Deformation monitoring of Kostanjek landslide in Croatia using multiple sensor networks and UAV

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Abstract

The Kostanjek landslide is the largest landslide in the Republic of Croatia, located in the western residential area of the City of Zagreb. The landslide was activated in 1963 and the main cause of sliding was excavation of the marl at the foot of slope. Investigation of Kostanjek landslide is one of the objectives of the Japanese-Croatian five-year (2009-2014) scientific joint-research project "Risk Identification and Land-Use Planning for Disaster Mitigation of Landslides and Floods in Croatia". As a part of scientific project, a real-time monitoring system was designed during the period from 2010 to 2011 and established in the period from 2011 to 2013. The monitoring system consists of multiple sensor networks including 15 GNSS sensors for displacements monitoring. By GNSS sensors displacements of only 15 points can be monitored. From UAV surveys, movements of the landslide as well as changes in the surface topography can be detected, which enables us to obtain more detailed information on landslide dynamics, necessary for studying landslide activity.
In this paper, results of three periodic UAV surveys of landslide performed within a period of two months are shown. Since within this period, no significant displacements on landslide had occurred, we examined the achieved accuracy of UAV surveys. Survey was done using senseFly eBee RTK with integrated GNSS RTK receiver. Since, in many cases there are sites where ground control points (GCP) cannot be placed and measured easily or safely, in this paper we analyzed the achieved accuracy of survey with and without the use of GCPs.

Key words: senseFly eBee, landslide, UAV survey, displacements

1 INTRODUCTION

The Kostanjek landslide is the largest landslide in the Republic of Croatia, located in the western residential area of the City of Zagreb. Area of landslide is approximately 1 km^2 and estimated sliding mass of 32x106 m^3. Landslide velocities have been changing over the last 50 years from landslide activation until the present day, ranging from extremely slow to very slow according to the classification of Cruden, D. M. et al. (1996).

Determination of landslide dynamics is of great interest to scientist studying landslide activity. For that purpose, on Kostanjek landslide, a real-time monitoring system was installed in the period from 2011 to 2013. Monitoring system provides information necessary to establish an early warning system for the residents in case of dangerous slope movements. The sensor network that was installed in the Kostanjek landslide area encompasses approximately 40 sensors (Mihalić Arbanas, S. et al. 2016).
To provide additional data for studying landslide activity, three periodic surveys of the landslide by UAV were performed within a period of two months. UAV survey is characterized by easy, cheap and fast method for monitoring active landslide movements over the time as well as changes in the surface topography. Movements of the points on the landslide can be detected by the comparison of orthophotos as well as digital surface models (DSMs) from different dates. Such measurements can be performed manually or automatically, for example by image correlation algorithms (Leprince, S. et al. 2008). Suitability of UAV for landslide monitoring was demonstrated in several studies (Niethammer, U. et al. 2010, Turner, D. et al. 2015, Erenoglu, R. C. et al. 2014).
Since within the period of two months, monitoring system detected maximal displacement of 7 mm, in this paper, we couldn't compare displacements detected by UAV surveys with those detected by GNSS from landslide monitoring system. Instead, we examined the accuracy of UAV survey by comparison of the point coordinates determined by UAV survey with coordinates measured by GNSS RTK method. For that purpose, prior to UAV survey, 21 ground control points (GCP) were distributed in the landslide area and measured by Trimble R10 GNSS using High Precision Positioning Service (VPPS) of CROatian POsitioning System (CROPOS) with registration interval of 30 seconds in three cycles. Also, prior the UAV survey, coordinates of 85 detail points on the landslide were measured to test the precision of manually detected point movements from orthophotos from different dates. Since, for UAV survey we use senseFly eBee RTK with integrated GNSS RTK receiver, in this paper we also analyzed the achieved accuracy of survey without the use of GCPs.

2 KOSTANJEK LANDSLIDE

Kostanjek landslide was activated in 1963 and main cause of sliding were mining activities, i.e., undercutting of slope toe and uncontrolled massive blasting at cement factory "Sloboda".

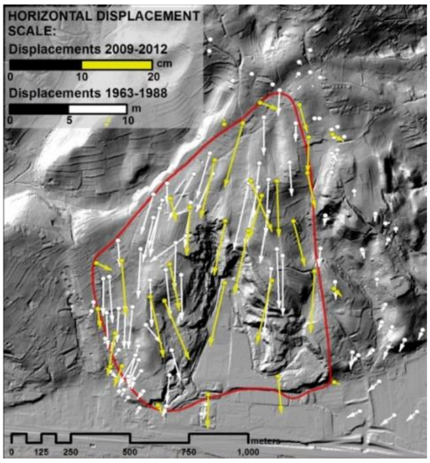

Fig. 1 Comparison of horizontal displacements determined between 2009. - 2012. (yellow arrows) and 1963. - 1988. (white arrows) (Mihalić Arbanas, S. et al. 2016)

Following the initial slow movements that caused settlements and fractures of industrial cement factory objects in 1963, and damaging numerous private houses at the area of approximately 1 km^2 in very short period, attention shifted to unstable slopes above cement factory. Within the last 50 years, landslide velocity has been changing from extremely slow to very slow according to the classification of Cruden, D. M. et al (1996). According to the photo interpretation of aerial stereo pairs from 1963 to 1988, the horizontal displacements of the ground surface in the period 1963–1988 were detected in range 3 - 6 m (average 12–24 cm per year according to Ortolan, Ž. et al. 1992), as shown in Figure 1.

The monitoring results of recent movements from 2009 – 2012 at 35 stable geodetic points show similar movement directions to historical data (Figure 1).

3 KOSTANJEK LANDSLIDE MONITORING SYSTEM

Based on the joint research in the frame of Croatian-Japanese project, the monitoring system on the Kostanjek landslide was designed to include different types of instruments to measure changes in conditions that affect the potential for a reactivation of sliding from slope cuts of abandoned open pit mine, and to provide early warning of extreme conditions to authorities responsible for emergency preparedness. Also, it should provide an opportunity for the research community to test and develop instrumentation and monitoring technologies and to better understand the mechanics of slowly moving masses of soft rock-hard soil.
Monitoring system of Kostanjek landslide is operational and measurements from installed sensors are analyzed in near–real time at the data acquisition-processing center located at the Faculty of Mining, Geology and Petroleum Engineering, University of Zagreb. The sensor network that was installed in the Kostanjek landslide area encompasses approximately 40 sensors for the monitoring of landslide movement and landslide causal factors (Krkač, M. et al. 2014). Figure 2 provides the layout of the sensor network which is currently installed at the Kostanjek landslide.

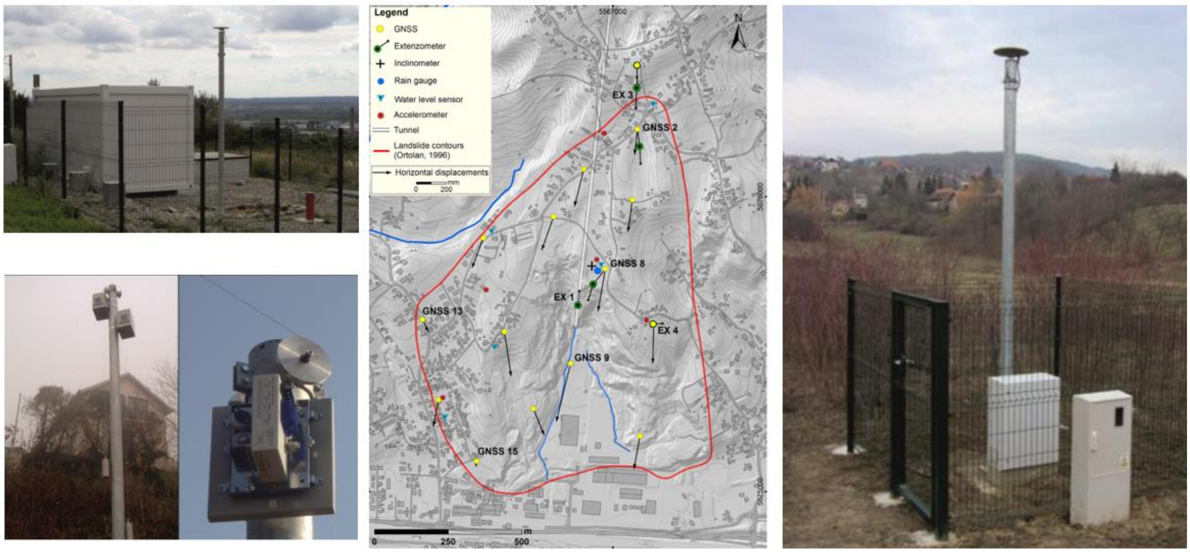

Fig. 2 Monitoring sensors at the Kostanjek landslide, their location, and the horizontal displacements recorded by the GNSS sensor network from January 2013 to January 2015 (Krkač, M. 2015).

The monitoring system consists of multiple sensor networks for the measurement of

1. external triggers (a rain gauge, a meteorological station and 7 accelerometers)
2. displacement/deformation/activity (15 GNSS sensors, 7 extensometers, 4 borehole extensometers and an inclinometer), and
3. hydrological properties (3 pore pressure gauges and 5 water level sensors in boreholes and domestic wells, and 2 water level sensors at outflow weirs).

The general design of the monitoring system is described in Krkač, M. et al (2014). From displacement sensors measurements, multiple reactivations of the Kostanjek landslide caused by external triggers in 2013 and 2014. were recorded. Five periods of faster movement (landslide reactivations) were identified based on analyses of observations from the GNSS network (Krkač, M. 2015). The cumulative horizontal displacements that were recorded by the GNSS sensor network over these two years are shown in Figure 2 (the maximal displacement of 426 mm - lower central part of the landslide).

4 UAV SURVEY OF THE LANDSLIDE

UAV surveys of the Kostanjek landslide were performed on 20 February 2017, 20 March 2017, and 24 April 2017. All three flights were performed using a fixed wing senseFly eBee RTK (Fig. 3a). The eBee RTK is made of expanded polypropylene foam with carbon structure and some composite parts, weighs approximately 0.73 kg and has a wingspan of 96 cm (URL 1). In the first survey, UAV was equipped with CanonPowerShotG9X RGB camera while in the second and third survey, with senseFly S.O.D.A. RGB camera. SenseFly eBee has integrated RTK GNSS receiver for precise determination of image capturing coordinates in real time (RTK GNSS receiver taking RTK corrections from CROatian POsitioning System - CROPOS).

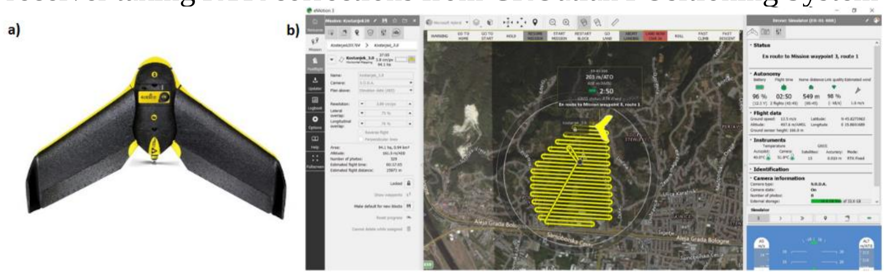

Fig. 3 senseFly eBee RTK (a), the fligh plan in senseFly eMotion3 software (b)

The flight was planned in senseFly eMotion3 software (Fig. 3b). Images were recorded from an average height of 160 meters above ground level with a forward overlap of 70% and a side overlap of 75%. A total of 577 images were acquired during the first flight with 3.95 cm GSD and covered area of 160 ha. Flying speed of UAV was 10 m/s which resulted with 40 minutes flight time. Second and third UAV surveys were planned with same characteristics as first flight. All the flights were performed between 11:30 – 12:30 with good weather conditions (the sky was sunny and clear and wind speed was up to 8 m/s).

At the landslide area, 21 ground control points - GCP were signalized by white circles marked on the darker background. Those points were used for photogrammetric data georeferencing and their coordinates were determined by GPS RTK method (Trimble R10 GNSS) using CROPOS High Precision Positioning Service – VPPS with registration interval of 30 seconds in three cycles (achieved 3D precision of 1-2.5 cm).

Processing of the images was done in Pix4D software and the generated point cloud with average point density of 45 points per m^3 and ortho-mosaic with pixel size of 1 GSD of the whole area are shown on fig 4.

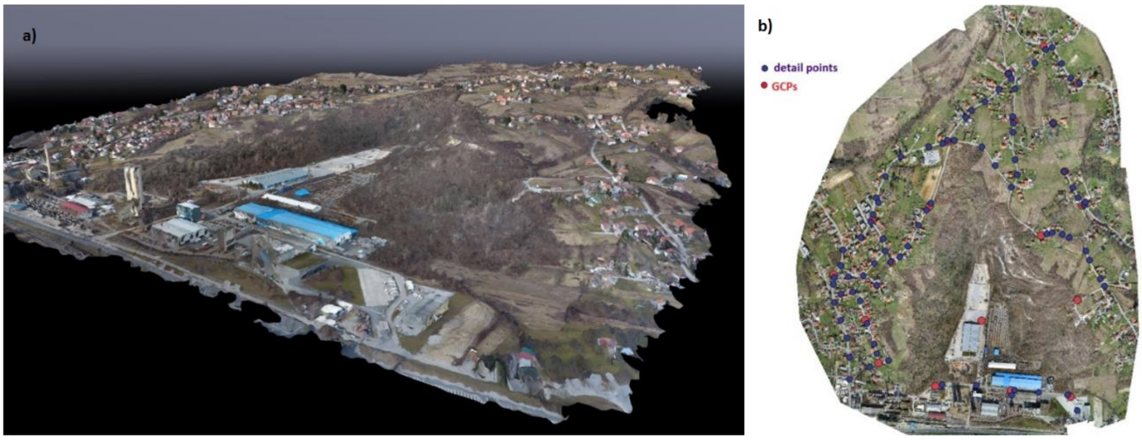

Fig. 4 Point cloud (a) and ortho-mosaic with position of GCPs and detail points (b) of the landslide

5 ACCURACY ANALYSIS

In order to test the accuracy of UAV survey without the use of GCPs, acquired images from all three flights were processed by two different approaches:

- Method 1 – Georeferencing was done using the camera positions (without use of GCPs),
- Method 2 - Georeferencing was done using the camera positions and 10 GCPs.

The achieved accuracy of the approaches was evaluated at check points (CP) with known coordinates (GCPs that was not used for georeferencing). Table 1 shows computed the Root Mean Square Error (RMSE) of the coordinate differences, the standard deviations, and the mean values for each approach.

Table 1 Summary of checkpoints spatial errors

Value	N Error (m)			E Error (m)			Z Error (m)		
Method 1 - statistical values for 21 CP									
	1st flight	2nd flight	3rd flight	1st flight	2nd flight	3rd flight	1st flight	2nd flight	3rd flight
Mean	-0,001	0,013	0,013	-0,005	-0,007	0,017	-0,014	-0,024	-0,026
STD	0,018	0,042	0,038	0,012	0,024	0,035	0,033	0,040	0,044
RMSE	0,018	0,044	0,040	0,013	0,025	0,038	0,036	0,047	0,051
Method 2 – statistical values for 10 GCP									
Mean	0,001	0,003	0,001	0,001	-0,001	0,001	0,004	-0,004	-0,003
STD	0,010	0,028	0,023	0,010	0,014	0,021	0,022	0,020	0,020
RMSE	0,010	0,028	0,023	0,010	0,014	0,021	0,022	0,020	0,020
Method 2 – statistical values for 11 CP									
Mean	-0,001	-0,011	0,005	-0,001	0,006	0,019	0,015	0,005	-0,007
STD	0,013	0,022	0,025	0,013	0,028	0,024	0,028	0,041	0,048
RMSE	0,015	0,025	0,026	0,014	0,029	0,031	0,031	0,042	0,049

As we can see from table 1, maximal RMSE on control points in N direction was 4.4 cm, in E direction was 4.0 cm and in Z direction was 5.1 cm for method 1. For method 2 maximal RMSE on GCPs was 2.8 cm (N), 2.1 (E) and 2.2 cm (Z), and on CPs 2.6 cm (N), 3.1 cm (E) and 4.9 cm (Z). As we can see from shown results, better results were obtained for method 2, in vertical and horizontal plane.

In second part of analysis, we try to analyze the precision of manually detected point movements from orthophotos created from all three UAV surveys. Prior each UAV survey, coordinates of 85 not signaled detail points (center of a manhole-locations of the points are shown on Fig. 4b) distributed across landslide were measured by GNSS RTK method, from which their displacements in period between UAV surveys were determined. Displacements of detailed points determined by GNSS RTK method were in a range of ± 3 cm and they are result of measurement accuracy of GNSS RTK method and don't present real displacements. That was confirmed by results from monitoring system of landslide, according to which, maximal detected value of horizontal displacement was 7 mm (average displacement on 15 GNSS monitoring points was 3 mm). For each of three UAV surveys, orthophotos were generated by two approaches; by georeferencing using the corrected camera positions - without use of GCPs (Method 1), and by georeferencing using the corrected camera positions and 10 GCPs (Method 2). In CAD software coordinates of 85 detail points were determined from each orthophoto. Displacements of these 85 points were determined for epoch II and III with respect to epoch I for both methods of generating orthophotos. As no displacement of landslide occurred between epochs of measurement, differences in coordinates between epochs represents errors of determined displacements. Table 2 shows statistical data of displacement errors in all 85 detail points.

Table 2 Summary of 85 determined coordinate differences from orthophotos between different epoch

Value	$2^{nd} - 1^{st}$ flight				$3^{rd} - 1^{st}$ flight			
	Method 1 (cm)		Method 2 (cm)		Method 1 (cm)		Method 2 (cm)	
	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN	ΔE	ΔN
Min	-13.0	-16.6	-11.5	-15.8	-11.0	-13.0	-5.8	-10.2
Max	12.5	10.8	10.6	9.9	16.7	7.2	14.2	6.7
Mean	2.1	-0.3	0.6	-0.1	1.6	-0.1	1.6	1.0
STD	5.5	5.1	4.2	5.3	5.5	4.1	4.5	3.2

Graphical representation of displacement error distribution (Figure 5 and 6) shows normal distribution of displacement errors in horizontal direction for both II and III epochs.

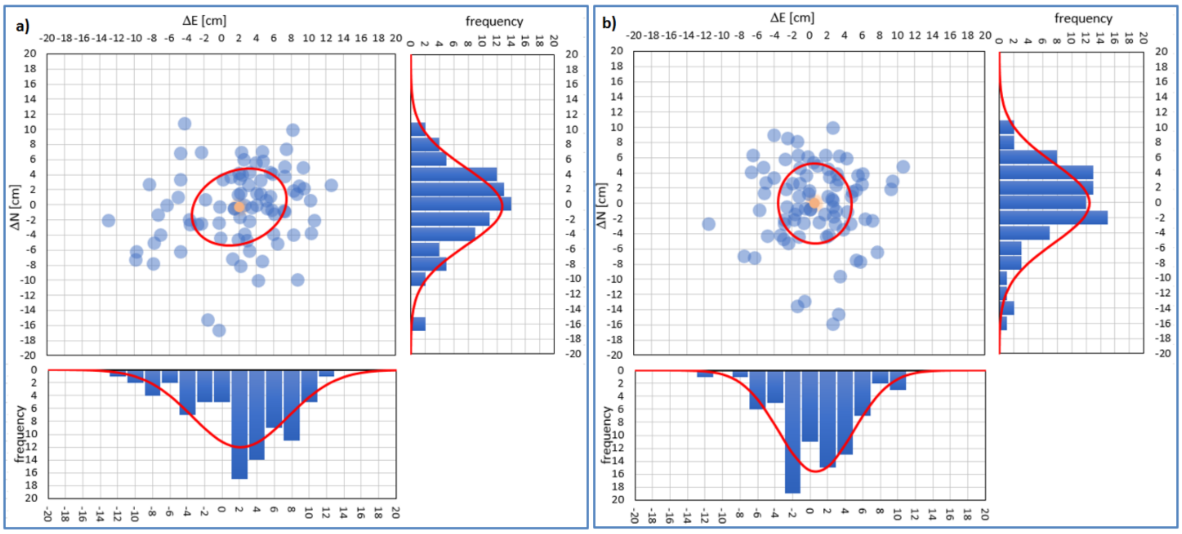

Fig. 5 Distribution of displacement errors (epoch II – epoch I) for Method 1(a) and Method 2 (b)

From the results shown in table 2 we can see that standard deviations of 85 coordinates differences are up to maximal 5.5 cm for both methods, with slightly better results achieved for method 2. Also, tighter distribution of displacement errors can be noticed for method 2 when GCPs were used (Figure 5 and 6).

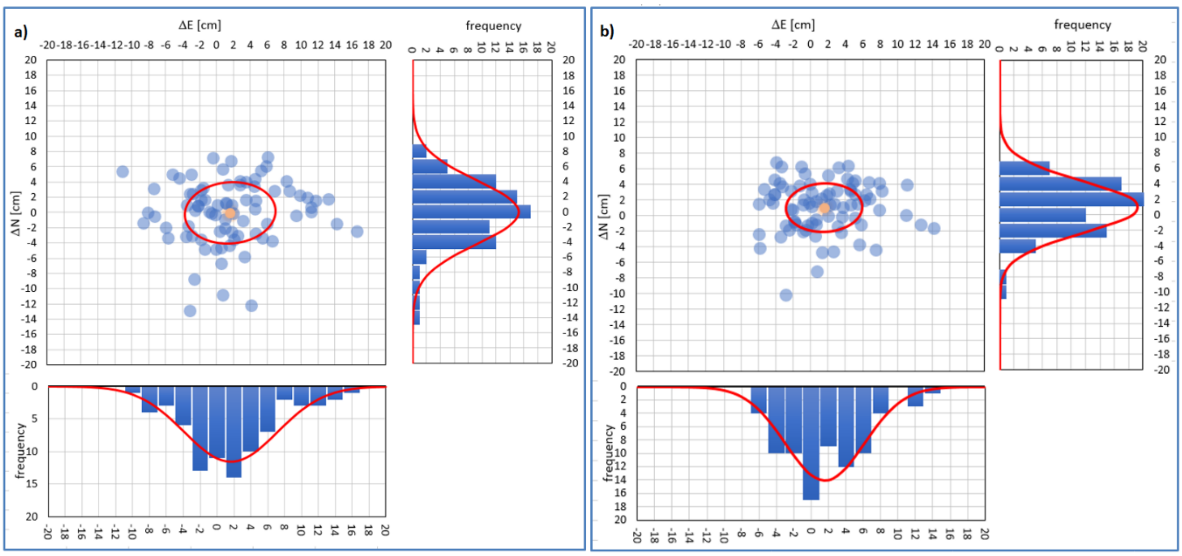

Fig. 6 Distribution of displacement errors (epoch III – epoch I) for Method 1(a) and Method 2 (b)

6 CONCLUSION

In this paper, results of three UAV surveys of Kostanjek landslide are shown. Flight were performed on 20 February 2017, 20 March 2017, and 24 April 2017. Since within this period, no significant displacements on landslide had occurred, we examined the achieved accuracy of UAV surveys. SenseFly eBee RTK with integrated GNSS RTK receiver was used for UAV surveys. Since, in many cases there are sites where GCPs cannot be placed or measured easily or safely, in this paper we analysed achieved accuracy of survey with and without the use of GCPs.

The accuracy of the two approaches (with the use of GCPs and without the use of GCPs for georeferencing) was evaluated at check points. For both approaches, very good results were obtained with maximal RMSE on control points in vertical direction of 5.1 cm and in horizontal direction of 4.4 cm. Also, from presented results, we can see that slightly better accuracy were obtained when GCPs were used for georeferencing.

The analysis of the precision of manually detected point movements from orthophotos created from different dates UAV surveys was also done for both approaches. Displacements of these 85 points were determined for epoch II and III with respect to epoch I for both ways of generating orthophotos. As no significant displacement of landslide occurred between epochs of measurement, differences in coordinates between epochs represents errors of determined displacements. From the presented results, we can see that standard deviations of 85 coordinates differences are up to maximal 5.5 cm for both methods, with slightly better results achieved for method 2.

Although, from the results of three periodic UAV surveys of the landslide, we didn't detect any movements of the landslide due to their small value (average displacement was 3 mm), it could be expected that those measurements are going to be useful for future studying of landslide activity.

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