LANDSLIDE SURVEYS USING LOW-COST UAV AND FOSS PHOTOGRAMMETRIC WORKFLOW

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ABSTRACT:

Unmanned Aerial Vehicle have found their usage in various academic and industry domains, mainly due to the versatility of options that one aircraft can offer from onboard sensors for data acquisition and positioning, through different weight and size categories allowing different applications, including landslide mapping and surveying. Survey-grade UAVs can provide very precise flight and data but usually are very costly, and their use can be further bounded by many regulations. In this work, we have adopted a low-cost consumer-grade UAV to do multitemporal monitoring of an active landslide (Ruinon) in Northern Italy to evaluate the applicability of such setup in the landslide hazard domain. Moreover, for flight planning, photogrammetric reconstruction, and comparative analyses we have adopted free and open-source software solutions. The resulted dense point clouds and orthophotos yielded very satisfactory results from accuracies of few meters and even sub-meter level when reconstructed with field-surveyed ground control points. As a result, from the two surveys comparisons, July and October 2021, several displaced boulders and debris were detected where no significant reactivations were detected from our surveys. Such low-cost setup can be used also from non-professionals and in citizen science campaigns which can significantly contribute to additional landslide mapping and analyses by providing valuable datasets.

1. INTRODUCTION

In recent years we have noticed an increasing number of applications of Unmanned Aerial Vehicles (UAVs) in various domains – from agriculture, archaeology to disaster preparedness and response, and many more (Remondino et al., 2012). This is because UAVs allow us to collect high quality information from a distance and perspective that usually only very high resolution spaceborne cameras can provide. However, the quality and usability of such vehicles are tightly related to the price, starting from consumer-grade class with basic camera sensors, going to more professional, survey-oriented category, where such systems can be equipped with high-end multispectral cameras and positioning systems. Of course, the latter systems can ensure final products with millimetre precision, but usually on a very costly price. In addition to the cost of the UAV, currently European legislation for airborne systems is demanding additional courses and qualifications for operators, depending on the weight of the device and associated risk within an operation. Except for the price of the surveying equipment, usually in mapping campaigns, it should be included an additional cost for the processing and post-processing software suits. However, Free and Open-Source Software (FOSS) had always their supporters and backers usually due to the lack of limitations in usage, and the possibility to modify and contribute to the code according to the needs and targets. FOSS tools nowadays are widely used also for Structure-from-Motion (SfM) photogrammetry, for postprocessing and analysing SfM point clouds.

The aim of this work was to carry out the monitoring of an active landslide at regular time-intervals, using low-cost UAV setup and FOSS tools for processing the collected data. Some minimum requirements for the choice of the UAV narrowed to a system recently entitled as 'mini' class due to their very low weight (< 250 gr), coupled with high resolution complementary metal oxide semiconductor CMOS camera sensor and built-in positioning system. According to the European legislation such lightweight airborne systems can be used in a wide range of applications without too demanding and costly courses for the operator.

2. CASE STUDY

The case study chosen for the work was the Ruinon landslide (Figure 1 andFigure 2) in the Upper Valtellina, Northern Italy. It is one of the most active slope failures in Italy, also very well monitored and studied (Del Piccolo, 1999; Agliardi et al., 2001; Tarchi et al., 2003; Del Ventisette et al., 2012; Carlà et al., 2021). The landslide can be characterized as a "translational rock-debris slide" sitting at the base of deep-seated gravitational slope deformation which is affecting the entire slope. The Ruinon landslide is composed of two scarps (upper and lower), where the focus of this work was the lower, which was the most active in the last few years with seasonal reactivations after heavy precipitations during the summers of 2019 and 2020. The surveys were planned and carried out in July and October 2021, and they happened before and after another reactivation.

Figure 1. Ruinon landslide, lower scarp.

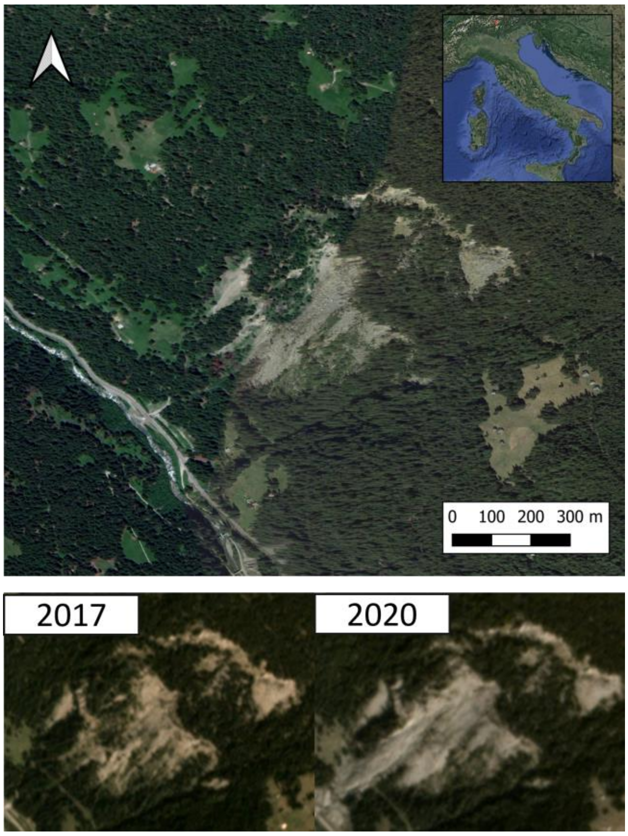

Figure 2. The location of Ruinon landslide. The landslide in 2017 and 2020 (*source: Planet,2017; basemap - Google Satelite through QuickMapServices QGIS plugin, Map data © Google*)

3. UAV SETUP

To cover the requirements of the surveys, a DJI MINI 2 consumer-grade low weight (249 gr) unmanned aircraft was used. It is equipped with 12 MP CMOS sensor and f/2.8 lens with a field of view 83°. The compact UAV has an onboard built-in Global Navigation Satellite System (GNSS) which uses the Global Positioning System (GPS), GLObal NAvigation Satellite System (GLONASS)and GALILEO constellations. Along other features that the device offers, some of the most relevant to the current surveying task could be considered the long-range communication between the controller and the receiver, which, by specification, could ensure bidirectional transmission up to 6 km (according to European health, safety, and environmental protection standards) and 10 km (regulated by Federal Communications Commission of the US). In addition, the lightweight body of the aircraft has a wind resistance of level 5, which can ensure flight speed up to 30-38 km/h. The system comes with batteries of 2250 mAh and this ensures the flight maximum time of around 30 minutes (in no-wind condition and flying with average speed). All those features make reliable the usage of the UAV for surveying tasks in mountainous areas where weather conditions can change simply due to altitude differences (from 1,500 to almost 2,000 asl. in the case of Ruinon) or due to sudden atmospheric changes.

On the other hand, the UAV has a couple of drawbacks corresponding mainly to the precision of the acquired imagery and to flight-security features. The built-in GNSS receiver is a consumer level module which has an accuracy in the range of few meters. In addition, the aircraft lacks obstacle avoidance sensors which is also the reason for the manufacturer to further restrict the device also from automated flights according to a predefined flight plan. It should be noted that at the time of the surveys, in 2021, there was no mean to carry out automatic flights with this particular UAV model, while in 2022 a third-party paid application that enables this feature is present.

Another aspect, when considering UAV, are the local flight regulations. Currently, in Europe the implementation of synchronised national policies according to European Union Aviation Safety Agency (EASA) (*EU 2019/947*, 2019) is in progress. Therefore, the selection of a lightweight aircraft (< 250 g) eases the use also from a legal point of view, as it is required to the operator only to carry out a short online course and a successful examination about the European regulations for the use of UAV, a registration in a national system as operator, and finally, a liability insurance of the unmanned aircraft.

Lastly, before carrying out a flight survey, local regulations should be consulted. In the case of Ruinon landslide, as it is situated in the Stelvio National Park, to carry out such an activity an authorization from the park's administration (www.stelviopark.it) is needed.

4. TOOLS AND METHODOLOGY

For a complete analysis of possible terrain displacements, a relatively straightforward workflow was applied. It can be roughly separated into four main stages: survey preparation, data acquisition, data processing and post-processing. As the landslide under considerations is relatively large, a proper survey planning had to be carried out. In order to plan the flight paths accordingly, it had to be taken into account the terrain relief and the final photogrammetric quality that it is expected from the dataset. Further, the acquired datasets were processed using standard Surface-from-Motion and Multi-View Stereo photogrammetry packages. In the last stage activities for precise product co-registration (between two consecutive survey results) and analysis of the resulted point clouds were carried out.

The field activities for data acquisition were performed once in July and once in October 2021, and additional surveys are planned for the2022. The observations were executed before and after the summer season, since the last reactivations of the landslide (e.g., 2019 and 2020) were exactly in those periods because of heavy rainfalls, therefore presumably before and after a new reactivation.

To help with the planning, processing and post-processing stages, three FOSS solutions were used in the workflow. FOSS for geospatial applications (FOSS4G) has been discussed over the years (Moreno-Sanchez, 2012; Brovelli et al., 2017) and it is gaining more and more support and advocacy, mainly not for the 'free' as 'free of charge' but as 'freedom to run, copy, distribute, study, change and improve the software' (GNU Project, 1996).

4.1 Flight Planner and survey setup

The Flight Planner package is a QGIS plugin allowing the determination of the flight plan for photogrammetric surveys (JMG30, 2021). The main outputs are related to a layer containing the projection layer and exterior orientation parameters, and the size of the images for averaged height of the terrain. The main inputs that are required are: the shapefile with the boundaries of the area of interest, the Digital Terrain Model (DTM) and the value of the target ground sample distance (GSD). With computed imaging locations and parameters, one can easily construct a general flight plan with properly computed horizontal

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and vertical speed and total flight length. Depending on the area of interest, the flight plan can be further subdivided in more feasible flight blocks according to the device's battery lifetime.

In the case of the Ruinon landslide, the target minimum GSD was set to 10 cm/pix, which was considered more than satisfactory considering the scale of the landslide body and the already monitored displacements. In addition, it was ensured that the average flight height was no more than 110 meters above the terrain with image overlap of minimum 80% in longitudinal direction. Example of such plan can be seen in the following Figure 3 where the waypoints to be followed are separated in the transversal and longitudinal direction according to the landslide body. This separation was need to the different flight parameters needed – on one hand, the vertical and horizontal speed, the flight altitude and on there the camera settings (in terms of photo interval and lens inclination). In the case of transversal flights, the altitude was kept constant per each stripe, the vertical speed was null and the horizontal was set to 6 m/s, the camera inclination was set to 0°, i.e. along the nadir direction. In the second case of the UAV following longitudinal direction, the vertical speed was set to be constant to 3 m/s independent of direction (up- or downslope), the horizontal was 4.5 m/s, and the camera orientation was set to be oblique at 57° in order to be pseudo-nadir to an average slope plane of the landslide of 33°.

Except for flight parameters, the preparation of the acquisition plan is critical also for the final product quality. The inclusion of transversal flight path contributes to the camera calibration, which on its side reduces the systematic errors in the Digital Elevation Model (DEM) deformation (James and Robson, 2014; Yordanov et al., 2019b). On the other hand, the inclusion of pseudo-nadir images during longitudinal flights is actively filling gaps, where some occlusions can occur (Scaioni et al., 2018a) during the nadir acquisitions, for example, vertical rockfaces.

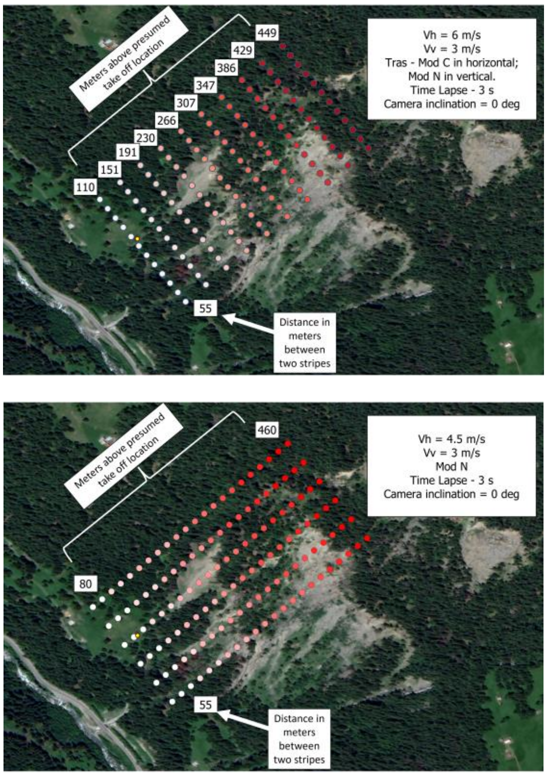

Figure 3. Flight plans in translational and longitudinal direction. (*basemap - Google Satelite through QuickMapServices QGIS plugin, Map data © Google*)

It should be noted that the general flight plan created by the tool is depicting the overall need of the images requested for a model with the predetermined quality, however, such long flight paths are not completely feasible both by limitations of the aircraft battery life and flight regulations. In our case, the general plan (only half of it in Figure 3) was subdivided into four blocks and the waypoints following by the aircraft was operated manually.

4.2 OpenDroneMap

OpenDroneMap (ODM) is an ecosystem for processing, analyzing and visualizing aerial data (OpenDroneMap Authors, 2020). It utilizes several additional libraries where it mainly relies on OpenSFM and OpenMVS for the 3D reconstruction of the objects and for the densification of the clouds. Additional to the sparse and dense point clouds, other outputs of the processing can be a texturized 3D model, orthophoto, quality report.

Moreover, ODM has a built-in integration to directly upload the resulted orthophotos to OpenAerialMap (www.openaerialmap.org) which is a tool for searching and sharing crowdsourced UAV images under open license, where such orthophotos can be in great asset for landslide inventory compiling and susceptibility analyses (Yordanov and Brovelli, 2020; Yordanov et al., 2021) .

4.3 CloudCompare

CloudCompare is tool for postprocessing point clouds and triangular meshes, mainly used to quantify the changes between two surveys outputs (CloudCompare Development Team, 2021). In addition, it has built-in advanced tools for registration, point cloud resampling and segmentation, volume calculation and comparison, etc.

The variety of implemented algorithms in the software package allows the integration of photogrammetry point clouds in the landslide studies from more traditional analysis of the geometric properties of rock faces using the facet/fracture detection (Scaioni et al., 2018b), to monitor landslide displacements by directly comparing point clouds using Multiscale Model to Model Cloud Comparison (M3C2) (Lague et al., 2013), cloud-to-cloud (C2C) distance (Yordanov et al., 2019a). In fact, in this work were applied the last two approaches, were the M3C2 cloud comparison approach is based on the local roughness, point local normal direction and the registration error between both clouds.

4.4 Ground Control Points

For an improved georeferencing of the final products during the July 2021 survey 5 Ground Control Points (GCP) were acquired using Leica AX1200 in real-time kinematic positioning (RTK)mode with respect to Bormio permanent reference station (Spin GNSS network, https://www.spingnss.it/). For each point 3 independent repetitions were done. The location of the GCPs was selected to be outside of the unstable body, on the right-sided landslide flank (Figure 4).

4.5 External dataset

Independently of our surveys, which took place during 2021, the local environmental agency of Lombardy region in Italy (ARPA Lombardia) had already carried out several airborne campaigns during the Ruinon activations of the years 2019 and 2020. For the completeness of our analysis, we were provided with the point clouds and orthophotos from their campaigns. It should be noted that the provided point clouds were georeferenced relying only on the used UAV built-in GNSS, without the use of any GCPs.

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The complete list of the observations used in this work is reported in the Table 1.

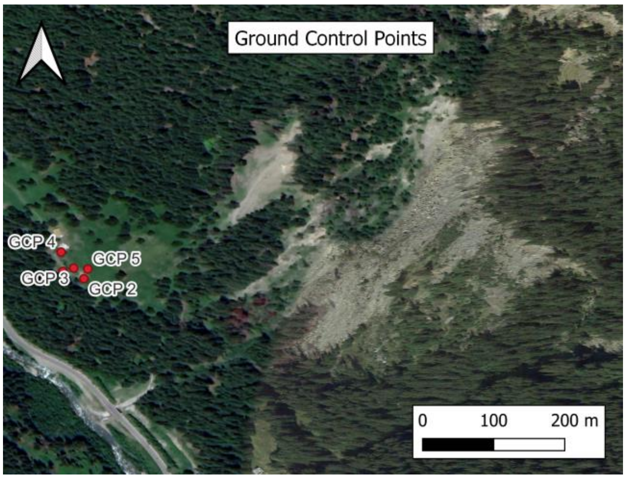

Figure 4. The location of the GCPs. (*basemap - Google Satelite through QuickMapServices QGIS plugin, Map data © Google*)

N	Date	Institution
1	06/07/2021	Politecnico di Milano
2	29/10/2021	
3	27/09/2019	ARPA Lombardia
4	10/09/2020	

Table 1. List of the observation surveys.

5. RESULTS

5.1 Data acquisition and processing

From the point of view of data acquisition, the implemented setup showed very satisfactory results – the usage of the UAV, even manually operated, managed to cover the area of interest separated in blocks with a total flight time of around 1 hour. The collected image sets resulted into July batch of 1533 shots and October batch of 1354 shots. The difference is mainly due to a particular increase of image acquisition during the July session in the areas, where the targets for the GCPs were placed.

From model point of view both reconstructions have an average ground sampling distance equal to 10 cm/pix. The July dense point cloud resulted in around 35,000,000 points (Figure 5), while 25,000,000 points were (Figure 6) in the October processing. The difference is again due to the particular attention that was paid to the GCP area, which also resulted in around 0.05 km^2 higher area cover from the July products. The GSD for both orthophotos is also 10 cm/pix (Figure 7 and Figure 8). Both the orthophotos are available on the OpenAerialMap (July and October 2021).

In terms of the registration error for the October survey, without GCPs and directly using the UAVs GNSS, it is in the range of Root Mean Square Error RMSE=3.11m. With the GCPs surveyed with high precision GNSS RTK, it improved to 0.12m. Similarly, there is a notable difference in the horizonal (CE90) and vertical (LE90) accuracies: in the case of July products, they are estimated as 0.29m and 0.27m, in October CE90=2.79m and LE90=4.91m.

5.2 Data post-processing and point cloud comparison

To compare the two point clouds, they need to be properly co-registered. CloudCompare has two options for cloud aligning – by manually selecting at least 4 common points and fine registration of clouds which are already roughly aligned by applying Iterative Closest Point (ICP) algorithm. The initial "rough" alignment was done using 15 point pairs that were manually determined in stable areas outside the landslide body and using the July cloud as reference. The outcome resulted in a co-registration error of around 0.35m. Before fine aligning, the point clouds were separated – the landslide body was detached from the "stable" areas, and the fine alignment was carried out on the latter clouds. This was done under the assumption that there can be displaced areas after the July survey and that the co-registration in that area would not be correct as the algorithm computes the RMS on the randomly sampled points. Therefore, the aim was to obtain a more rigid cloud alignment. Finally, the resulted transformation matrix of the stable areas was also applied to the point segments related to the unstable areas. The overall final RMSE was estimated as 0.25m.

During the summer 2021, local authorities did not announce any abrupt changes and reactivations for the landslide. Moreover, in the beginning of the 2022 the mayor of Valfurva municipality released a statement related to the landslide noting that in the past year limited displacements were present without critical issues, pointing out that the main reason for the stabilization of the slope is the divert of a local river (Confinale river) (Comune di Valfurva, 2022). Therefore, no severe cloud difference was expected to be calculated as a result from both surveys.

However, carrying out C2C and M3C2 (Figure 9 and Figure 10) analyses highlighted some changes where two significant zones can be noted one depicting an accumulation (red area towards the landslide toe) and one depicting displaced material (blue area towards left flank in Figure 9). The zone of accumulation is in fact a rock barrier that was under construction during the July survey and almost at its finishing phase in October. The explanation for the larger negative difference is not that straightforward: upon manual inspection of the orthophotos it was noted that there are not significant changes. It was inspected more into detail the quality of the point cloud from October since it was noticeably not as dense as the rest of the cloud. According to the ODM report in this area there is a significant drop of the reconstructed features due to a lack of enough matching images as some of them were omitted during the matching phase. In general, those significant changes are discarded to be as a result from a landslide reactivation. However, several relatively small changes were noted mainly depicting accumulation areas, which upon verification using the orthophotos were determined to be resulting from some sparsely displaced boulders with varying sizes (1-2 meters) (Figure 11). The M3C2 difference also depicts small changes in the central part of the body, which probably can be associated with small surface displacements of debris due to intensive precipitations, as additional channeling formations were noted on the point clouds.

5.3 September 2019 – 2020 point cloud comparison

Similar to the case of the 2021 comparison, the provided point clouds by ARPA Lombardia were post-processed in the same manner: rough alignment by manual point-picking, followed by fine alignment using ICP, both done on the stable areas outside of the landslide body. There was a significant difference in the point cloud density, the one product from 2019 (Figure 12) had a total number of 17,000,000 points, while the one in 2020 (Figure 13) – 53,000,000 points. This significant difference resulted in more difficult point-picking process during the manual alignment, as it was not always possible to distinguish the exact positions of common markers. After the final alignment the RMSE was equal to 0.31m.

Figure 5. July 2021 dense point cloud.

Figure 6. October 2021 dense point cloud.

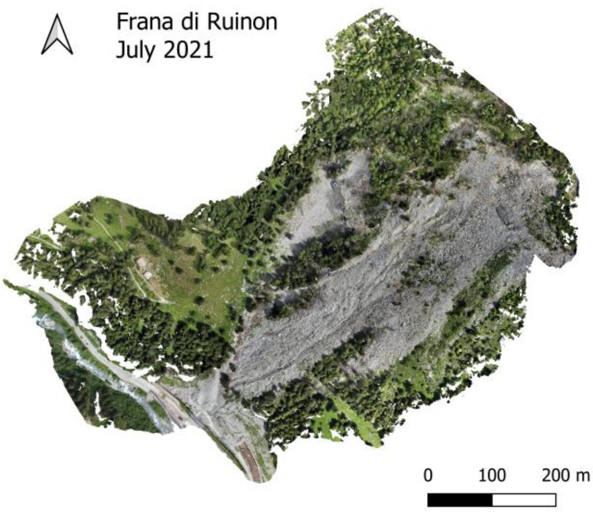

Figure 7. July 2021 orthophoto.

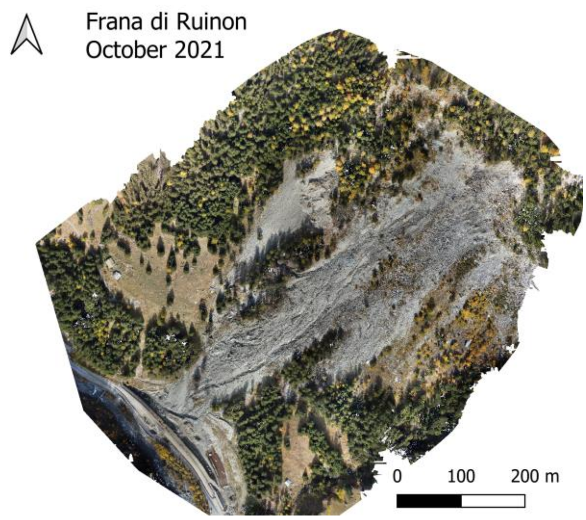

Figure 8. October 2021 orthophoto.

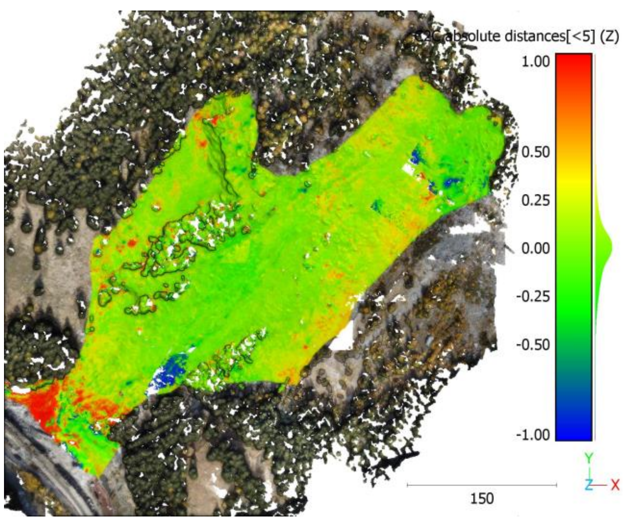

Figure 9. July-October 2021 cloud-to-cloud distance in meters.

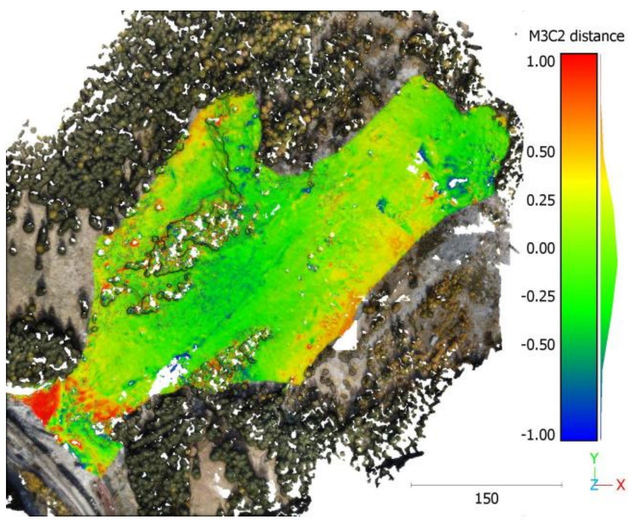

Figure 10. July-October 2021 M3C2 distance in meters.

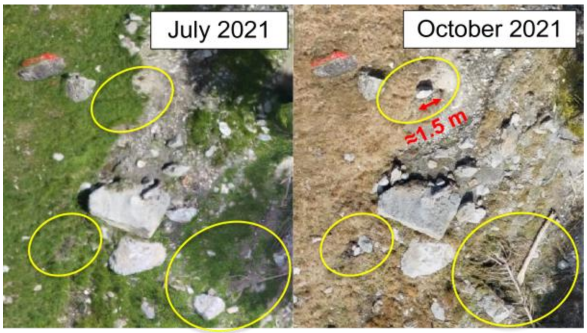

Figure 11. Details of displaced boulders between July and September 2021.

As expected, there were more significant changes during this period, notable from the RGB models where large, vegetated areas are missing. More detailed difference is notable from the cloud comparison (Figure 14).

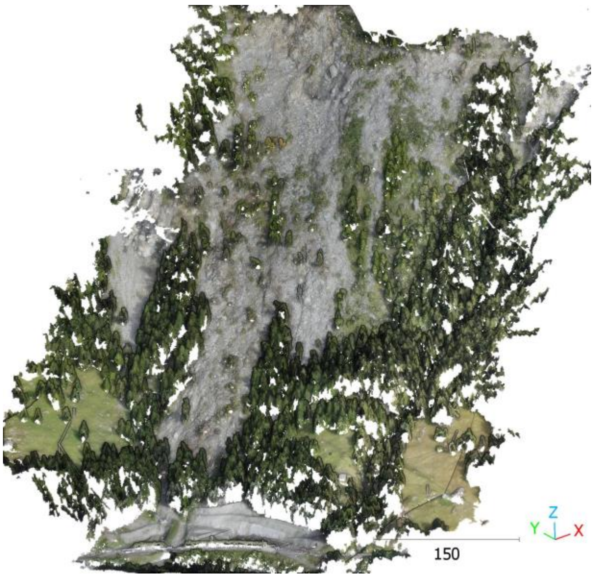

Figure 12. September 2019 point cloud.

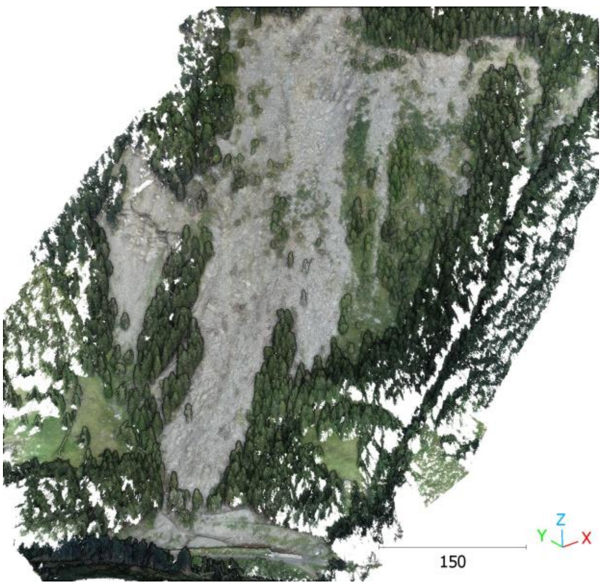

Figure 13. September 2020 point cloud.

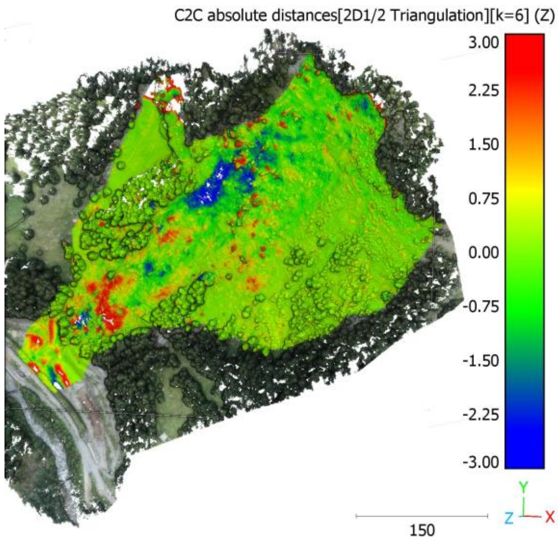

Figure 14. 2019-2020 cloud difference in meters.

From the comparison, the zones of depletion and accumulation (the blue and red larger zones) are evident, where their main difference can reach to ± 3meters in vertical direction. It should be considered that this also includes fallen trees that are piled or displaced.

6. CONCLUSIONS

In the recent years we have witnessed an evolution of UAV production, coupling them with high-precision sensors for data collection and significant improvements in their flight time. Naturally, such developments are quickly developed in the industry and academic domains to be implemented for various civil and military applications: from precise agriculture to archaeological documentation, to surveillance and many more. They are well adopted in the landslide hazard domain for search-and-rescue operations and evaluating post-disaster consequences, but they are used in preparedness applications (e.g., landslide inventory compiling) and in the monitoring of the landslide state. Professional class UAVs with onboard sensing, navigational and safety instruments, and long flight capabilities, usually are very costly and require several patent courses. For that reason, in this work we decided to test and use a consumer grade low-cost UAV setup and FOSS photogrammetry packages to carry out multitemporal surveys of the Ruinon landslide in Northern Italy. The landslide reactivated during the summer periods of 2019 and 2020, and this is the reason for which we have done two surveys, one before and one after the summer of 2021. The aircraft under consideration is lacking automatic waypoint flights so a flight plan was prepared, also taking into account the target quality of the expected orthophotos and point clouds. The resulted products managed to satisfy the target of 10m/pix. During the first survey the positions of several GCPs were acquired with a survey-grade instrument. Naturally, the point cloud with the GCPs had lower georeferencing error and higher vertical/horizontal accuracies, compared to the one with the consumer grade onboard GNSS. From the reconstruction point of view, during the two surveys images were collected with enough quality to reconstruct fully the area of interest and to use both point clouds to detect possible changes that might have occurred between the two them. The comparative analysis did not highlight any significant reactivation of the landslide body, however managed to detect several displaced boulders. The multitemporal surveys will continue in the future with possible improvements during surveys, e.g., including more GCPs or more optimized flight paths while keeping the image quality high.

Such low-cost setups for landslide surveys cannot bring cutting-edge precision into the domain, however for certain scales they can bring sufficient enough precision, for example, to calibrate monitoring approaches using satellite data, or can update landslide inventories in countries where such are missing or simply not up-to-date, especially through platforms for sharing crowdsourced datasets.

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