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D-SITE

Drones - Systems of Information on Cultural Heritage for a spatial and social investigation

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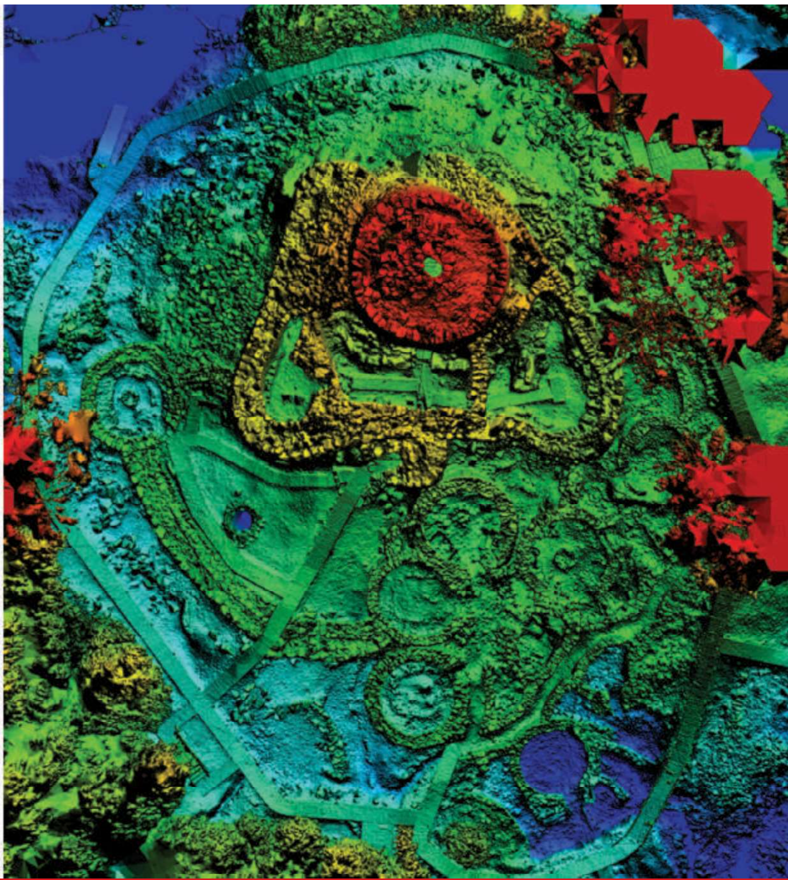

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Survey data Integration, Data Comparison, Image and Range Based Survey, Survey for Cultural Heritage, Software Performances.

ABSTRACT

This paper aims to evaluate the performance, in terms of accuracy and speed, of various commer-cial software (Reality Capture®, Agisoft Metashape® and 3DF Zephyr®) for the integration among image and range-based survey data. Datasets were collected in the Nuragic complex called "la Prisgiona" (Arzachena, SS, Italy), during a collaborative research project between CNR – ISPC and the Municipality of Arzachena, using aerial photogrammetry, topographic and TLS survey. Re-sults of comparative tests demonstrates that, when working on architectural scale survey, passive and active techniques are to be considered homologous in terms of accuracy and precision.

A 3D survey in archaeology. Comparison among software for image and range-based data integration

1. Introduction

Three-dimensional survey techniques are nowadays commonly used as part of Cultural Heritage professional and academic practice, aiming at documenting, understanding and preserving ancient civilizations historic and material legacy (Hassan et al. 2019). Archaeology, among the disciplines that deal with Cultural Heritage makes frequent use of geomatic technologies, to such an extent that this can no longer be considered a phenomenon but more of a consolidated practice (O' Driscoll 2018; Hoon Jo et al. 2019; Trillo et al. 2020). Digitization using image-based and/or range-based techniques applied on archaeological remains is commonly used for excavation records, conservations tasks and heritage management and communication. The massive use of these technologies in CH studies has been, in recent years, a frequent subject for publications aimed at identifying good practices, even if the scientific community has not yet agreed on a formalization for standardizable workflows and procedures. (Remondino et al. 2006; Bitelli et al. 2007; Hoon Jo et al. 2019; O' Driscoll 2018; Aragòna et al. 2017; Erenoglu et al. 2017; Apollonio et al. 2021).
One of the most stimulating aspects in this still open field is the integration between different measurement paradigms, in particular among range and image-based. (Rönnholm et al. 2007). In fact, both techniques have advantages and disadvantages, which are offset by the integration of the two technologies to achieve a more complete coverage of the surveyed area (Rönnholm et al. 2007; Russo et al 2014; Russo et al. 2015). The integration of image and range-based measurement data, considering the high effectiveness of the technique, has a well-established tradition of studies. Search addresses usually consider datasets acquired from TLS and close range or UAV-based images (Rönnholm et al. 2007), then focusing on data registration and, with various approaches, on range maps matching analysis, (Gonizzi et al. 2012; Russo et al. 2014) sometimes using SWOT analysis (Hassan et al. 2019).
This paper aims to analyze workflows within commercial software (Reality Capture® - RC -, Agisoft Metashape® - AM - and 3DF Zephyr® - 3DF -) to evaluate the effectiveness of these approaches for integrating datasets. In particular, a performance evaluation will be made in terms of speed, completeness and accuracy in the cameras positioning. The survey conducted at the *La Prisgiona* nuragic complex, located in *Arzachena* (SS), was used as a case study for this analysis. For dimensions, location and geometry it lends an excellent opportunity to evaluate different approaches and produced data quality.

2. Case study

The three-dimensional architectural survey of the Nuragic complex "*la Prisgiona*" was carried out whitin the agreement "*per un progetto di studio e di ricerca sulla Conoscenza e ricostruzione del paesaggio storico del territorio di Arzachena*". The Agreement was established in 2021 between the CNR ISPC and the Municipality of Arzachena (SS, Italy). The agreement's object is the

On the cover, Top view of "*La Prisgiona*" nuragic complex: Orthophoto (left) and DEM (right).

archaeological study and the digital three-dimensional reconstruction of the territory of the Municipality of Arzachena, the monuments documentation, from a metric, archaeometric and cultural point of view, and the anthropic study of the territory in antiquity. The first activities were carried out in collaboration with the municipality of Arzachena between July and September 2021 allowing to carry out a 3D survey of some archaeological sites including the "*la Prisgiona*". The archaeological site, a large Nuragic village built in a strategic position with a panoramic view of the surrounding area, dates back to the late bronze age and its architectures are the result of 3 different construction phases. (Antona 2012) The *nuraghe* is a *tholos* type construction, consisting of a central tower with a bastion incorporating two side towers. A curvilinear surrounding wall protects the *nuraghe*, enclosing a large courtyard occupied by a well. The village is outside the wall consisting of numerous circular huts and fences. Survey's aims were various, mostly: archaeological remains' accurate documentation and implementation of a digital replica for future public dissemination within 3D visualization systems. The data captured on the field were also exploited for research purposes in geomatics, in this article the result of the integration of image-based and range-based measurement data are presented here for the first time.

3. Data aquisition

Preliminary to 3D acquisition, a topographic survey has been performed with a Ruide R2 total station and a Geomax Zenith 20 system GNSS. Nineteen automatic detection targets (16 bit) have been measured stationing on 6 positions. This data has been used both in the photogrammetric process, to scale and adjust camera orientations, and in TLS survey for registration evaluation and to have homologous coordinates system among range maps from different technologies[1].
As for photogrammetric survey, a DJI mini 2 UAS has

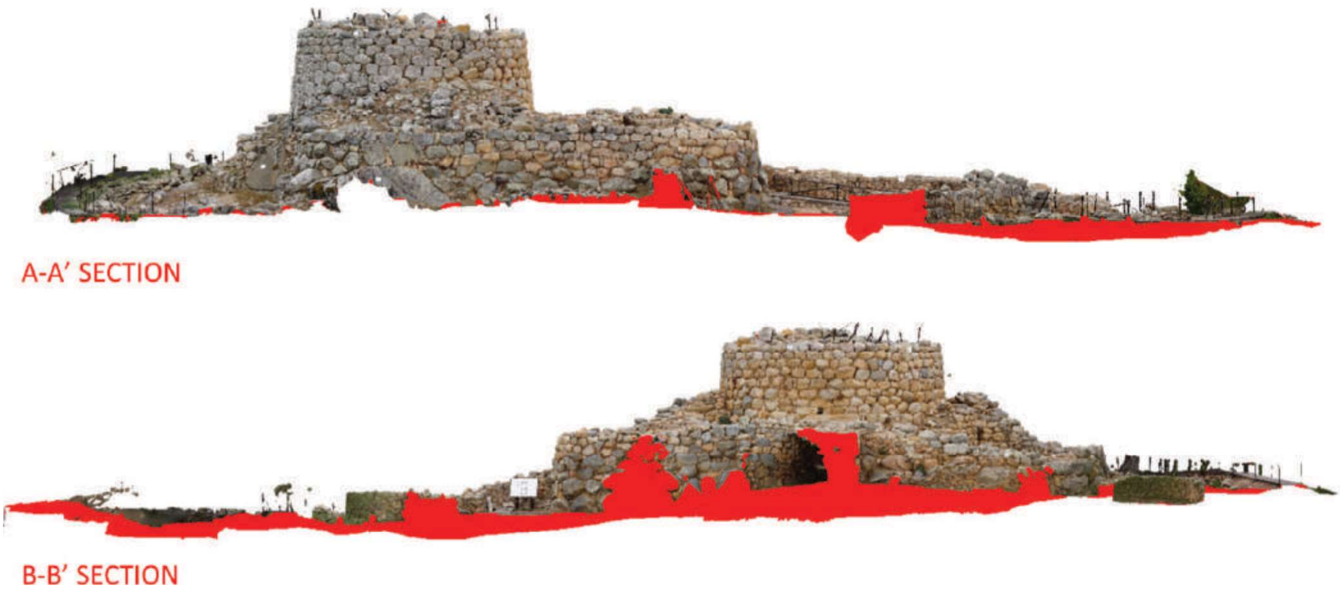

Figure 2. "*La Prisgiona*" nuragic complex: cross sections.

been used (1/2,3'' CMOS, 12 MP.), the images were taken operating a manual flight, surrounding the structure with circles at various distances (4 mm GSD). In order to have an adequate overlapping and resolution, 329 photos have been chosen and processed. After topographic and photogrammetric survey, fifty-seven scans were acquired with a Leica BLK 360[2], mounted on a tripod at different heights but never below 2m. Scan resolution was set to high. Point clouds were registered using C2C registration (RMS 3 mm). in Autodesk Recap®.

4. Data processing and comparison[3]

Photogrammetric set was processed in AM (High Accuracy) producing a dense cloud of 77 mil. points, in RC (normal detail[4]) generating a dense cloud of 28, and in 3DF (urban landscape), having a dense cloud of only 2. Alignment results after optimization showed, in all three software, a noticeable consistency in error estimation (+/- 1 cm).
TLS reference cloud was obtained using Autodesk Recap® through a C2C registration of fifty-seven structured scans. TLS cloud was later referenced in local coordinates and exported as structured data in.e57 format. The same format was chosen for exporting 3D products (dense cloud) from AM and 3DF, while for RC, the export format was.xyz, due to the impossibility to export in.e57.

4.1 Data integration

Integration among photogrammetric and TLS data, within the three tested software, is obtained by different technical approaches, more specifically: RC and AM have a camera alignment approach, even if AM allows a geometric alignment too, which could be useful for the integration of unstructured scans. 3DF on the other side does not make use of photos taken by the scanner while aligning TLS and photogrammetric sets, the procedure has then an approach purely based on range maps geometry registration.
In RC integration is based on synthetic images generated from the TLS registered point clouds using color or intensity. These spherical images, one for each standpoint, are converted into six.lsp files (Julin et al. 2019). The.lsp files are calibrated and oriented for each rotation, generating a cube that is externally positioned and orientated as the TLS standpoint (Luhmann et al. 2020). Photogrammetry image matching and orientation is based the on TLS synthetic images (Luhmann et al. 2020).
AM mainly uses spherical panoramas or TLS depth maps, when the instrument can't acquire spherical images, for the co-registration of TLS and photogrammetric data. Photogrammetric depth maps are merged with the TLS depth data during the dense cloud or mesh generation[5]. If TLS clouds are unstructured, the integration is obtained performing a self-calibrating bundle adjustment through GCPs that can be refined with an ICP between two clouds by the means of external software tools (Fiorillo et al. 2021).

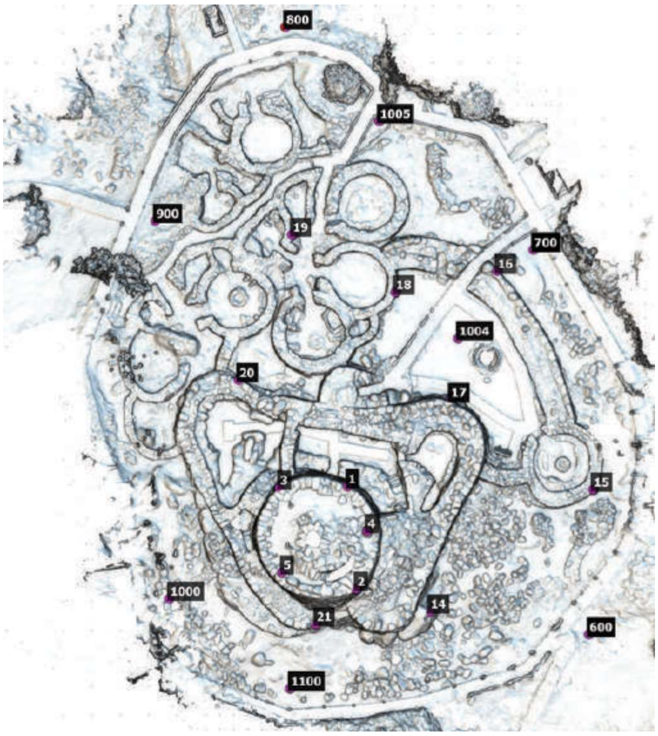

Figure 3. Topographic measures displayed over dense point cloud.

In 3DF the integration among clouds is obtained by merging photogrammetric and TLS data that are always read by the software as "non structured". The integration of the two clouds is articulated in two steps: rough alignment, which can be done by a manual superposition or by corresponding homologous GCPs, and fine alignment, using ICP[6].

4.2 Comparison methodology

Comparison among dense clouds was performed between each photogrammetry-based set and TLS reference cloud. Before comparison, photogrammetric clouds have been finely registered with TLS reference using ICP in Cloud Compare with a consistent result for all sets (RMS 0.25). After fine registration, all clouds, including TLS, were decimated with a maximum density of 5 mm to have a homologous resolution for all data. After this preparatory step a cloud comparison has been performed in Cloud Compare using C2C distance.

In order to specifically analyze deviation among areas shared by image and range-based survey, a first data filtering was carried out eliminating shadow cones area non-shared among TLS measurements and photogrammetric survey (Figure 4). Following this filtering, it has been observed that the average deviation between the photogrammetric clouds and the laser measurements is in a range between 0 and 3 cm. A first comparison was performed by setting the maximum deviation between the two clouds to 1m. The result for the three photogrammetry-derived clouds is close to 6 cm on the whole model. A consistent error in all three models derives from the upper part of the structure: this error is intrinsic to the model, since with TLS this portion of the structure was not correctly detected, given its morphology. To better understand the value of the error and where it lies within the model, the range of the deviation between the two clouds has been reduced performing a filtering of maximum deviation of 4cm to avoid TLS shadow cones.

4.3 Comparison outcome

Figure 5 shows in false colors the deviations among the clouds. Through the calculations performed it is noted that the mean and standard deviations do not exceed 2 cm. Major differences, excluding TLS shadow cones, are located on vertical surfaces.

5. Conclusions

A first observation is the substantial consistency of the deviation between all photogrammetric clouds and TLS reference with an average difference between 0 and 2 cm. The greatest deviation can be observed on vertical elements, especially on those described through images

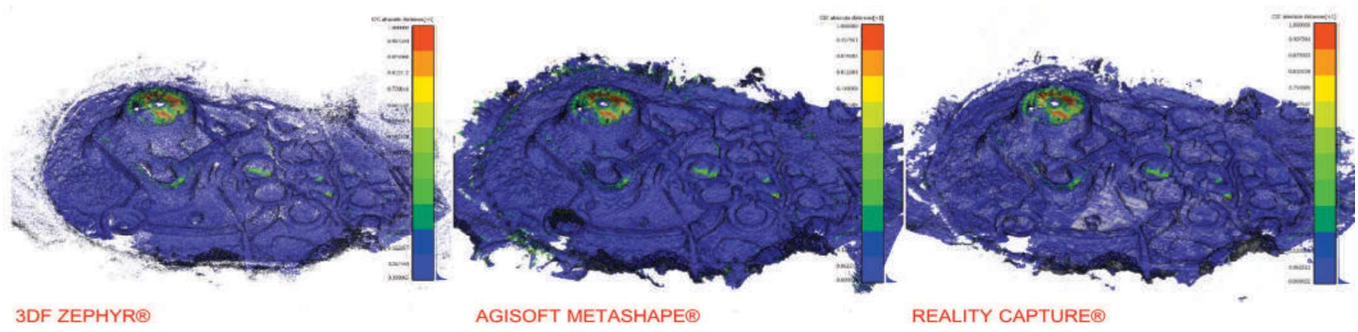

Figure 4. Comparison evidencing photogrammetric cloud distance on TLS shadow cones.

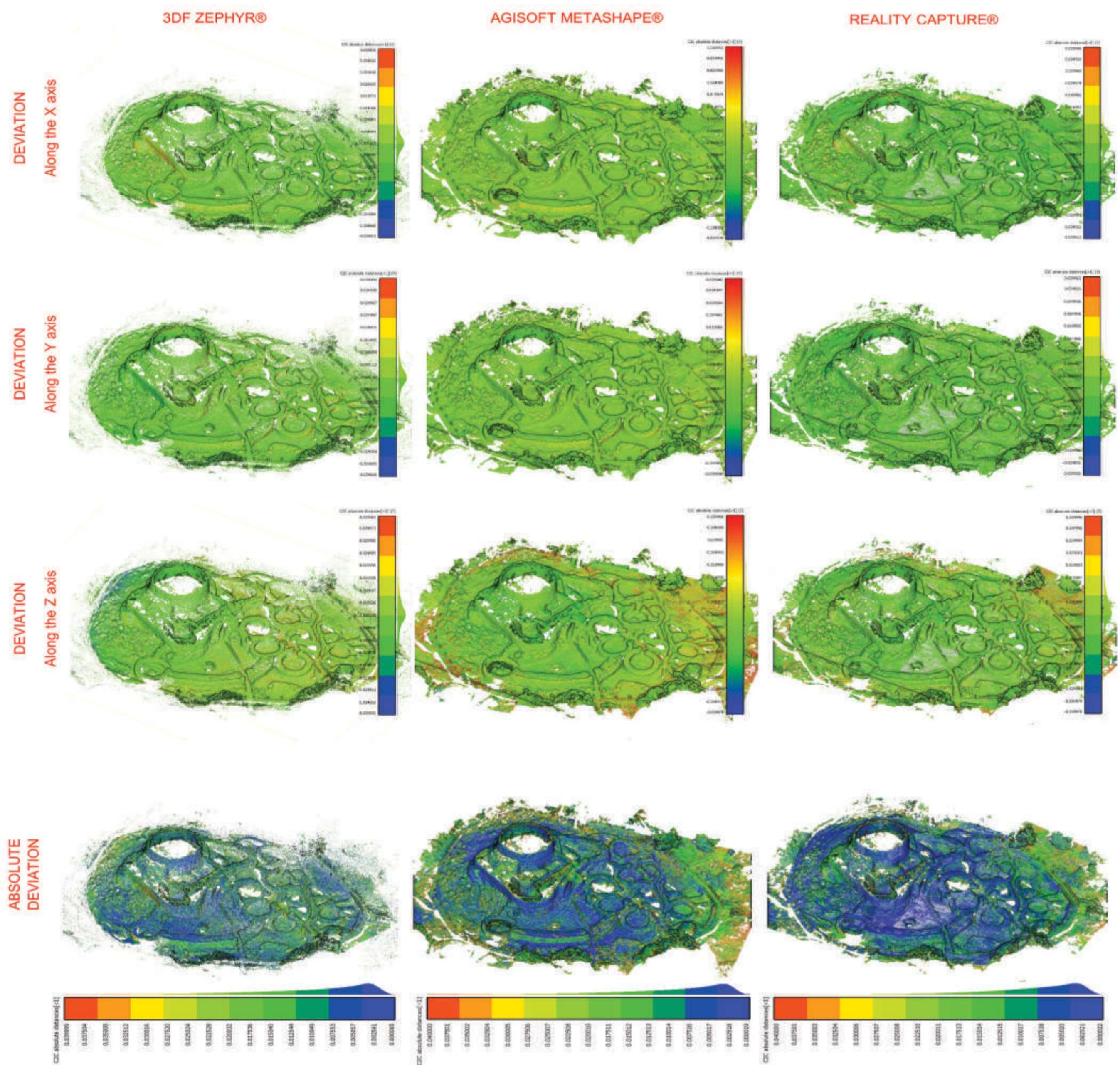

Figure 5. Comparison evidencing deviation.

taken with strong inclination, probably due to hard normal estimation and more difficult camera location.

As for software performance, from a 3D product generation point of view, the most evident difference is found in the 3DF dense cloud, characterized by a much lower density. As for processing time the best performance, considering both alignment and dense cloud generation, has been provided by RC (47 min.), followed by 3DF (74 min.) and AM (91 min.).

When taking into account data management, it is possible to observe a greater elasticity of AM, capable of implementing both structured and unstructured clouds, even if in a less linear solution for dataset management and with a longer processing time. The use of unstructured laser data in 3DF allows the use of a wide range of measurement data while saving storage space, considering the lower weight that unstructured data have compared to structured ones. However, pure geometric alignment can be not as smooth as the ones exploiting images taken from the scanner.

As for RC performance, despite the need to use structured, the ease of the process of registering data from both active and passive sensors using images taken from the scanner, is definitely worth consideration.

Moreover, it is necessary to add the rapidity of the overall processing for both three-dimensional data, through the out of core approach, and the two-dimensional one, a quality partially shared with 3DF.

In conclusion it is difficult, if not wrong, to identify a single solution as the best. The choice can be made only after considering the type of data available. The major advantage of the integration of data from active sensors with image-based techniques can be found on the one hand in the integration of any lack of data determined by the acquisition geometry in the photogrammetric survey and on the other in the integration of shadow cones characterizing TLS survey.

For architectural scale survey, this comparison verified that passive and active techniques are to be considered homologous in terms of accuracy and precision.

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Notes

1 More specifically, for the mean of data comparison, local coordinates were preferred.

2 Range 0.6 m - 60 m, max measurement speed 360.000 points/second, HDR integrated camera, field of view 300° on vertical - 360° on horizontal, ranging error 6mm @ 10m.

3 All processes and comparisons have been performed with the same graphic workstation equipped with: In-tel i9 9900k, RTX 3080ti, RAM 128 GB.

4 RC reconstruction process only results in a surface, not a dense cloud. The cloud compared is therefore made of vertices and not of points. That aspect might therefore affect the results of the comparison. https://agisoft.freshdesk.com/support/solutions/articles/31000159101-terrestrial-laser-scanning-data-processing

5 http://3dflow.net/zephyr-doc/3DF%20Zephyr%20Manual%206.0% 20English.pdf

6 Allowing only rotation and translation not scaling.

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