3D modelling of the oldest olive tree of the world

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Abstract

The Monumental Olive Tree of Vouves, known as the oldest olive tree in the World is an important part of our cultural heritage. Branches from this olive tree were used for the wreath bestowed upon the winners in the Olympic Games in Beijing and Athens and the winners of the Classic Marathon in Kalimarmaron Stadium. This ancient tree became an inspiration for sending messages of peace and hope worldwide. The process of developing a geometrically accurate 3D model of the Monumental Olive Tree of Vouves, using modern reverse engineering techniques is described in this paper and its complexity is analysed and compared to other scanned objects. The derived 3D model allows for a twofold employment: a) the creation of a virtual model for internet dissemination activities, and b) the enabling of enhanced possibilities for scientific study and analysis of the tree.

Keywords: oldest olive tree, terrestrial laser scanning, 3d tree model, complex tree physiognomy

1. Introduction

Our research aimed to examine the potential of reverse engineering technologies for developing a geometrically accurate 3D model of the Monumental Olive Tree of Vouves and to explore the enhanced new usages provided from the 3D model. Extensive literature and 3d model database review indicates that this is possibly the first application of 3D scanning and layered fabrication of any individual tree, especially with such complex physiognomy. A detailed virtual and physical model is produced allowing for the first time to accurately calculate the tree's volume and to produce its sections at any various heights enhancing upon conventional measuring techniques and mathematical applications in volume measuring [1,2]. In order to assess the complexity of the tree's physiognomy, quantitative geometry-driven complexity criteria have been incorporated, and the results are compared against various 3D scanned objects.

The archaeological importance of the Monumental Olive Tree of Vouves, known as the oldest olive tree of the world [3,4] gives added value to the virtual 3d model created, since it can be used in two ways: for the creation of a realistic virtual model for internet dissemination activities, and to enable enhanced possibilities for scientific study and analysis of the ancient tree. Further-more, since this is the first published 3D tree model these novel results can used as a benchmark to future similar studies.

1.1. The Monumental Olive Tree of Vouves

Within the settlement of AnoVouves, a small village in the island of Crete in Greece, there is an ancient olive tree, which, with the 603/1997 decision of the General Secretary of the Cretan District, has been declared a preserved monument of nature named as the Monumental Olive Tree of Vouves (figure 1). The aforementioned characterization of the olive tree arose because it exhibits "a particular aesthetic, ecological and historical interest". The vascular tree layout does not form a discrete straight line, as is usually the case with most trees, instead it appears in a form of helical bundles, a distinctive characteristic of untamed olive trees. Thus a sculptural sensation is being imparted in the trees' bole speculated to reminiscent sculptures of the great sculptor of the Italian Renaissance, Michael Angelo.

The tree's age cannot be determined with great precision, since it is not possible to apply the radioisotopes method, since, because of the tree's very old age, there is no remaining material left from the original core of the trees' bole. There is, though, a less accurate approach that is being performed, based upon comparative data of the size and the perimeter of the bole, which are directly related with a trees age, further supported by several other secondary elements for age verification. Greek and foreign literature reviews indicate that there is no mention of an olive tree with such a large perimeter. The existence of the tree in AnoVouves could be possibly associated with another discovery by the Classical Antiquities Ministry of two cemeteries aging back to the Geometric era, around 700_{BC}, which are in close proximity with it. Archaeological analysis showed that olive growing first became widespread in the Aegean in the Early Bronze Age [5,6] .
According to Wikipedia [3] and the Mother Nature Network [4] the Monumental Olive Tree of Vouves, is the oldest olive tree in the world and has an age between 2000 and 4000 years old. Furthermore the information spread from generation to generation and throughout the ages and has been preserved till nowadays, now spoken by us, regarding the legacy of the oldest olive tree known, is by itself another valuable element in support of its extremely old age. The reputation of the

Monumental Olive Tree of Vouves, led to the Olympic Committee decision for using the Branches from this olive tree for the wreath bestowed upon the winners in the Olympic Games in Beijing and Athens and the winners of the Classic Marathon in Kalimarmaron Stadium. This ancient tree became also an inspiration for sending messages of peace and hope worldwide.

Figure 1. The Monumental Olive Tree of Vouves

Figure 2.The inner cavity of the tree.

1.2 3D Preservation of Cultural Heritage

Cultural Heritage is playing a growing role in the European integration process, contributing to economic prosperity and creating jobs. But culture is a fragile and non-renewable resource. During the 20th century, it is considered that nearly 50% of Europe's tangible cultural heritage was lost. The combined impact of atmospheric pollution, urbanisation, excessive tourism, negligence and inappropriate restoration measures often results in irremediable changes and, in some cases, even the complete disappearance of major examples of immovable and movable heritage [7]. In order to tackle this problem, the last two decades, the ability to record the cultural components of a landscape in 3-dimensions has been employed by many archaeological surveyors [8,9]. Furthermore cultural heritage web sites and artefacts get a significant added value from high-resolution 3D models [10]. The technology of implementing 3D virtual models to web sites can be an important vessel for preservation, reconstruction, documentation, research and promotion of cultural heritage [11-14].

1.3 Current Approaches in 3D Tree Measuring and Analysis

A complete measuring procedure of an individual tree, includes the determination of many parameters such as age, stem diameter, diameter at breast height (dbh), height, canopy cover, leaf area and stand volume[15]. Age estimates are usually obtained by counting the number of annual rings in a stem function, or by using radiocarbon dating, but still there are many pitfalls with both of these methods [16,17]. More computerised techniques for age estimation are based on models of growth increment [18]. Conventional methods for measuring tree diameter include standard measuring tapes that are used to measure stem diameter by placing the tape around the circumference of the tree in different heights. Current efforts in estimating wood volume are focused on developing functions for stem volume and taper that allow estimates from simple measurements [1,2].

Recently the usage of Terrestrial Laser Scanners (TLS) has introduced very interesting approaches in 3D measuring and analysis of trees [19-22], but these methods are mainly focused on measuring forest structure [23,24] or canopy structure [25]. It still remains challenging to obtain accurate 3D reconstruction of individual trees [26]. A major problem in individual 3D Tree measuring is the difficulty in recreating a detailed virtual model of the tree, due to its complex structure. TLS methods and the new emerging non-contact measuring technologies, can provide a solution to this problem, since they have much higher resolution than the conventional field surveying methods [27,28].

2. Methodology

The bole of the Monumental Olive Tree of Vouves has a very complex shape, not only due to the helical bundles of the outer surface, but also due to the existence of a significantly large and complex inner cavity (figure 2). The reverse engineering approach comprises of three steps (figure 3):

- 3D data acquisition
- Data processing
- 3D model applications

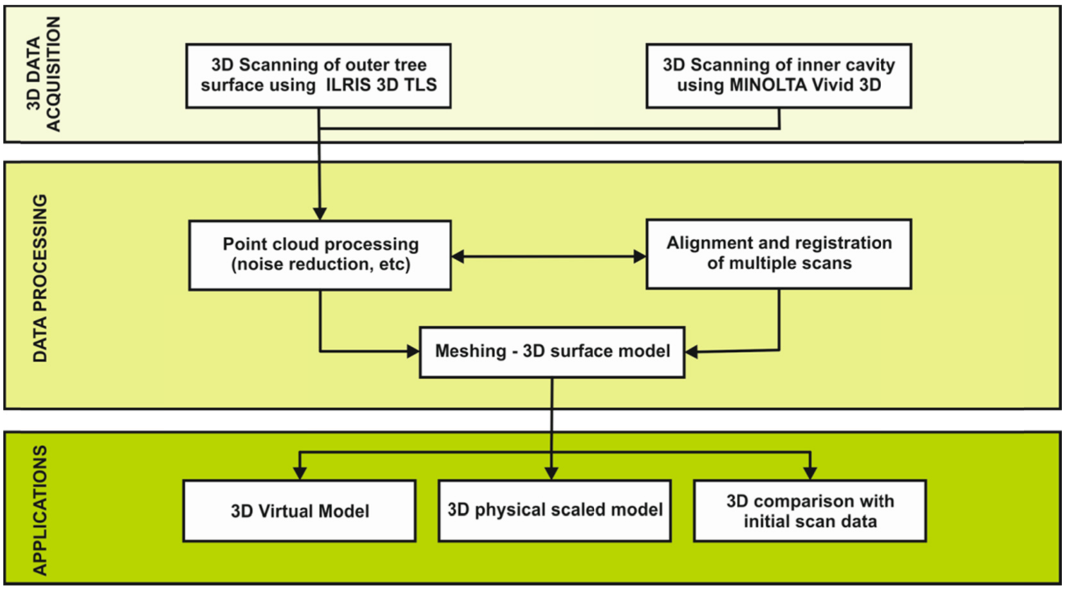

Figure 3. The reverse engineering approach

Light detection and ranging (LiDAR) technology was used for obtaining information of the physiognomy of the outer surface of the tree. In particular an eye safe tripod mounted ILRIS-3D scanner (Optech Inc., Ontario) was used, which emits 2500 laser pulses per second across a horizontal and vertical field of view of 40^o (figure 4). Since this scanner has a minimum scanning distance property of 3 meters, a close range non-contact 3D Minolta Vivid 910 digitizer (Konica Minolta, Tokyo) was used for the 3D data acquisition of the inner surface. Minolta Vivid 910 requires constant lightning to work properly, which made it necessary to carry out the scanning of the inner surface during the night.

Given the large size and complex geometry of the olive tree, the technique of multiple scans from different angles was employed, resulting in a total of 31 scans of the outer surface and 145 scans of the inner surface with a geometric accuracy of 0.5 cm. The choice of perspectives was done manually and the average scan range of ILRIS-3D was 6.3 meters, while the scanning range of Minolta Vivid 910 was much smaller, since the scanner was placed on the inside of the olive tree's cavity, where the space was limited.

Figure 4. 3D scanning of the outer surface of the trunk

The processing of the acquired 3D-data was done using the Geomagic Studio software. The first step was to prepare the different scans, eliminating the redundant data such as noise, objects from the background and even the foliage, until all that was left were the different scans of the trunk. Sampling and filtering were used in order to decrease the quantity of data without affecting the quality, reducing the average size of each scan from 22MB to 7MB.

The integration and alignment of the scans were conducted manually with an n-point registration, meaning that the number of common points selected on each scan were at least three. Because of the large number of the scans, they were divided into groups for easier use. The two main groups, which are the scans from the inner surface and the scans from the outer surface, were divided into sub groups, depending on the absolute position of the scans. The combined point cloud of the olive tree consisted of almost 14 million points which were subsequently reduced to 1,750,000, in this way enhancing the speed of the process. The procedure of aligning and merging the different scans was facilitated by the images captured by the integrated digital camera of ILRIS-3D.

3. The 3D Model of the Tree

The polygonal mesh created consisted of almost a million triangles, resulting in a good surface quality which revealed the complexity of the shape and texture of the tree trunk. Due to the particularity of the shape, there were certain blind spots that could not be scanned, creating holes on the surface that had to be filled. Similar anomalies appeared on the polygon mesh due to the noise which was not removed during the initial filtering. These anomalies showed up mainly in the areas near the crown and the roots of the olive tree where the removal of the noise created by the foliage and the weeds turned out to be challenging. These areas were treated by deleting the excessive triangles and filling the holes with smoother patches. Because of the bad visibility in these regions, assumptions were made based on the photos of the trunk concerning the shape and curvature of the fillings. The number of triangles that composed the final model was 1,200,000.

The complexity of a 3D model is closely related to a wide range of costs, in almost all phases of its lifecycle. These costs can include data acquisition or design costs, storage and transmission costs and computational and visualisation costs [29]. Many researchers also link complexity with manufacturing costs [30]. For this reason various criteria have been introduced to assess topological, morphological, combinatorial and representational complexity [29]. In this paper the shape complexity of the modelled tree was quantified using three geometry-driven criteria; the part volume ratio C_{PR}, the volume ratio C_{AR} and the thickness ratio C_{TR}[31]:

$$C_{PR} = 1 - \frac{V_p}{V_b}$$

$$C_{AR} = 1 - \frac{A_s}{A_p}$$

$$C_{TR} = 1 - \frac{T_{min}}{T_{max}}$$

whereV_p is the volume of the model, V_b is the volume of its boundary box, A_s is the surface of an imaginary sphere with volume equal to that of the model, A_p is the surface of the model and T_{min} and T_{max} the minimum and maximum thickness of the model respectively. The outcome from these criteria equations ranges between 0 and 1 with higher values indicating greater contribution to complexity. The weighted sum of these individual criteria is used to estimate the overall shape complexity factor C_F.

Table 1. Complexity criteria factors of the Monumental Olive Tree compared with various physical objects

	Monumental Olive Tree	cube	sphere	wooden temple	ancient horse sculpture	musical instrument	human skull
							
V_p	4,67	1,00	4,19	2566,00	0,07	218,00	446,27
V_b	67,16	1,00	8,00	3122,00	0,95	1679,00	3776,16
C_{PR}	**0,93**	**0,00**	**0,48**	**0,18**	**0,92**	**0,87**	**0,88**
A_s	29,03	4,84	12,57	906,40	0,85	175,17	282,41
A_p	572,44	6,00	12,57	1855,00	1,85	380,77	1800,17
C_{AR}	**0,95**	**0,19**	**0,00**	**0,51**	**0,54**	**0,54**	**0,84**
T_{min}	0,05	1,00	1,00	1,13	1,22	1,13	0,85
T_{max}	2,55	1,00	1,00	5,52	5,22	5,52	7,80
C_{TR}	**0,98**	**0,00**	**0,00**	**0,80**	**0,77**	**0,80**	**0,89**
C_F	**0,95**	**0,06**	**0,16**	**0,49**	**0,74**	**0,74**	**0,87**

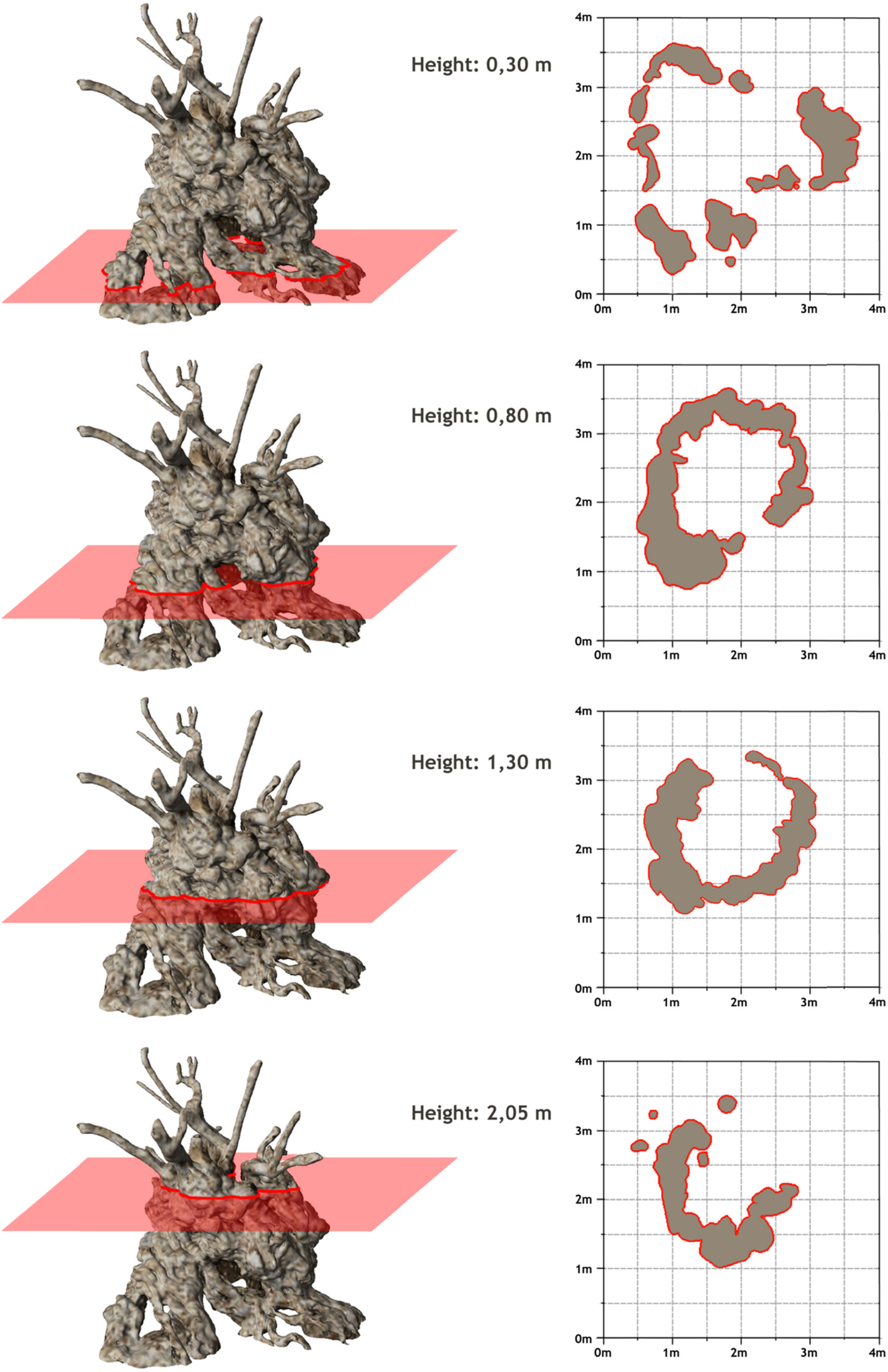

Figure 5. Detailed sections at different heights with a 0,5 cm accuracy

To further assess the complexity of the tree's physiognomy we compared these results with other physical objects scanned by our laboratory. In that aspect, to effectively investigate the relationship between the complexity and the physiognomy of the tree, the list of different physical objects used ranged from basic objects such as cube and sphere to more complex ones such as wooden temple, human skull etc. (table 1). The results indicated high values of complexity criteria factors for the Monumental Olive Tree of Vouves classing it towards the higher end of complexity among the selected objects.

The 3D model produced, introduced drastic improvements in tree analysis, compared with conventional, measuring tape based, tree analysis techniques. For example it was then possible to compute the volume of the trunk, which was 4.67 m^3, but also to produce detailed sections of the olive tree at any height with an accuracy between 12.92 mm (average positive error distance) and -5.96 mm (average negative error distance) (figure 5). From these sections the largest internal and external diameter at any height were calculated, which until now had only been estimated roughly. Some more significant measures calculated were the maximum inner and outer diameter at 1.3 m (Diameter at Breast Height - DBH), which were 2.01 m and 2.66m, respectively, the diameters at 0.9m DBH, which is 2.15m and 3.04m, respectively, as well as the longest distance between two points of the trunk at ground level, which is 3.95m.

In order for the olive tree- virtual model to be more realistic, five different color tones based on the real color of the trunk were projected on it, emphasizing its knobs and cavities. Also, lighter tones were used on the outer surface, while darker ones were used on the inner surface. After the color fitting was done, an animated gif was created for the Olive Museum's internet site using snapshots taken by rotating the trunk model around the perpendicular axis in equal degrees (figure 6). Finally an exact scaled replica of the Monumental Olive Tree of Vouves was manufactured (figure 7). The physical prototype was created by a Dimension Statasys 3D printer with a printing resolution of 0,245 mm per layer.

Figure 6. The 3D virtual model of the Monumental Olive Tree of Vouves

Figure 7.An exact scaled physical replica of the tree.

4. Discussion and Conclusions

To our knowledge this is the first detailed virtual model of an individual tree with such complex physiognomy. The archaeological importance of the Monumental Olive Tree of Vouves, known as the oldest olive tree of the world, gives added value to the virtual 3d model created, which can be used in two ways: for the creation of a realistic virtual model for internet dissemination activities, and to enable enhanced possibilities for scientific study and analysis of the ancient tree. Two different types of laser scanners were used in order to combine the outer and inner surface of the tree's bole. The processing of the obtained 3D data was done with commercially available reverse engineering software and produced a high quality 3D model result. Rough conventional inaccurate measuring techniques and mathematical applications, used by agricultural biotechnologist experts can this way be replaced with unlimited detailed measures of the ancient tree including accurate inner and outer diameters at any height and accurate computation of the trunk's volume. This methodology can be applied also to other important ancient trees, coming from the Wikipedia list of the oldest trees of the world. Future work includes re-scanning the tree's trunk after 5 years in order to calculate the tree's growth and provide valuable data to tree growth increment models, in order to make a more accurate calculation to the tree's actual age.

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