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CLOUD-TO-CLOUD COMPARISON AND INTEGRATION OF TLS AND UAV SURVEYS FOR THE MAINTENANCE OF COASTAL PROTECTION SYSTEMS

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1. Introduction

Impacted by natural agents such as waves, wind, floods, storm activity, sea level rise and anthropogenic agents, coastal areas are actually high-energy environments (King, Leon, Mulcahy, Jackson, & Corbett, 2017) and therefore subject to considerable dynamics (Saponaro, Tarantino, Reina, Furfaro, & Fratino, 2019). In order to mitigate and limit the health effects of these areas, different types of rigid or flexible coastal protection systems can be introduced. Rock walls and breakwaters are the most common structures: even if used to protect the coasts, these flexible structures can in turn be damaged or ineffective over time due to the general dynamism of the phenomena triggered in the marine ecosystem. Therefore, considered of equal importance in terms of frequency and strictness of the so-called coastal zone monitoring, measuring the changes of these structures, particularly after major events (Nikolakopoulos & Koukouvelas, 2018), can allow the economic and ordinary maintenance to be carried out before major and costly failure occurs (King et al., 2017). Furthermore, as the evolution of the current state of coastal areas and protection structures can be quite rapid, frequent, practical and not really predictable, structural-coastal monitoring is shown as a primary need to manage the entire marine ecosystem. On the other hand, their accessibility can be dangerous or uncomfortable due to the direct influence of the weather, especially in the case of major events, and the impracticability of places such as along cliffs. These requirements therefore exclude or affect many of the conventional detection techniques. The most conventional method consists of topographic surveys based on total stations or RTK-GNSS observations, which take a long time. They appear rather expensive and above all do not fully identify the phenomenon in progress or do not best represent the issue. Satellite images, alternatively, avoid operational difficulties with the coastal surveying site in case of limited access, but only provide spatial resolutions up to about 0.4 m per pixel with a revisit time dilated over time and at high costs. The use of Terrestrial Laser Scanner (TLS) detection techniques can provide coastal surveys of higher quality, frequently with sub-centimetric accuracy, obtaining robust three-dimensional reconstructions of the protection systems detected. However, they can be prohibitive in terms of costs for many coastal projects. The use of equipment in some areas can be impractical and, above all, causes quite long operating times. More recently, Unmanned Aerial Vehicles (UAVs) systems equipped with simple low-cost cameras or more sophisticated sensors, accompanied by a variety of software, provided with Structure from Motion (SfM) algorithms and suitable to process the sensor on-board acquisitions, are a valid alternative producing Digital Elevation Models (DEMs) and orthomosaics (Moon, Chung, Kwon, Seo, & Shin, 2019; Nikolakopoulos, Kozarski, & Kogkas, 2017; Saponaro, Tarantino, & Fratino, 2018).

In this work the application of the two competing survey techniques as TLS and UAV has been analyzed to evaluate the state of the protection systems related to a stretch of Margherita di Savoia coast (Apulia region, Italy). In particular, the two relative computed point clouds were subjected to comparison tests in order to highlight the convergences and divergences between the two techniques. A significant contribution on the achievable accuracies evaluation and the limits deriving from the two techniques were investigated.

Lastly, the results derived from the fusion of the points cloud obtained through the two different

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techniques were evaluated in order to identify any advantages in the structural maintenance of the systems.

2. Data acquisition

The presented study focused on the analysis of a short stretch of coastline bordering Margherita di Savoia (Apulia Region) (Figure 1), one of the test areas identified within the "*STrategie Innovative per il Monitoraggio ed Analisi del Rischio Erosione*" (STIMARE) project.

Figure 1. Orthomosaic of the study area characterized by GCPs location

Processing the two data acquisitions, performed in series, returned two point clouds (Table 1). The first one was extracted using Agisoft PhotoScan (version 1.4.1) from the images acquired by means of a prosumer UAV DJI Inspire 1, equipped with a ZenMuse X3 camera (characterized by a focal length of 3.61 mm and a pixel size of 1.56 µm) from a flight altitude of 30 m Above Ground Level (AGL), with a Ground Sample Distance (GSD) equal to 1.3 cm/pixel. The second points cloud was produced inside the JRC 3D Reconstruction software platform by processing data derived from 8 scans performed through the Terrestrial 3D Laser Scanner Z+F IMAGER 5006h (with an ambiguity interval of 79 m, a resolution range equal to 0.1 mm and max. data acquisition rate of 1,016,027 pixels/sec).

Table 1. Main features of points cloud from the two techniques analyzed

_cloud	**Acquisition time**	**Processing time**	**n° points**	**File Size**	**RMSE$_{GCPs}$**
UAV	7 min 31 sec	about 2 h	21,989,744	545 MB	0.0303 m
TLS	about 1 h 30 min	about 1 h 30 min	105,874,370	2.56 GB	0.0018 m

Table 1 shows both the times used for data acquisition and those ones due to data processing, i.e. the time required to generate the final point cloud, excluding the time spent in the collimation and georeferencing phase which are significative for both techniques. If on the one hand UAV techniques give the possibility of acquiring data in short times, on the other processing times give merit to the TLS techniques and the improvements of the last generation instruments, including the alignment and georeferencing of scans, solved autonomously during the on-site measurements.

As already mentioned, the elaborated point clouds were georeferenced and optimized through 21 Ground Control Points (GCPs), homogeneously distributed in the investigated area (Fig. 1) and measured, in the same day, in nRTK mode (i.e. network Real Time Kinematic) with a Leica Geosystem Viva CS15, connected to the local permanent station of Margherita di Savoia belonging to the national network (Rete Dinamica Nazionale RDN2008) of Continuously Operating Reference Stations (CORS). These ground truth points are represented by natural fixed points, such as edges and characteristic shaped elements that can be easily identified both in UAV imagery and in TLS scans, also useful in next monitoring phases. The resultant GCPs have an acceptable constant accuracy along the three axes X, Y and Z equal to 2 cm. Overall, the point clouds thus obtained have a final accuracy, assessed by the value of Root-Mean-Square Error ($RMSE_{XYZ}$) over the GCPs, of 3 cm and 1.8 mm respectively in the UAV and TLS cases (Figure 2), advisable values for the monitoring of coastal protection structures.

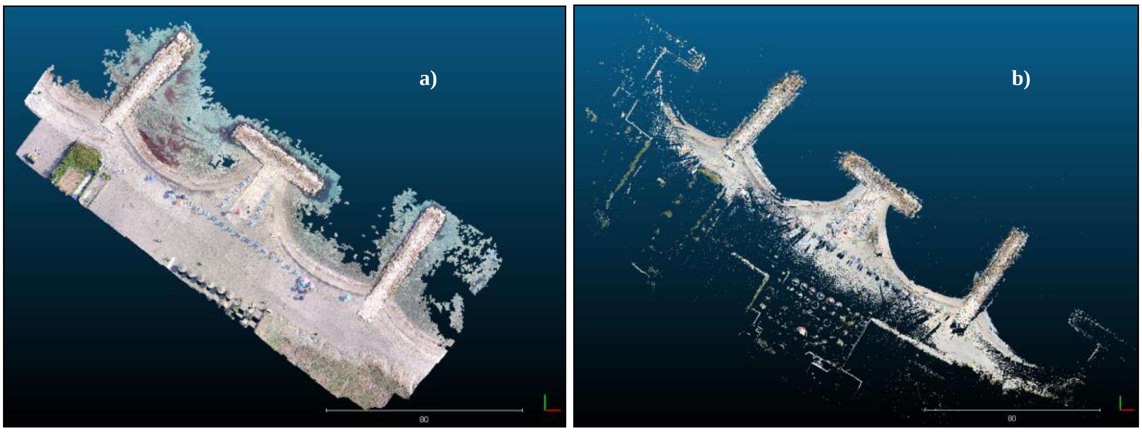

Figure 2. Dense Points cloud derived from: a) UAV acquisition; b) TLS scans

3. Data processing

Once the point clouds are independently generated by the two different survey techniques, a co-registration is required in order to compare them. In this case study, having been georeferenced based on the same GCPs, the two clouds were perfectly overlapped except for the differences to be described in next sections, deriving from the techniques used. Using the open-source CloudCompare platform, three distinct steps were addressed in order to get an overview of cloud-to-cloud differences and data fusion.

Firstly, the density of the points of each cloud was evaluated through the Density tool in 'Compute geometric features' drop down menu, in order to verify whether the two clouds can guaranty a quantity of information uniformly and similarly distributed. The Density tool provides three evaluation methods: as *linear density* calculated in the number of N points falling in a radius R, set equal to the GSD from UAV (0.013 m), or as *surface* or *volumetric density*, i.e. the number of points falling respectively in a circle or a sphere of radius R.

In the next step, the M3C2 plug-in was used to calculate the directly measurable distances between the two point clouds. Considering the point cloud from UAV as a reference, the plug-in searches for each point of this cloud, in a circle footprint of radius equal to 0.013 m projected in the TLS cloud, and for a height of 0.5 m, generating thus a cylinder, the corresponding TLS point and evaluates the distance. At the end of the process, M3C2 provides a scalar field in which the distributions of these distances are represented, an index of cloud-to-cloud variations (Lague, Brodu, & Leroux, 2013).

Lastly, the Merge tool inside CloudCompare was used to integrate the two 3D reconstructions data into a single point cloud.

4. Results

In the first phase the linear density was evaluated. The software generates scalar fields in which the distributions of the points in the investigated area are shown. After setting a radius equal to the GSD, the UAV cloud was assumed as a reference because, as expected, due to linear density value equal to 1 point/radius. In the Figure 3 is shown as comparison only the scalar field of the cloud TLS.

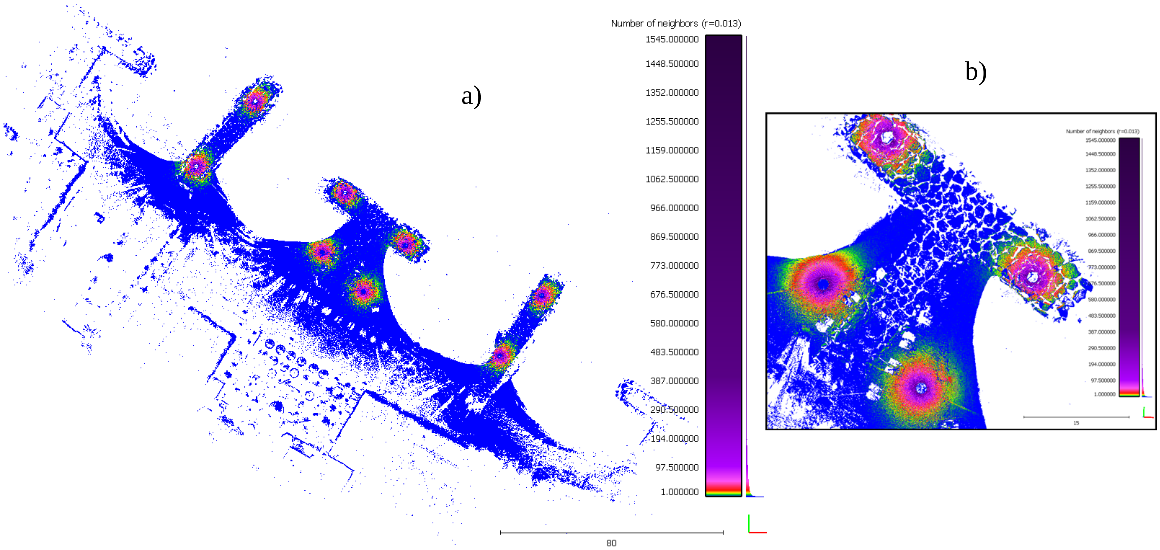

Figure 3. a) Computed density of TLS cloud; b) Detailed view of a TLS station area

In both point clouds there is a clear uniform points distribution, but in the TLS cloud there are peaks placed just near the data capture stations (Figure 3), where the beams are more conveyed. This, however, makes the TLS cloud significantly heavier for storage and management within the software, also considering that the TLS cloud was subjected to ambiguous point filtering (movable elements, water and its various reflections) and the entire UAV cloud is equal to about 1/5 of the TLS one (Table 1). It should also be pointed that the uncertainty of the data, although more numerous than the UAV acquisitions, increases proportionally, due to the low ambiguity interval of the TLS instrument used, as the acquisition distance from the station point increases.

The result of the third step related to the cloud-to-cloud comparison using the M3C2 plug-in is presented in Figure 4. The comparison shows that between the two clouds there are mainly maximum deviations on a centimetric scale, imputable to instrument tolerances and above all to the propagation of the georeferencing and co-registration errors of the two models. On the other hand, deviations that exceeding the decimeter can be attributed to the presence of bathers and noise caused by the reflectance of water, as previously mentioned.

Merging the two point clouds effectively returned a cloud composed by a multitude of redundant points that reduce the ability of processing data. On the other hand, however, this integration compensates for the limitations of both technologies. Fusing the TLS cloud with the UAV one, the Original Cloud Index indicated the points of the TLS source cloud in blue, while in red the points integrated by the UAV cloud (Figures 5). It is observed that on the generated models there are certainly differences related to the acquisition altitude and a different behavior related to the acquisition angle. While on the one hand the nadiral acquisition helps in recording planar points below the TLS station plan but at the same time create a smoothed surface, on the other hand the TLS scans from the ground allows to acquire more detailed surface but, due to the high incidence angle of beams, it is only apt to detect prospective information. It is therefore clear that, in case of merging data, this latter provides a comprehensive interpretation of coastal defense systems.

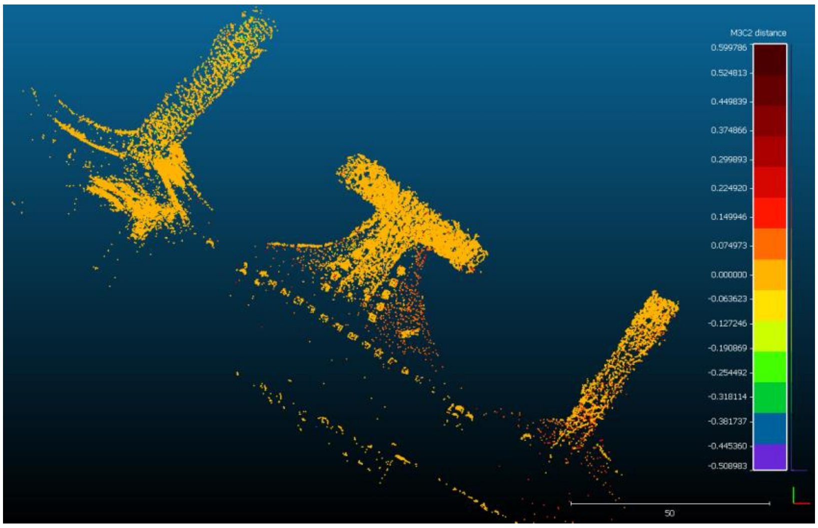

Figure 4. M3C2 plugin results. Cloud-to-Cloud Comparison of the two 3D models

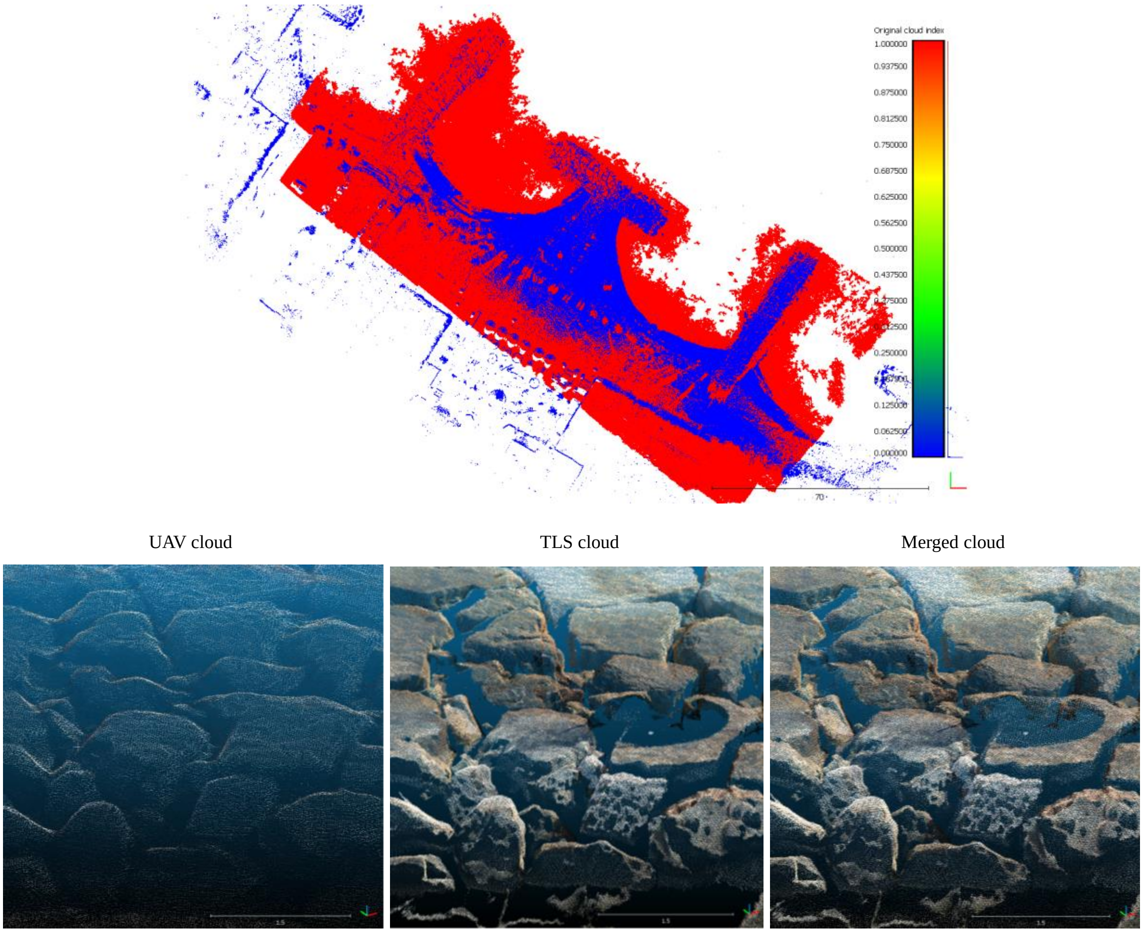

Figure 5. a) TLS-UAV Data Fusion: the scale bar represent the Original Cloud Index, i.e. considering the TLS cloud as reference (in blue), in red are shown points merged with the UAV cloud; b) Detail of the same area about the differences between the two single point clouds and the final one merged

5. Conclusion

Nowadays, different investigation techniques could be used in marine ecosystems to manage and monitor the environmental changes over time. But, at same time, each one of them is characterized by peculiarities and deficits that can affects the costs, the on-site effort and the efficacy of the entire monitoring program. The main purpose of this work was therefore to detect benefits and limits deduced from a 3D cloud-to-cloud comparison using Terrestrial Laser Scanner (TLS) and Unmanned Aerial Vehicle (UAV) survey techniques for the maintenance of a Coastal Protection System, i.e. a system of breakwaters.

Substantial benefits in terms of costs and time are evident acquiring UAV data, unlike the TLS techniques, which however excel with regard to processing times and achievable sub-centimeter accuracies. If used correctly, the UAV systems, supported by ground-truth controls and an optimized data processing, can produce 3D topographic surveys of structures as accurate and consistent as those derived from the TLS (Delaney, Shakoor, & Watts, 2019; Medjkane et al., 2018).

As demonstrated in literature (Bracci, Drauschke, Kühne, & Márton, 2018; Farella, Torresani, & Remondino, 2019), data fusion techniques generate exhaustive models in which the limits of one technique are compensated by the other one, considering a reduction in computing capacity. Due to the angle of incidence or acquisition, it is preferable to make the most of the TLS techniques in scenarios with predominantly vertical developments (for example the protective walls), on the other hand, using UAV technologies in flat scenarios and equipped with sensors suitable for the required accuracy.

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