Point cloud density enhancement within "PROION" project.

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ABSTRACT

Over the past few years Unmanned Aerial Vehicle (UAV) and Terrestrial Laser Scanner (TLS) have emerged as paramount remote sensing approaches for the generation of exceptional three-dimensional models. The current study aims to examine the synergistic use of UAV and TLS point clouds created in the context of "PROION" project. In particular, the project co-funded by the European Union and the Hellenic government, combines in situ measurements, remote sensing data and soft computing methods aiming at evaluating the possible deformation on national infrastructure located in Western Greece. 3D representations of the observation sites derived from UAV and TLS sensors constitute a key part of the validation procedure. In light of this, the spatial reconstruction of the observed infrastructure should be implemented in the best possible spatial resolution. Hence, each observation site was surveyed twice in a regular basis, i.e. a UAV flight was performed to collect points on the roof while a scanning was executed for the acquisition of facades. Afterwards the generated UAV and TLS 3D representations were fused in order to produce a more comprehensive 3D model of each infrastructure. The point clouds generated at the different processing stages were compared in terms of their density.

Keywords: UAV, TLS, fusion, infrastructure, monitoring

1. INTRODUCTION

Both Terrestrial Laser Scanners (TLS) and Unmanned Aerial Vehicles (UAV) are considered as the most reliable methods for collecting point clouds of an area or object under investigation. For more than two decades, the laser scanner systems have been established as suitable means for the automated production of high digital elevation and surface models, while recently UAVs are emerging as a powerful tool for the same purpose. The density of the collected XYZ points is their common big advantage compared to classical survey measurements. Generally speaking, both methods have pros and cons. Although the accuracy of laser scanners is very high, they are ultra-expensive and data collection is a time-consuming procedure. On the other hand, UAVs are becoming popular in the field of surveying, and photogrammetry, especially due to their flexibility and ease of operation [1,2]. Yet, there are doubts about the accuracy of point clouds obtained from UAVs.

Although both TLS and UAV produce point clouds, data acquisition is completely different, resulting in point clouds with important dissimilarities [3]. Terrestrial Laser scanner produces and emits a beam (or series of pulses) of highly collimated, directional, coherent electromagnetic radiation. The same system is used for the recording of the backscattered radiation creating large amounts of 3D information of the terrain at an extremely fast rate. Usually, the derived 3D cloud needs to be georeferenced. UAVs collect a huge number of images and then software based on computer vision and Structure from Motion algorithms produce a dense 3D point cloud. The density depends on the initial flight height and the image overlap. The processing procedure is time consuming, but the final 3D point cloud has the advantage of georeferencing [3].

In light of research, there are many studies comparing the accuracy of TLS and UAV point clouds. [4-10]. A Leica BLK360 laser scanner was tested for steep slope mapping and the produced point cloud was compared to point clouds generated from UAV data [3]. Another research compared point clouds derived from low-cost UAV (Phantom 4 pro) and TLS. The comparison was implemented via three different ways: a) Metric based comparison b) C2C & M3C2 algorithm-based comparison and c) running linear regression for selected points on both the point clouds [4]. In another case [5], a baseline terrestrial laser scan model of a landslide was compared with corresponding models developed from digital photos acquired from three different UAV platform/sensor combinations. The photographs and laser scans data were captured during the same two-day campaign. A similar study tried to evaluate the suitability of terrestrial laser scanning and unmanned aerial system (UAS) photogrammetry for collecting elevation data required to generate accurate, high-resolution digital elevation models (DEMs) over a small watershed area [6]. Multiple TLS scans were collected without using high-definition surveying (HDS) targets, which are generally used to mesh adjacent scans. To assess the vertical accuracy of the DEMs created from the TLS scan data, 1098 ground control points (GCPs) were used [6]. In another study, data captured with TLS and a UAV-based imaging system were utilized to answer the following questions: usability of both systems in the field, comparison of the collected data, capability of both methodologies to detect some temporal changes and assessment of the measured height values against reference measurements. [7]. Added to this, data collected with Terrestrial Laser Scanner and data from terrestrial photogrammetry was also compared for the precise representation of an outcrop [8]. Furthermore, the combination of the UAV capabilities and Lidar technology was presented in another study [9]. The objective was to examine the geometric accuracy of the produced points clouds as it is a fundamental qualification for the detection and recognition of objects in a single-flight dataset as well as for change detection purposes [9]. Concerning 3D model generation, TLS and UAV systems were used to create ground plans of Somuncu Baba Mosque [10]. The extracted TLS and UAV plans were compared in terms of positioning accuracy using a reference base map [10]. Another study presented two methods using 3D coordinates (TLS, UAV) for measuring large spatial objects [11]. The authors focused on measuring the angle of repose, the value of which is important in many technological processes involving granular materials [11].

The more recent studies focus on the fusion on 3D point clouds derived TLS and UAV. In such a study a data fusion algorithm was developed, which optimally combines sensor data to obtain an improved and complete 3D mapping model of a structure [12]. In particular, TLS data was collected along with the DJI Phantom 4 Pro and terrestrial close-range Sony a7R camera images for the reconstruction of the exterior of a building. Several ground control points and targets were established throughout the scanned building in order to achieve a correct registration [12]. In another study, researchers evaluated the efficacy of standalone unmanned aerial vehicle-laser scanning (UAV-LS) and terrestrial laser scanning data to accurately estimate forest tree metrics under differing management types. The objective of the research was to test whether fusion can improve the mapping of the 3D structure of individual trees to facilitate accurate estimation of tree metrics [13]. Moreover, other researchers tried to integrate ground-based and UAV-LiDAR (ULS) data to better compute tree parameters based on quantitative structure modelling (QSM). The specific fusion was performed in three steps [14]. At first, the ground-based/ULS LiDAR data was co-registered trough the local density peaks of the clustered canopy. Afterwards, redundancy and noise were removed from the ground-based/ULS LiDAR data fusion. Finally, tree modelling and biophysical parameter retrieval were based on QSM [14]. Other studies combined terrestrial laser scanner and unmanned aerial vehicle with a GNSS receiver [15]. In more details data from a DJI S1000 multirotor, equipped with a Sony ILCE 7R digital camera, was combined with data from a Leica P40 ScanStation terrestrial laser scanner. To carry out the measurement, as well as to integrate the measurement data with UAV and TLS, customized targets and numbered reference spheres were used [15]. To overpass the fact that some of the point cloud data were missing in the blind area of TLS measurement, authors used the iterative closest point (ICP) algorithm in the Cloud Compare software to conduct data fusion between the point clouds obtained using the DJI Phantom 4 RTK and TLS [16]. It was proved that after the data fusion, the point clouds not only retained the high-precision characteristics of the original point clouds of the TLS, but also filled in the blind area of the TLS data [16].

In this framework the current work aims to combine UAV and TLS point clouds in order to create denser and more accurate 3D representations of the observation sites of “PROION” project. Detailed descriptions of the applied methodology and the produced results are given in the following sections.

2. DATA AND METHODS

2.1 Data collection

As already mentioned, the current research concerns the synergistic use of UAV and TLS data in the framework of “PROION” project. The project co-funded by the European Union and the Hellenic Government, utilizes in situ measurements, remote sensing data and soft computing algorithms to assess the potential deformation occurred in critical national infrastructure located in Western Greece. The observation sites include: a) an embankment dam and b) a building of the University of Patras. As it can be noticed in Figure 1, 3D representations of the observation sites derived from UAV and TLS sensors are an essential part of the monitoring procedure. In more detail, 3D UAV and TLS point clouds are used for the validation of the identified deformation. With regard to this, the spatial reconstruction of the observed sites should be performed at the best possible spatial resolution. Therefore, each observation site was surveyed twice on a regular basis. Each survey is consisted of a UAV flight for the collection of points on the top view as well as a terrestrial laser scanning for the acquisition of facades. UAV flights were carried out using a Trinity F90 fixed-wing Vtol, while scanning was executed with a Leica ScanStation P50. It is worth mentioning that square black and white targets (4.5") were distributed over the test sites during the UAV and TLS surveys in order to minimize the georeferencing errors. These targets were measured using a Leica GS08 GNSS receiver.

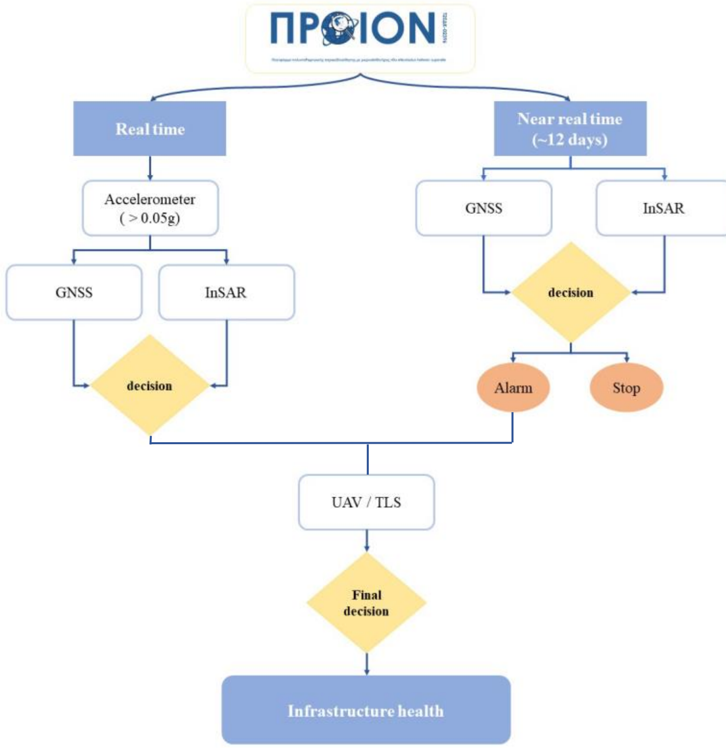

Figure 1. Overview of the processing chain of “PROION” project.

2.2 Processing methodology

To process the obtained UAV imagery, we utilized Structure from Motion (SfM) photogrammetry and Agisoft Metashape software. The technique creates a 3D object model through the digital transformation of a set of overlapping UAV images with different viewing angles [17-19]. Moreover, the alignment of the collected imagery was performed through the highest quality option, which contributes to the improvement of the model quality. At the same time, ultra-high quality setting was specified to create a remarkably dense point cloud.

On the contrary, Leica Cyclone software was utilized for the processing of the collected TLS data. The full coverage of the observation sites requires the execution of multi-position scanning surveys. Hence, the correct registration of the multi-positions scans is a fundamental step in procedure. The registration is performed through the identification of 4.5" black-and-white targets into Leica Cyclone REGISTER 360. A millimetric-accuracy (~ 6 mm) 3D representation of each observation site is generated as a final product.

Afterwards, these multi-sensor 3D representations were further processed to create a more comprehensive in terms of spatial coverage and point density, 3D model of each infrastructure.

3. RESULTS

3.1 Observation site: Asteri dam

As already mentioned, UAV and TLS surveys are regularly performed over the observation sites of "PROION" project in order to be used for validation purposes. In this framework, UAV and TLS point clouds were generated covering the first observation site i.e. Asteri dam. Specifically, Figure 2 illustrates the point cloud created by UAV imagery, while Figure 3 displays the corresponding point cloud emerged from TLS surveys. Despite the higher density and therefore the increased precision of the TLS representation, there areas without any information (Figure 4). Such areas are those with a flat shape which are located at higher altitude regarding the scanning position. To resolve this issue, UAV and TLS point clouds were fused. The joined point cloud is displayed in Figure 4. The fusion enhanced the density of the cloud and the spatial coverage of the initial clouds. The red squares mark the parts that have either been completed or spatially improved. Added to the above, a comparison of the density of the different point clouds is presented in Table 1. It is worth mentioning that the high density of the UAV point cloud is related to the large coverage and not to the spatial resolution of the product.

Figure 2. UAV point cloud of Asteri dam.

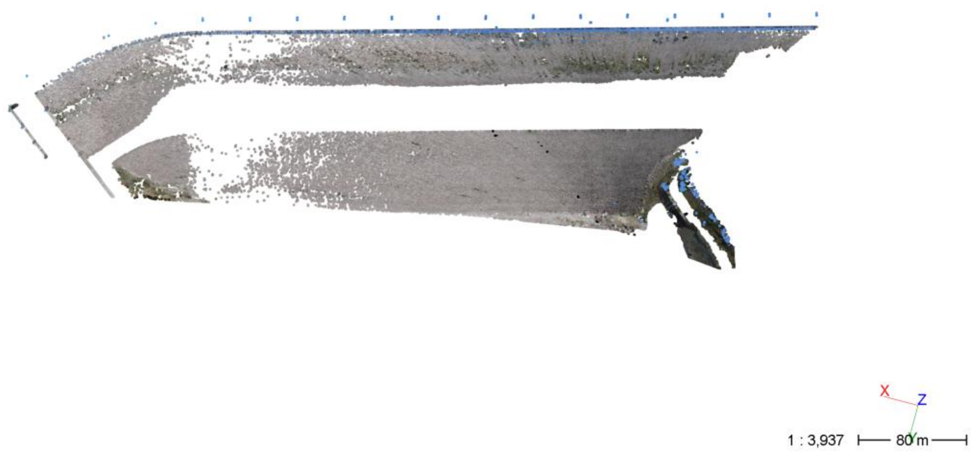

Figure 3. TLS point cloud of Asteri dam.

Figure 4. Fused point cloud of Asteri dam.

Table 1. Point cloud density of the generated 3D models of the dam.

3D model	Number of points
UAV point cloud	604,613,462
TLS point cloud	5,774,346
Fused point cloud	610,387,808

3.2 Observation site: Department of Geology, University of Patras

Concerning the second observation site i.e. the building of the Department of Geology, the processing of the collected UAV and TLS data resulted in the generation of two different point clouds. In particular, the extracted UAV point cloud is depicted figures 5 and 6 in nadir and oblique viewing perspective, respectively. In addition, a 3D model of the building created from UAV imagery is displayed in figure 7. Besides the coverage of larger areas in less time, the main advantage of the execution of UAV flights is the capturing of the roof of the building with great accuracy (cm).

On the other hand, TLS surveys are time consuming, but they can provide point clouds with remarkable detail. Figures 8 and 9 present the generated TLS point cloud in nadir and oblique viewing, while a 3D model of the building is illustrated in Figure 10. As it can be observed, the facades of the building are characterized by a high fidelity of reproduction. Nevertheless, the complete absence of a roof is evident in both the TLS point cloud and the corresponding 3D model.

To overcome the difficulties related to the functionality of each sensor in order to create extremely accurate point clouds for the validation purposes of “PROION” project, the extracted UAV and TLS 3D representations were jointed. Therefore, the newly-created point cloud (Figure 11) shows an increased density of points compared to the original ones (Table 2). Moreover, the red squares in Figure 11 enclose the areas that have been sensibly refined to form a more comprehensive model of the building.

Figure 5. UAV point cloud of the Department of Geology at the University of Patras (top view).

Figure 6. UAV point cloud of the Department of Geology at the University of Patras (oblique view).

Figure 7. UAV 3D model of the Department of Geology at the University of Patras (oblique view).

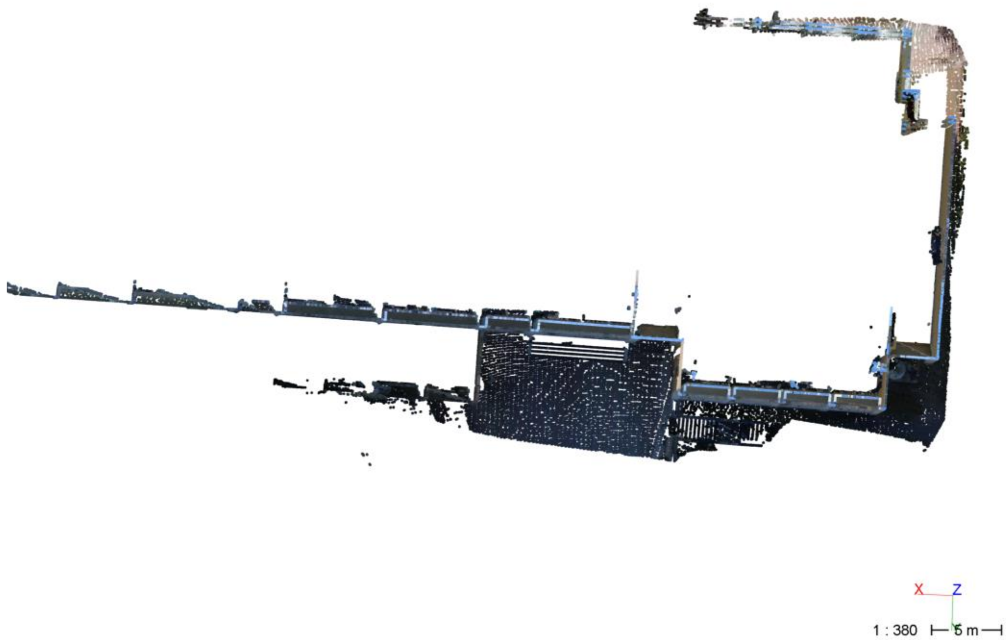

Figure 8. TLS point cloud of the Department of Geology at the University of Patras (top view).

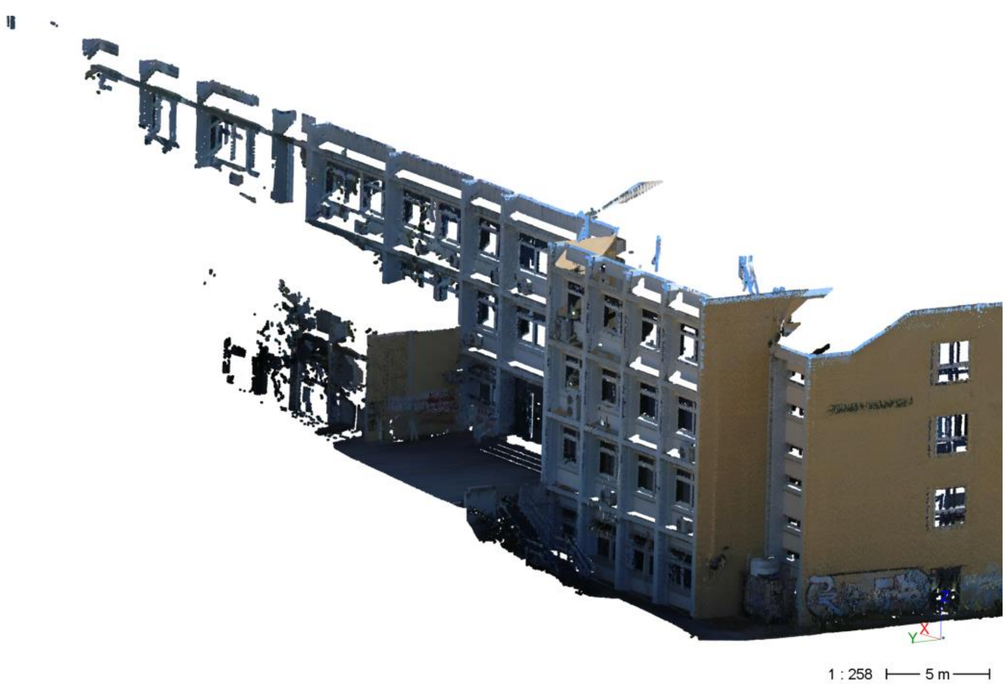

Figure 9. TLS point cloud of the Department of Geology at the University of Patras (oblique view).

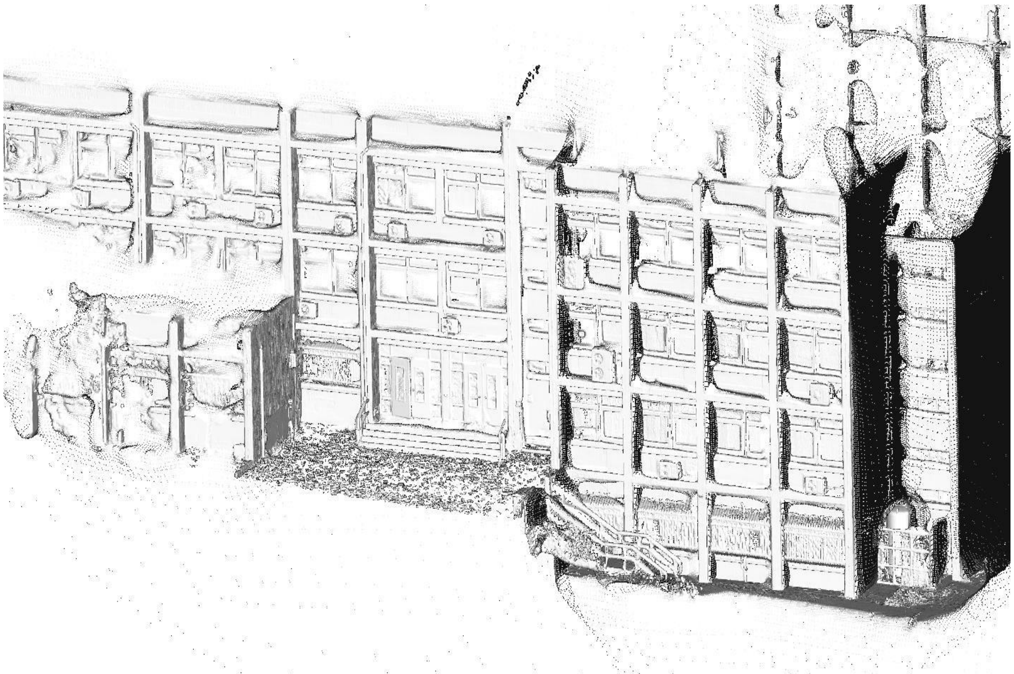

Figure 10. TLS 3D model of the Department of Geology at the University of Patras (oblique view).

Figure 11. Fused point cloud of the Department of Geology at the University of Patras (oblique view).

Table 2. Point cloud density of the generated 3D models of the dam.

3D model	Number of points
UAV point cloud	15,402,717
TLS point cloud	29,436,338
Fused point cloud	44,839,055

4. DISCUSSION AND CONCLUSIONS

The main objective of the current work is the synergic use of UAV and TLS point clouds in order to create denser and more accurate 3D representations of the observation sites falling under "PROION" project. It is particularly important to create high-fidelity 3D models as these are used to validate the results of the other monitoring methods. In this context, UAV flights and TLS surveys over the observation sites were executed on a regular basis. The processing of the collected UAV imagery was performed into Agisoft Metashape, while TLS data were operated by Leica Cyclone software. The generated UAV point clouds manifest the top view of each infrastructure with particularly high accuracy. On the contrary, TLS sensors provide extensively detailed point clouds. To combine the advantages of both approaches, UAV and TLS 3D representations were fused. Hence, an enhanced in terms of spatial coverage and point density point cloud was extracted. Similar studies have recently been conducted, focusing mainly on the correct implementation of fusion algorithms [12, 16].

To conclude, the most important points of the current work are:

- UAV and TLS surveys can be successfully used to create 3D representations of infrastructure.
- UAV sensors cover large areas in a short time and the generated point clouds capture the top view with great precision.
- TLS point clouds present high fidelity in the reconstruction of facades, but they fall short in representing top views.
- UAV and TLS data fusion generates an enhanced in spatial coverage and point density point cloud.

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