m]
1	-0.034	-0.101	-0.045
2	-0.027	-0.082	-0.055
3	-0.302	-0.527	-0.297
4	0.001	-0.073	-0.027
5	-0.533	-0.29	-0.274

6	-0.174	-0.305	-0.166

Table 1. Tachymetric determination of control point displacements

Point no.	X[m]	Y[m]	Z[m]
1	-0.059	-0.092	-0.016
2	-0.031	-0.096	-0.037
3	-0.235	-0.444	-0.230
4	-0.044	-0.602	-0.049
5	-0.502	-0.291	-0.160
6	-0.141	-0.277	-0.133

Table 2. Photogrammetrically determined control point displacements

Point no.	dX[m]	dY[m]	dZ[m]
1	0.025	-0.009	-0.028
2	0.003	0.014	-0.017
3	-0.067	-0.083	-0.067
4	0.044	-0.011	0.022
5	0.031	-0.005	-0.114
6	-0.033	-0.028	-0.033

Table 3. Comparison between photogrammetric and tachymetric determination of displacement vectors at positions of displacement control points (Tachymetric points minus photogrammetric points).

Displacement vector comparison shows that smaller displacement vectors can be observed more accurately than larger ones. In addition, X and Y horizontal components of displacement vectors tend to be more reliable than vertical Z component. Most importantly it shows that even low-magnitude displacement vectors (roughly 10 cm) can be successfully observed through photogrammetry.

5. ANALYSIS

Economic aspects of a UAV landslide activity survey are seriously favourable. To perform, a day of work is required for a team of two people. In our case it took 3 hours travelling and transporting equipment to and from the site, 1.5 hours to signalise and measure ground control point positions and an additional 0.5 hour to measure tachymetric control point positions. A UAV flight with an aerial image recording is the fastest of operations, taking only about 20 minutes. Additional 20 minutes, however, are required to plan the UAV flight mission. Slightly more than 5 hours of terrain work were needed all together, with 2 days of office work in order to process and calculate all the data and to write detailed technical reports.

During periodic measurements we also encountered some problems. Most notable were the unfavourable weather conditions – strong wind gusts – that forced us to interrupt the survey and land the UAV, return home and perform the survey another day. In one of our later measurements, sliding land mass had destroyed some of tachymetric control points which then had to be re-signalised.

CONCLUSIONS

All in all photogrammetric measurements of displacements on Potoska Planina were a success. Compared with classic tachymetric measurements one of the biggest advantages of photogrammetric measurements was the completeness of the data. Displacement vectors were calculated for the landslide as a whole not just for random points of interest. All that has enabled geologists to accurately analyse the influence of meteorological events, such as quantity of rainfall, on landslide dynamics. Process of a UAV based landslide monitoring was already repeated on Slano Blato landslide, the largest in Slovenia. Future monitoring of other landslides is also planned.

REFERENCES

Hartley, R., & Zisserman, A. (2003). Multiple view geometry in computer vision. *Cambridge University Press*.

Karsli, F., Yalcin, A., Atasoy, M., Demin, O., Reis, S., Ayhan, E., 2004. Landslide assessment by using photogrammetric techniques, In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXV, Commission VII, WG VIII/3, Congress, Istanbul, Turkey*

Niethammer, U., Rothmund, S. and Joswig, M., 2009. UAV-based remote sensing of landslides, In: *International Archives of Photogrammetry, Remote Sensing and Spatial Information Sciences, Vol. XXXVIII, Part 5 Commission V Symposium, Newcastle upon Tyne, UK. 2010 496*

Travelletti, J., Malet, J., Schmittbuhl, J., Toussaint, R., Bastard, M., Delacourt, C., (2010). Multi-temporal terrestrial photogrammetry for landslide monitoring. *Proceedings of mountain risks international conference, (pp. 183-191). Florence (Italy).*