INTEGRATION OF GEOMATIC TECHNIQUES FOR THE 3D REPRESENTATION AND MONITORING OF A VETERAN CHESTNUT TREE

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ABSTRACT:

This study concerns the application of different geomatic techniques in forestry sector. An accurate 3D model of a veteran chestnut tree (*Castanea sativa* Mill.) has been realised integrating point clouds by Mobile Laser Scanner (MLS) and photogrammetry techniques. The surveys were conducted in two seasons (summer time: July 22nd 2021; autumn time: December 10th 2021), since chestnut is a deciduous tree and thus taking the chance to detect it also without leaves. Therefore, it was obtained tree’s metric data such as the diameter at breast height (DBH), the total height (TH), the crown basal area, the wood and crown volume. Annual surveys will result in a dataset of virtual trees that will be used to monitor the evolution of these noteworthy plants through time, which are expected to be considered as cultural heritage, given their story and their importance at regional and landscape level. The 3D model was then released for virtualization, making it accessible and available as a data container for different users. Such data will also provide historical memory about the presence of these veteran trees that might be lost in the future if affected by species-specific phytopathologies such as Ink Disease (*Phytophthora Spp.*).

1. INTRODUCTION

In the last two decades, environmental and land surveys have rapidly evolved due to the fast advancement of technologies (Di Stefano et al., 2021). The new techniques involve both remote sensing and proximal sensing devices, making these acquisitions affordable and suitable even in locations with limited or no accessibility. This aspect provides further opportunities for integrated research activities. A growing synergy, between forestry and geomatics can shed new light in the comprehension of partially unrevealed natural dynamics. Recent studies have demonstrated the reliability of aerial or terrestrial photogrammetry for an accurate forest and individual tree three-dimensional (3D) reconstruction, even in combination with point clouds obtained by Mobile Laser Scanners (MLS) (Aicardi et al., 2016, Zhu et al., 2021). MLS provides a point cloud through the Light Detection and Ranging (LiDAR) unit. The LiDAR beam records the position of each point according to the device’s relative reference system, providing an XYZ position for each point in space. Previous forestry applications of this technique report the inability of the beam to hit the tree crown top (Bauwens et al., 2016), which is generally concealed in summer by the leaves, making the tree height estimation uncertain. Therefore, it is advisable to combine other detection methods to obtain an accurate 3D representation of the tree. Indeed, through Unmanned Aerial Vehicle (UAV) photogrammetry, the dense cloud of the upper part of the canopy could be combined with the MLS point cloud, allowing to extract precise tree metric data, such as diameter at breast height (DBH), total height (TH), crown basal area, crown volume and wood volume. In this study, MLS point cloud and UAV photogrammetry are combined i) to obtain an accurate 3D representation of a veteran chestnut tree (*Castanea sativa* Mill.) in two different phenological phases (with and without leaves), ii) to provide accurate metric data for tree structural parameters estimation and iii) set the basis for monitoring the veteran tree through the years. A veteran tree is widely considered as a tree of exceptional conservation value, because of its high cultural, historical, or ecological importance (Jim, 2017, Skarpaas et al., 2017, Wetherbee et al., 2020). The specific criteria for defining veteran trees are not precisely and universally defined, with interpretations and definitions that may slightly vary from region to region (Bauhus et al., 2009, Nolan et al., 2020). The main criteria to discriminate veteran trees are tree age, size, species, management practice, or aesthetic or heritage value. These trees need to be inventoried, monitored, and protected (Maravelakis et al., 2012, Krebs et al., 2012). Differences in crown volume, derived by structural parameters extracted, if monitored during different years, will provide useful information about the healthy status of such ancient tree.

2. MATERIALS AND METHODS

2.1 Tree Location and Features

The surveyed tree is in a private chestnut grove in the municipality of Acquasanta Terme, one of the southernmost of the Marche region (Italy). Traditional chestnut (*Castanea sativa* Mill.) groves have been longtime cultivated for fruit production and are common in this area hosting sparse large-size and old individuals featuring considerable landscape and historical values. A few of these veteran trees are mapped and measured and, among them, a suitable candidate for this study has

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been chosen, both for its structural and accessibility conditions. Indeed, the selected tree was located at a suitable distance from other trees in the grove, making the complex architecture (trunk, limbs, and branches) detectable from most of the instruments used. The estimated age of the veteran tree, by counting the number of tree-rings in cores extracted through an increment borer, turns out to be at least 210 years. Since *C. sativa* is a deciduous species, the survey was carried out in two different seasons of the year: i) during summer (July 22nd 2021), when the tree was in full vigor with leaves forming a voluminous crown and ii) in winter (December 10th 2021), when the tree was almost completely defoliated. Moreover, the surveyed chestnut tree shows the typical symptoms of Ink Disease. In different European countries, the *Phytophthora* complex is associated with the *Castanea sativa* and the *P. cambivora* is one of the species related to the symptoms of Ink Disease, which causes tree declining (Vettraino et al., 2005). Specifically, this pathogen affects the tree's root system and the consequences are mainly evident on the crown, slowing its development and causing a reduction of the canopy volume, due to the anticipated phylloptosis. Moreover, the leaves are smaller and chlorotic, whereas the developing branches are shorter when compared to those of a healthy chestnut. Unfortunately, this pathogen is widespread in spotted areas of Marche region and the surveyed chestnut tree is located in one of them.

2.2 Surveying With Geomatic Tools

The surveys were conducted in two seasonal moment, being the chestnut a deciduous tree and thus taking the chance to detect the tree skeleton architecture from the MLS point cloud. Both the surveys were carried out using the same methodological approach (Table 1). All the survey outputs must be aligned in order to correctly overlap and scale the different point clouds. For this purpose, each survey was done using a TOPCON GPT 7000 total station which allows to acquire several points in a local reference system. It was not possible to use the GNSS system because the satellite signal was occulted by the forest cover and there were no possibility to acquire correct GNSS points. With the MLS instrument, the Kaarta Stencil 2, the point cloud of the veteran tree was obtained. This technology is equipped with a LiDAR Velodyne VLP-16 sensor, an Inertial Motion Unit (IMU) and an internal processor. The integration of these three components permits a real-time localization (Chang et al., 2019) of the instrument while it is mapping the surrounding environment, making the survey expeditious (Ullrich and Pfennigbauer, 2019). Being a MLS, it is a light weight device and it can be moved in a handheld mode (Di Stefano et al., 2021). This mobile devices can be installed in different platforms and they are ideal for surveys in areas with limited accessibility (Di Pietra et al., 2020). The LiDAR has a beam with a vertical field of view of 30° and an horizontal one of 360°. The scanning path has been planned according to these information, indeed it was done a circular path around the targeted chestnut tree in order to correctly scan all the tree skeleton and being sure that the scanner was able to detect the highest part of the tree crown. Along the path, 5 highly reflective targets have been placed in clean areas, where the MLS beam was able to hit them without occlusion, and registered with the total station. The raw point cloud data has been processed in CloudCompare, removing all the surrounding trees which are not part of the ancient one surveyed. Thanks to the Cloth Simulation Filter (CSF) the above ground points have been differentiated from the ground and then, after normalization of the point cloud, the tree height has been calculated (Krček et al., 2020) as the maximum point distance in the Z axis. The MLS beam is reflected by the leaves and, when the crown is too dense and the user path is too close to the targeted tree, the occlusion effect do not permit to correctly detect the highest part of the canopy (Bauwens et al., 2016, Gollob et al., 2019). In this study, the surveyed tree has a wide crown and, even if it is partially isolated, the MLS path did not have sufficient distance for the total crown detection. In order to overcome this problem, different authors suggest to combine the MLS point cloud with output of UAV equipped with LiDAR sensors or cameras but the Airborne Laser Scanning (ALS) surveys are usually used to detect large forestry areas and they do not accurately register single tree due to their partial inability to detect the lower part of the crowns (Gollob et al., 2020). In this research, a DJI Mavic Mini drone has been used to acquire nadiral RGB photos of the surveyed tree, setting a flight plan up at 30 meters above ground and applying the aerial photogrammetry techniques to reconstruct it, thanks to the Structure from Motion (SfM) algorithm (Zhang et al., 2021). Thanks to the combination of the upper part of the crown by UAV and to the lower part acquired by MLS, the whole canopy has been recorded and aligned according to the ground control points (GCP) registered by the total station. Moreover, to obtain a clear representation of the veteran tree trunk, close-range photogrammetry has been carried out thanks to a single-lens reflex (SLR) Sony Alpha77 camera allowing to obtain a high definition RGB dense cloud of the trunk. Two circular paths all around the ancient tree allowed to photograph the trunk and the chestnut radical buttresses, capturing also the different targets placed at the ground for the subsequent referencing. Using the points acquired with the total station, it has been possible to correctly align the different point clouds, resulting in a complete 3D reconstruction of the veteran chestnut. Indeed, (Remondino, 2011) affirms that it is fundamental to integrate heterogeneous data from different sources in case of complex 3D surveys. The point-pair registration between our point clouds and GCP results in a subdecimeter error value (RMSE = 0.0459).

2.3 Pre-processing analysis

The MLS point clouds have been imported in CloudCompare and then it has been manually segmented in tree skeleton and tree crown. The first includes the stem and main branches, up to the point of canopy insertion whereas the second includes secondary branches and leaves, up to the top of the tree. In the winter season, the chestnut had no leaves and the "crown effect" is due to the smaller twigs composing the aerial part of the tree skeleton that are noisily detected due to the MLS accuracy. The tree clouds segmentation has been possible thanks to some filters which have highlighted certain geometric features. In particular, "number of neighbors" and "verticality" allowed the user to distinguish which points were part of the tree crown and which were not. The summer survey is not suitable to obtain the full crown, due to the beam occlusion effect. On the other hand, the winter MLS point cloud has recorded all the tree structure and this is due to the lack of leaves intercepting the LiDAR beam. This last survey has therefore allowed to obtain the correct tree skeleton, which has been manually segmented removing the smaller twigs and limbs. Moreover, using the "Statistical Outlier Remover" (SOR) function, all the acquisition-phase noise points have been removed (Rusu and Cousins, 2011). Thanks to the UAV surveys, 71 images have been collected during the summer and 68 in the winter. Using the GCPs during the SfM steps, the images have been aligned and subsequently the dense clouds is obtained. In a similar way, 63 frames obtained from the single-lens reflex camera were

Geomatic Equipment	Model's name
	TOPCON GPT 7000
	DJI Mavic Mini
	Sony Alpha77
	Kaarta Stencil-2
	Reflective Target

Table 1. Geomatic Equipment used for the surveys.

aligned to reconstruct the trunk, up to the level of the first main branches. The upper part of the crown was reconstructed with the UAV summer survey and, mixing the dense cloud with the MLS summer cloud, a complete 3D canopy was reconstructed. The UAV winter survey, on the other hand, did not permit to reconstruct the tree without leaves because the skeleton was too complex and the different pixels values were not detected by the software since the background was the soil and the latter was not easily distinguishable from the tree skeleton's pixels, which had similar color. Thus, the summer tree model is composed by MLS point cloud, UAV and reflex dense clouds while the winter model only by the MLS point cloud and the reflex one.

3. RESULTS AND DISCUSSIONS

3.1 Tree Metric Data

As firsts results, a semi-automatic approach for the extraction of precise tree metric data (Bienert et al., 2021) and tree volume have been developed. The trunk RGB dense cloud by close-range photogrammetry has been processed in CloudCompare and through the ”Cross Section” tool, a slice at 1.30m has been exported as new cloud. Then, the contour of this cloud has been created as a polyline and its mesh has been reconstructed thanks to the plugin ”PoissonRecon” (Kazhdan et al., 2020). Once obtained the mesh (Figure 1), thanks to the command ”measure the surface” and assuming that the slice had a circular shape, through the reverse formula the diameter has been obtained that, in our case study, was 164 cm. Other studies confirmed a strong linear relationship between the DBH obtained via field measurement and the SfM technique (Bayati et al., 2021, Hunčaga et al., 2020).

Figure 1. Mesh of the DBH section from the RGB reflex point cloud. The red color represents the surface created by the section contour (yellow line).

The 3DForest open-source software allowed to extract the TH and the crown surface with an orthogonal projection into plane, using the concave hull algorithm (Trochta et al., 2017, Krček et al., 2020). In July, the TH was 18.75 m, while in December was 18.5 m. On the other hand, the crown surface was 258.67 m^2 in summer (Figure 2) and 165.47 m^2 in the winter period (Figure 3).

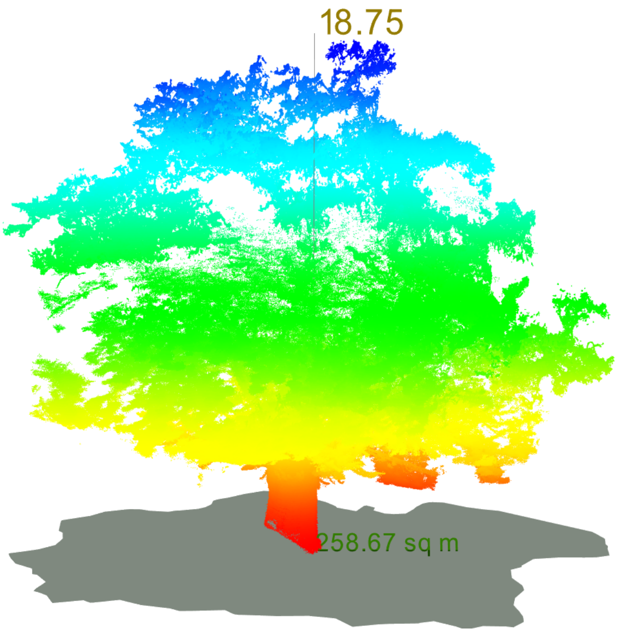

Figure 2. The veteran chestnut tree in the summer season. 3DForest outputs showing the TH (m) and the crown basal area (sq m). The color scale is in accordance with the z-axis gradient.

In order to extract accurate wood volume, the MLS tree skeleton was used. It has been processed with the AdQSM algorithm (Fan et al., 2020), which is a new tree quantitative structure model (QSM) and it allows to reconstruct the 3D branch geometry of a single MLS surveyed tree (Dong et al., 2021). The values of the parameters ”Height Segmentation” (HS) and ”Cloud Parameter” (CP) are the ones recommended

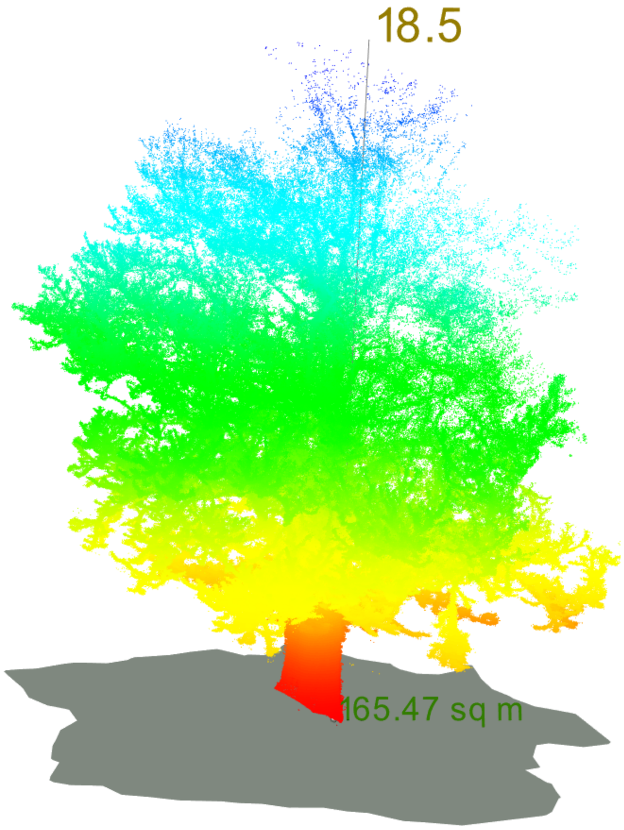

Figure 3. The veteran chestnut tree in the winter season. 3DForest outputs showing the TH (m) and the crown basal area (sq m). The color scale is in accordance with the z-axis gradient.

Figure 4. Mesh of the tree skeleton by AdQSM algorithm.

by the Authors, i.e. 0.50 and 0.003, respectively. The exported tree skeleton, as mesh, is then imported in CloudCompare (Figure 4) and the wood volume resulting by the mesh volume measurement was 39.83 m^3.

On the other hand, a commonly used geometric calculation method in literature for the extraction of crown volume is the ”Alpha Shape” algorithm (Miranda-Fuentes et al., 2015, Vauhkonen et al., 2009, Vauhkonen et al., 2010). The latter is based on the extraction of contours from a set of unordered points, resulting in the geometric reconstruction of surfaces. Within an enclosed polyhedron, the value of alpha allows to encompass a certain number of points. This value ranges between 0 and 1 and, by decreasing it, the algorithm tends to consider fewer points and to increase the number of mesh faces, making the 3D model more realistic (Yao et al., 2012, Vauhkonen et al., 2012, Zhen et al., 2016, Vauhkonen et al., 2008). This approach, for tree canopies, has highlighted that a low alpha value tends to deteriorate the representation of the canopy because the latter usually presents an inhomogeneous density of points (Korhonen et al., 2013). Our ancient crown has been processed in MATLAB (MATLAB, 2010) and the alpha value has been set at 0.25, both in summer (merging Kaarta and UAV point clouds) and in the winter cloud (Figure 5). The former has a volume of 328.39 m^3 while the latter results to have a value of 290.4 m^3.

3.2 3D Graphic Restitution

Once that the outputs are generated, a 3D graphic restitution is obtained (Figure 6). In the summer season, the MLS beam was not able to reach the top of the crown and, in order to obtain the full tree, the output must be merged with the upper part of the canopy obtained by the UAV photogrammetry. Whereas, with the winter survey, the Kaarta Stencil-2 allowed to reconstruct all the tree skeleton, from the trunk base to the top of the structure. Without the leaves, indeed, the beam reached the upper part while the UAV photogrammetry does not allow to obtain the 3D model, given the skeleton complexity. On the other hand, the reflex has allowed to obtain the RGB trunk dense cloud in both the seasons. The 3D model, used to extract all the metric data, has been uploaded to Sketchfab (`https://skfb.ly/o8QRn`), as first solution to share our final product to different users.

3.3 Contribution To Virtualization

The three-dimensional veteran chestnut tree is consequently used as a ”data container”, usable by multiple users, due to the opportunity to include the 3D model in various software or digital visualizers. This cloud can be updated throughout the years, obtaining an historical representation useful to monitor the evolution and the decay of this ancient tree, with the integration of new data and applications that will increase the awareness and the use of the resulting output. In addition, the chestnut tree is an ideal candidate to be listed among the Veteran Trees of Italy, in terms of metric data and age, and therefore eligible for inclusion in the list of Monumental Vegetation Formations, since it represents a unique natural archive. The importance of preserving and enhancing these ”green patriarchs” must be a priority, especially in Natura 2000 network of protected areas.

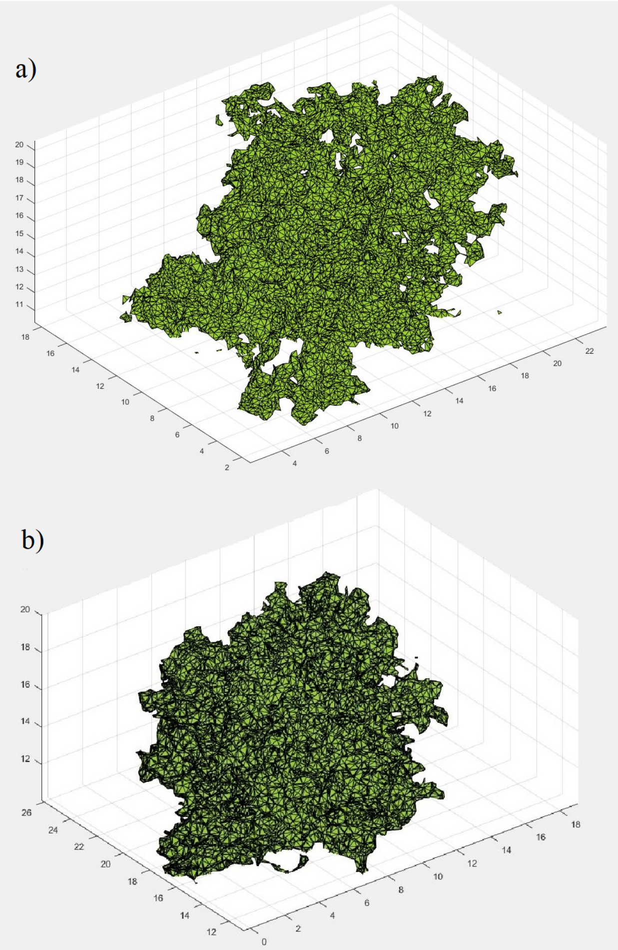

Figure 5. a) Summer canopy and b) Winter canopy reconstructed with the alpha shape (α: 0.25) algorithm.

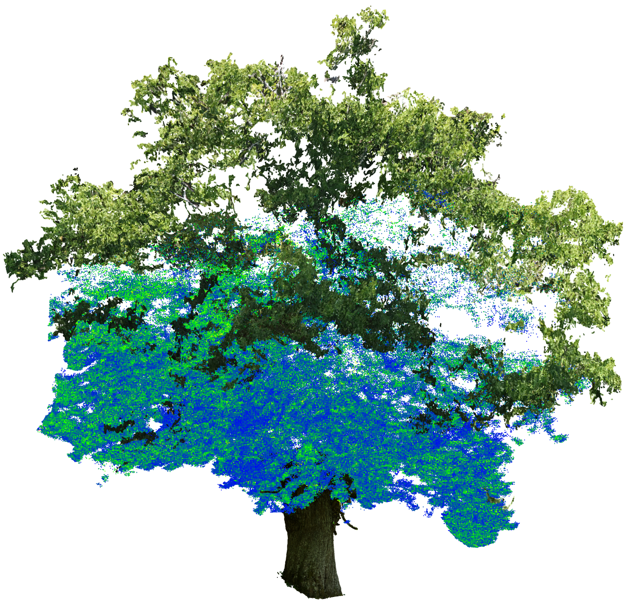

Figure 6. 3D tree model: upper crown by UAV, lower crown by MLS and trunk by reflex.

4. CONCLUSION

Thanks to the integration of geomatic techniques, the 3D Veteran Chestnut model has been reconstructed. The MLS point cloud allows us to obtain an accurate tree skeleton that, once reconstructed with the AdQSM algorithm, gave us the possibility to extract the wood volume. The latter, when estimated with the yield tables on trees such as the veteran tree analyzed, tends to be inaccurate and not suitable for specific studies on complex individuals. Thanks to the combination of the MLS point cloud with the aerial photogrammetry, all the tree crown has been recorded, overcoming the beam occlusion effect, thus allowing to obtain the crown volume and its basal area. Moreover, the close-range photogrammetry permits to recreate an accurate RGB 3D model of the veteran tree trunk, allowing to extract its DBH. The obtained tree metrics are accurate and now permit to census the tree in an objective way, monitoring both its growth and its vegetative status. In particular, considering the ink disease diffusion (*Phytophthora cambivora*) which causes chlorosis, microphylly and wilting (Vettraino et al., 2005) of leaves. This disease can lead to the death of the chestnut tree (Akıllı et al., 2012) and therefore, in ancient individuals such as the one surveyed in our study, it must be monitored. The differences in crown volume, derived by structural parameters extracted, if monitored during different years, will provide useful information about the healthy status of such veteran tree. With the proper control and repeating the survey yearly, it will be possible to understand which trees are suffering the most and take timely action to preserve these cultural heritages. An annual measurement of crown volume and its 3D reconstruction will provide an accurate dataset that will track the progress of the pathology and the adaptation/reaction of the monitored tree. Thanks to these three dimensional reconstructions, the data will be made more accessible to different users who will then use the available information for multiple purposes. Given the encouraging results and after suitable replication on other specimen in different years and seasons, it is possible to extend the virtualisation of this first veteran chestnut tree at landscape or regional scale to implement both the conservation and the monitoring of these cultural (Maravelakis et al., 2012, Krebs et al., 2012) and ecological resources, providing a database that will help to structure a ”Veteran Tree Network”.

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