GEOMORPHOMETRY 2020 PERUGIA, ITALY JUNE 22 - 26 2020

Guidelines for optimization of terrestrial laser scanning surveys over gully erosion affected areas

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Abstract — **Quantification and monitoring of complex geomorphic spatio-temporal changes requires multiple field surveys and creation of very-high resolution (VHR) digital elevation models (DEMs). Due to pronounced terrain roughness and complex surface topography modelling of gully erosion induced spatio-temporal changes can be very challenging. Although advanced geospatial technologies, such as terrestrial laser scanning (TLS), provide good basis for modeling of complex morphological features, certain limitations still exist that can lead to the overall devaluation in model quality. Most of these limitations are related to the non-systematic TLS survey approach, that lacks thorough survey planning and preparation phases.**

Main aim of our research was to provide guidelines for optimization of TLS surveys over gully erosion affected areas, through development of new systematic survey methodology. Established systematic TLS survey methodology allows multiple detection, quantification and monitoring of spatio-temporal changes, where survey characteristics are adjusted to the local terrain characteristics and specifications of available terrestrial laser scanner. Developed survey methodology was applied for TLS survey over chosen gully site at Pag Island, Croatia.

I. Introduction

Terrestrial laser scanning (TLS) represents state-of-the-art topographic modelling technique, that has broad application in various geomorphic researches, with special emphasis on application for detection, quantification and monitoring of various spatio-temporal changes (e.g. landslides (Kromer et al., 2017.), rockfalls (van Veen et al., 2017.), glacial dynamics (Fischer et al., 2016.), volcanism (de Zeeuw-van Dalfsen et al., 2017.), etc.).

As such, ground-based LiDAR surveys have been successfully implemented for monitoring of gully erosion induced spatio-temporal changes (e.g. headwall retreat (Rengers & Tucker, 2015; Goodwin et al., 2017.), volume of eroded material (Perroy et al., 2010; Castillo et al., 2012; Goodwin et al., 2017; Taylor et al., 2018.), etc.). However, pronounced terrain roughness and complex surface topography of certain gullies can lead to significant limitations and challenges in field scanning surveys, as well as in later modelling and creation of DEMs. For example, complex surface topography can obstruct laser beams from scanning certain areas (e.g. overhangs and steeper parts of gully headwall, inner deeper parts of gully channels), that can lead to introduction of "shadows" in collected point cloud (Perroy et al., 2010.) (Fig. 2.B). Such obstructed areas can lead to the overall devaluation in model quality and introduction of various errors (e.g. volume underestimation or overestimation (Bremer & Sass, 2012.)). Most of these limitations are related to the non-systematic TLS survey approach, that lacks thorough survey planning. However, such limitations can be eliminated through introduction of more scanning positions (Fig. 2.C) within systematic survey planning and preparation. Due to the time or resource constrains planning and preparation phases have been avoided or neglected in many TLS surveys, where scanning positions were determined on site, based entirely on user experience and judgment (Perroy et al., 2010; Bremer & Sass, 2012; Rengers & Tucker, 2015; Goodwin et al., 2016; 2017.).

Therefore, main aim of our study was to provide guidelines for optimization of TLS surveys over gully erosion affected areas, through development of new systematic survey methodology, that would allow multiple detection, quantification and monitoring of gully erosion induced spatio-temporal changes. Special emphasis in our research was given to the planning (1), preparation (2) and implementation (3) phases of TLS topographic surveys, that had to be accurate and repeatable. Established systematic TLS survey methodology allows multiple detection, quantification and monitoring of spatio-temporal changes, where survey characteristics are adjusted to the specifications of used terrestrial laser scanner (e.g. Faro M70; Stonex X300, etc.) and local terrain characteristics (terrain roughness, gully size and divergence, etc.).

Developed TLS survey methodology was applied on example of gully Santiš, located on SE part of Pag Island, Croatia (Fig. 1). Gully Santiš is simple, unbranched gully, with recent traces of active gully erosion. As such, this gully was perfect test site for validation of developed systematic TLS survey methodology.

Fran Domazetovic, Ante Siljeg and Ivan Maric (2020) Guidelines for optimization of terrestrial laser scanning surveys over gully erosion affected areas:

in Massimiliano Alvioli, Ivan Marchesini, Laura Melelli & Peter Guth, eds., Proceedings of the Geomorphometry 2020 Conference, doi:10.30437/GEOMORPHOMETRY2020_59.

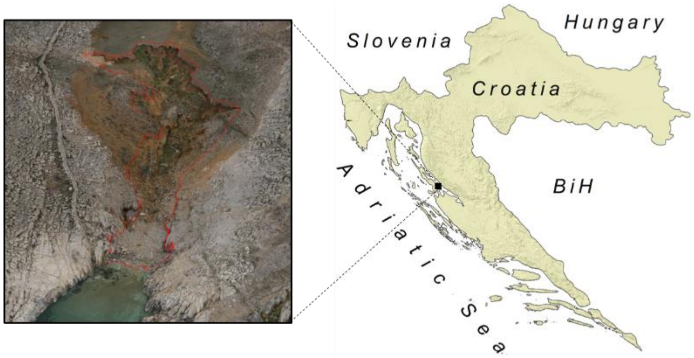

Figure 1. Study area covering gully Santiš within SE part of Pag Island, Croatia

II. METHODS

Field survey of chosen gully site was conducted on December 17, 2019 with Faro M70 terrestrial laser scanner (Fig. 2.A).

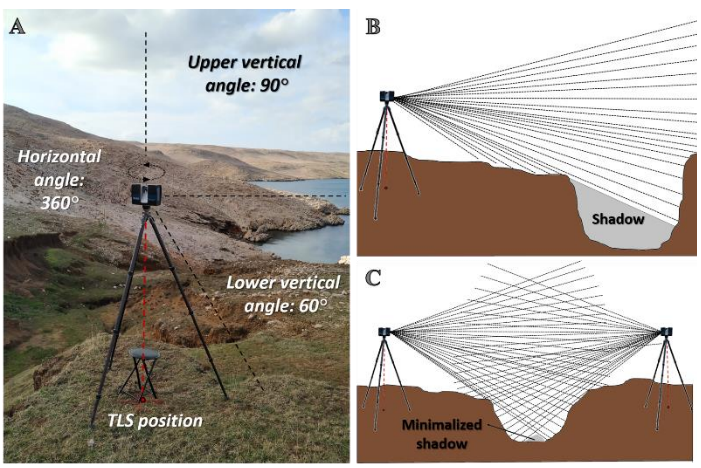

Figure 2. Field survey with Faro M70 TLS (A); Obscured areas within steep gully channels (B); Minimization of obscured areas with introduction of more TLS positions (C)

Whole systematic TLS survey methodology that was developed and applied within this research can be divided in four main steps: *survey planning* (A), *filed preparations* (B), *field TLS survey* (C), *creation and validation of gully model* (D).

A. Survey planning phase

TLS survey planning phase (A) is crucial phase in systematic TLS survey methodology, that serves as basis for all later activities. Planning of systematic TLS survey was performed in ArcGIS 10.1 software, based on available high resolution DEM of chosen study area. For that purpose, VHR DEM (2 cm spatial resolution) and digital ortophoto image (0.5 cm) of gully Santiš were derived from available data collected earlier by aerophotogrametric survey carried out with DJI Matrice 600 PRO drone.

First step in planning phase is *definition of study area extent* (A1), that in our case was defined by the extent of gully Santiš in initial DEM (1163 m²). Then *total number of scans* (A2) has to be determined, in respect to available survey time. As it was planned that survey lasts between 3 and 5 hours (due to short winter daylight), it was decided that survey will have around 8 scans (around 30 minutes per scan). In order to stay within 30-minute range per scan, scanning parameters in Faro M70 had to adjusted accordingly (resolution: ½; quality: 3x).

After determination of total number of scans, it is necessary to *find optimal positions for these scans* (A3), which was performed through the visibility analysis. Visibility analysis was performed by Interactive Visibility tool, where analysis parameters were adjusted to the specifications of Faro M70 laser scanner (Fig. 2; Table 1.).

Table 1. Specifications of Faro M70 used for adjustment of visibility analysis

MIN Range	MAX Range	Horizontal angle	Upper vertical angle	Lower vertical angle	TLS height
0.6 m	70 m	360º	90º	60º	1.9 m

Interactive Visibility tool was used to test more than 100 potential laser scanning positions, where areal spatial coverage and overlap were calculated for every tested position. From all tested potential TLS positions 8 locations with highest overlap and areal coverage were determined as optimal scanning location (Fig. 3.).

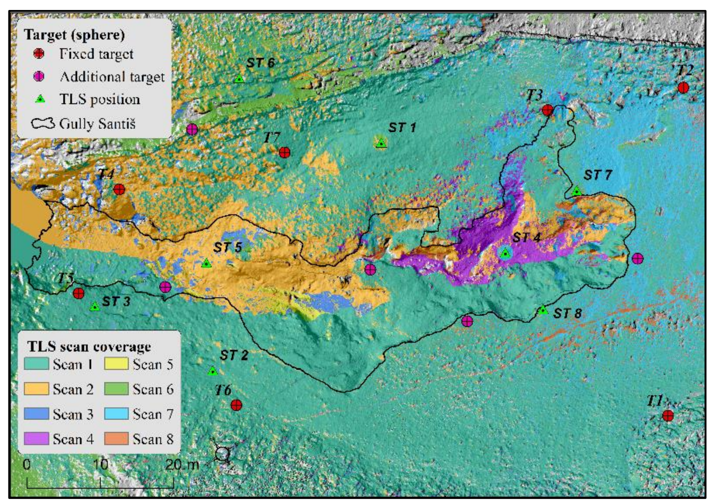

Figure 3. Visibility analysis carried out for 8 optimal TLS scanning positions

Final step in survey planning phase is *definition of optimal positions for survey reference targets* (A4). Survey reference targets (e.g. spheres, chessboards, etc.) are indications used in TLS surveys for accurate registration of multiple surveyed scans. As such, these targets have to be placed on exact XYZ location, which are identical for every repeated TLS survey and that won't be affected by ongoing gully erosion process. Therefore, optimal locations for these targets are on surrounding carbonate rocks, outside of the soil material affected by gully erosion. Visibility of every chosen target from defined 8 TLS positions was validated by *Line of sight* tool, which confirmed that at least three targets are visible from every TLS position. In total 7 targets were defined around study area and their height was set to 2 meters above ground, so that targets are visible from all parts of the gully.

B. Field preparations phase

Second phase in our methodology covers the field preparations (B) for later field TLS surveys, which includes *GPS stakeout of target positions* (B1), *construction of fixed and anchored target positions* (B2) and *GPS stakeout of scanner positions* (B3).

Seven target positions were stakeout and marked on the ground with Stonex S10 RTK GPS. At every marked target location fixed stands were carved in carbonate rock with Bosch hammer drill (Fig. 4.A) and leveled with self-leveling concrete (Fig. 4.B). Four anchors were then drilled in every fixed stand (Fig. 4.C), which serve as basis for metal poles that are holding the reference targets (spheres).

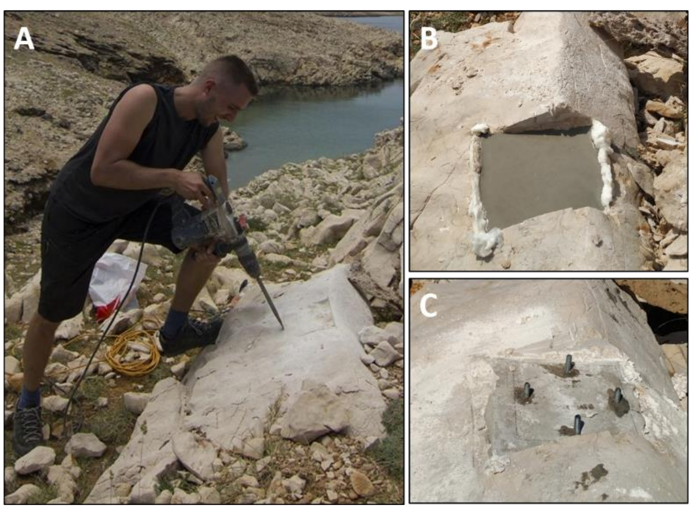

Figure 4. Construction of fixed target (sphere) stands with Bosch hammer drill (A); leveling of carved stand (B); fixed anchors for target poles (C)

Seven 2 m long metal poles were then used to fix targets above constructed stands. Metal poles can be dissembled and stored in-between two TLS surveys, while constructed TLS stands are protected from exposure to weather and salt depletion by nylon and gypsum protective caps.

After construction of all seven target stands, eight TLS scanning positions were stakeout and marked with red spray. Since most TLS positions are located within study area and within loose soil material, no permanent position marks haven't been made. In order to avoid disturbance of natural gully erosion process only red spray was used, as non-destructive marking method. Therefore, TLS positions have to be stakeout and marked with RTK GPS repeatedly before every new TLS survey.

C. Field TLS survey

Prior to the TLS field survey all seven reference targets (d = 69.5 cm) were placed on metal poles fixed to the constructed stands (Fig. 5.), while additional targets were placed in-between. Additional targets are optional, as they serve only to improve registration of collected scans, if main fixed targets are not sufficient. Precise coordinates of every TLS target, placed on top of metal pole was collected with 50-epoch RTK positioning using the Stonex S10 RTK GPS.

Figure 5. Reference target (sphere) placed on the fixed metal pole anchored to the constructed stand (A); one of seven target poles distributed around study area (B)

At the end, Faro M70 TLS mounted on carbon tripod was used to scan entire gully from all eight defined TLS positions.

D. Creation and validation of gully model

Collected scans were processed in Faro Scene 2019 software, which was used for registration of scans and creation of point cloud representing whole study site.

III. Results and Conclusions

A. Coverage of gully study area with TLS scans

Carried survey planning phase based on visibility analysis and eight defined optimal TLS positions resulted with very high percentage of study area coverage (over 95 %). Despite complex terrain morphology, survey planning minimized occurrence of shadows, as extend of obstructed areas were limited to the bottom of steep and incised sub-channels within the main gully channel.

Reference target stands prepared within survey preparation phase proved to be practical solution for accurate positioning of targets within and around the study area. Constructed target stands are allowing accurate multiple TLS surveys, as spheres are positioned on identical locations for every new survey.

Conducted TLS survey included eight scans that covered entire study area. Every scan lasted around 24 minutes, including time required for TLS setup and duration of scanning. In total scanning of the whole gully lasted around 3 h (3 hours, 10 minutes and 36 seconds).

B. Scans registration and point cloud creation

Collected eight scans were registered in Faro Scene through manual registration, with 1.7 mm mean horizontal target error and 2.9 mm mean vertical target error. Registered scans were used for creation of point cloud with 368 549 177 points. Created point cloud successfully covered whole study site, with exception of small obstructed areas at the bottom of steep headwall sections or within steep sub-channels (Fig. 6.). Thus, created point cloud has confirmed the accuracy and reliability of performed planning phase.

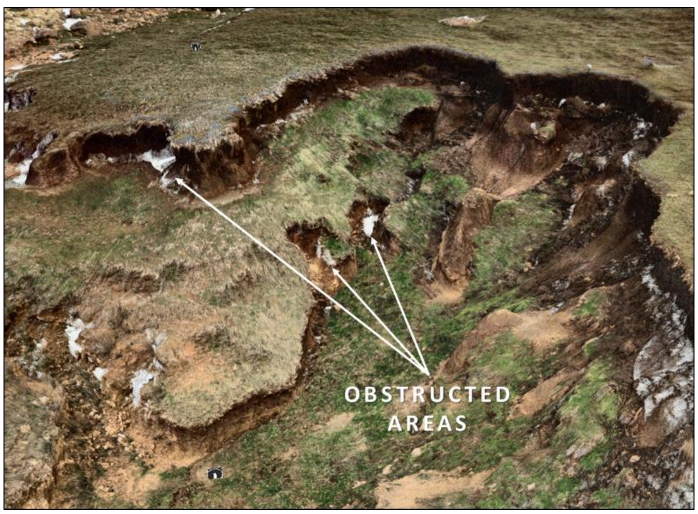

Figure 6. Initial part of gully Santiš represented within collected point cloud

In conclusion, developed systematic TLS survey methodology allowed accurate scanning of complex gully site. As planned, created point cloud successfully covered over 95% of complex gully surface, while obstructed areas were minimalized. Survey planning and preparation phases proved to be crucial for systematic scanning of complex morphological features, especially if multiple surveys and quantification of spatio-temporal changes are required.

Results of conducted survey will be compared with next systematic TLS survey, which is scheduled for June 17, 2020.

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