B.Sc. Thesis, Faculty of Forest Sciences and Forest Ecology
Georg-August-Universität Göttingen

A Comparison between Photogrammetric Measurement and Measurement with the Electromagnetic Digitizer for Acquisition of Stem Surface

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Ein Vergleich zwischen fotogrammetrischer Messung und Messung mit dem elektromagnetischen Digitizer bei der Aufnahme von Baumstämmen

Zusammenfassung

Heutzutage gibt es in den Forstwissenschaften viele verschiedene Methoden, um Bäume auf effiziente Weise zu vermessen. Sie haben alle einzigartige Eigenschaften, wie Bearbeitungszeit, visuelle-, ergonomische- und wirtschaftliche Aspekte. Eine elektromagnetische und zwei photogrammetrische Methoden zur Erfassung der Stammoberfläche wurden getestet und ausgewertet. Diese Bachelorarbeit zielt nicht auf die Bewertung der Genaugkeit dieser Techniken ab, sondern ihr Zweck ist, die Vor- und Nachteile in ihrem Betrieb und der Datenerfassung zu beschreiben. Für diese Auswertung wurden insgesamt acht Bäume der Familie der Pinaceae untersucht. Jeder Baum wurde zunächst mit dem Polhemus Fastrak Digitizer digitalisiert und dann mit einer Digitalkamera und einem Smartphone für die 3D-Rekonstruktion mit der Software Agisoft PhotoScan Professional bzw. Scann3D erfasst.

Die drei verwendeten Techniken lieferten Datenpunkte aus den Stämmen auf drei Koordinaten-Achsen, aus denen ein 3D-Modell für jeden Stamm generiert wurde. Des Weiteren wurde der Abstand zwischen den einzelnen Punkten bestimmt und damit der Umfang und der Brusthöhendurchmesser (BHD) einzelner Stämme. Zunächst wurden die beiden photogrammetrischen Methoden (Agisoft und Scann3D+MeshLab) verglichen, um zu sehen, wie ähnlich die daraus gewonnenen Messungen waren. Aus der Analyse wurde eine Korrelation zwischen den Werten der Umfänge und den Werten der BHD durchgeführt, die von jedem Baum durch eine lineare Regression erhalten wurde. Dann wurden Messungen der mittleren Differenzen und der Standardfehler des Mittelwertes durchgeführt. Sie zeigten, dass es einen leichten Unterschied zwischen den Werten beider Techniken gibt. Höhere Unterschiede gab es beim BHD. Als nächstes wurden die Werte, die durch die drei Techniken erhalten wurden, verglichen. Die geringsten Unterschiede wurden zwischen Fastrak und Scann3D gefunden, da es sich um die Techniken mit den ähnlichsten Werten handelt. Es ist zu beachten, dass es die Möglichkeit gibt, dass menschliche Fehler Einfluss auf die Erfassung der Messwerte haben können.

Einer der Vorteile der beiden photogrammetrischen Verfahren gegenüber der elektromagnetischen Digitalisierung ist die 3D-Visualisierung. Bezüglich der Bearbeitungszeit ist Fastrak die vorteilhaftere Lösung. Wirschaftlich betrachtet ist Fastrak die teurere Methode, und ihre Nutzung ist ausschließlich auf die Digitalisierung beschränkt. Im Gegensatz dazu bieten Agisoft PhotoScan Professional und Scann3D+MeshLab weitere Funktionen neben der 3D-Rekonstruktion und der Entfernungsmessung.

Abstract

Nowadays, there are many different methods employed in the forest sciences to obtain measurements of trees in efficient manners. All of them have unique features, such as processing time, visual-, ergonomic-, and economic aspects. One electromagnetic and two photogrammetric techniques for the acquisition of the tree stem surface were tested and evaluated. This thesis does not aim to evaluate the accuracy of these techniques, moreover its purpose is to describe the advantages and disadvantages of their operation and data acquisition. For this evaluation, the number of trees of the chosen sample was eight, all belonging to the Pinaceae family. Each tree was at first digitized with the Fastrak, and then captured by a digital camera and a smartphone for their 3D reconstruction by using the Agisoft PhotoScan Professional software and the Scann3D application respectively.

The three techniques were used to obtain data points from the stems on three coordinates axes, which allows to generate a 3D model for each stem, and to estimate the distance between the points, making it possible to obtain the Perimeter and the Diameter at breast height (DBH) from the stems. At first both photogrammetric methods (Agisoft and Scann3D+MeshLab) were compared in order to see how similar the measurements obtained from them would be. The analysis conducted was a correlation between the values of perimeter and DBH obtained from each tree through a linear regression. Then measurements of the mean difference and the standard error of the mean were taken. They showed that there is a slight difference between the values obtained from each technique, being higher for DBH. Secondly, the values obtained by the three techniques were compared. The lowest differences were found between Fastrak and Scann3D, being techniques with the most similar values obtained. It should be noted that there is the possibility that human error may have influence on the acquisition of the measurements.

One of the advantages offered by both photogrammetric techniques over the electromagnetic digitization is the 3D visualization. In terms of processing time, Fastrak is the most advantageous. Nevertheless, in terms of cost, Fastrak is much more expensive than the others, in fact its usage is limited to digitization. In contrast, Agisoft PhotoScan Professional, and Scann3D+MeshLab offer other functions apart from 3D reconstruction and measurement of distances.

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1. Introduction

1.1. Motivation

Nowadays technological tools in forest science such as photogrammetric measurement, and the electromagnetic digitizer measurement (FastrakDigitizer®) are increasingly being employed for tree data acquisition. This is due to a new range of available 3D devices and their affordable cost to the consumer (Svensson, 2001), as well as powerful processing and increased storage capacity (Schenk, 1999). These tools are continually evolving, improving efficiency and efficacy at work. In fact, the use of software to analyze 3D images facilitates quantitative studies since the large amount of data contained in them cannot be examined directly by humans (Svensson, 2001). Moreover, these measurement methods vary in their operation, cost, precision, and other aspects. Due to all these aspects, there is a need to evaluate and compare between the methods.

1.2. Problem statement

"Manual inventory methods for collecting forest information used nowadays are labor cost- and time-demanding and there is a need to find alternative methods" (Mikita *et al.*, 2016). Due to a large number of factors to consider, it is not always easy to decide which is the most suitable measurement method for our work. What are the advantages and disadvantages of photogrammetric and electromagnetic digitization methods? What is the most suitable method to use according to our purposes?

1.3. Aim of the work

This thesis offers a comparative perspective between the different stem measurement methods. Two photogrammetric and one electromagnetic method were evaluated. The eight trees tested for this experiment were three *Pseudozuga menziesii* and five *Pinus sylvestris* trees, from which the stems were measured. Aspects such as economy, ergonomics, processing, and measurement time were compared, highlighting their respective advantages after the use of each method.

1.4. Introduction to the methodological approach

In order to compare these methods, I proceeded to digitize the stem circumference of the eight trees at different heights with the Stylus receiver (electromagnetic method), thus automatically generating several point rings. Moreover, each stem was photographed from different angles achieving the capture of all surfaces (photogrammetric method).

Once each software generated the three-dimensional models I followed a number of steps in order to obtain the Perimeter and the Diameter at Breast Height (DBH) of a standing tree. The steps are further described below in the Section 3.2 of this thesis. Then, I exported and stored the measurements obtained to different tables in Excel. After that, I used the information in the tables as a basis for the comparison between the methods creating graphs for a further analysis.

1.5. Structure of the thesis

This thesis is divided into five sections. In the first section, I present a brief overview and introduction of the study, while in section 2 I describe the technology related and the operation of each method, taking several studies previously carried out on them as references. In Section 3, the data acquired with each measurement method are show, with their respective analysis and their corresponding results. Outcome evaluations, comparisons and conclusions are found in section 4. Finally, in section 5, I present a critical reflection.

2. Overview of the two methods

Nowadays, in a high technological world, where we are used to get the information we desire with just the fingertips, three-dimensional measurement tools are constantly developing and evolving. At present, anyone can find a wide range of methods to perform 3D reconstructions. These methods are supported by a wide number of software and applications that are increasingly flooding the market as long as the technology develops. Even at the beginning of the current millennium Svenson (2001) noticed that the number of devices for obtaining 3D data showed a remarkable growth and therefore the use of these devices was increasing in the academic and professional areas.

2.1. Acquisition of 3D data using different technologies

In this section an overview about the electromagnetic and photogrammetric methods used to obtain stem surface data is presented. Despite the methods described here were initially developed for medical implementation (Svensson, 2001), they can be applied for forest science.

2.1.1. 3D data from magnetic digitization

In this work, I made use of the Polhemus Fastrak® to obtain a magnetic digitization of the tree stems. The Polhemus technology has a more than 40 years development in the magnetic motion tracking and its technology has been used for different applications like health care, military and science research (Polhemus, 2018). The developers assure that their technology delivers true 6DOF (6-Degrees-Of-Freedom) due to two main reasons: first, “the position and orientation are measured natively to the tracking technology” and second “no hybrid data calculation is needed” (Polhemus, 2018). In addition Surový *et al.* (2016) mentioned that the magnetic motion tracking is a direct 3D measurement.

The Polhemus Fastrak® utilizes a device source (transmitter), which emits an electromagnetic dipole wave. The larger the magnetic field generated from the source is, the larger is the coverage area that can be digitized. Moreover, the receiver measures this field and tracks the position and orientation of the object to witch it is attached (Polhemus, 2012). In this thesis, the tree stem position is tracked on three coordinates axes (X, Y and Z).

2.1.2. 3D data from photogrammetry

The idea of obtaining 3D data through digital photogrammetry is quite old, and it was only after the photographic technology evolved that this method became competitive among other methods (Korpela, 2004). Digital images for use in photogrammetry can be obtained through two different ways; the first is directly through digital cameras and the second indirectly through scanning aerial photography (Schenk, 1999). In this thesis, I obtained the digital images directly through a digital camera.

The main goal of photogrammetry is to reconstruct the three-dimensional world from two-dimensional images and then analyze and interpret it (Schenk, 1999). As Albertz & König (1991) also mention, the role of photogrammetry is to obtain spatial information from digital photos. One of the most important processes in digital photogrammetry is image matching, (Schenk, 1999) which automatically finds conjugate points in photographs. Image matching techniques are used in the process of orientation, achieving ground control points by triangulating tie points and identifying equal points in different images of the same object (Albertz & König, 1991). Nowadays, it is possible to use common optical cameras for three-dimensional reconstruction of tree stems due to the combination of computer vision and photogrammetry, and by using algorithms such as SIFT (Scale-Invariant Feature Transform) and SURF (Speed Up Robust Features), this technique is known as multi-view stereopsis (Panagiotidis *et al.*, 2016).

Nowadays, after an accelerated technological evolution of mobile devices and the improvement of their operational systems, smartphone-based scanners are part of the market, and they are constantly improving some aspects of data processing by adopting the functionality of computer systems (Ivanov, 2017). Nevertheless, Ivanov (2017) also mentions that the standard configured smartphone 3D scanners, that use the principles of photogrammetry, are represented as standalone applications. For this thesis I made use of the Scann3D Android application, which differs from other applications of its kind. Scann3D performs all the reconstruction on the device, while others execute it on the cloud (Ivanov, 2017).

2.2. Accuracy and application of the two technologies

2.2.1. Magnetic Digitization

The developers of the Polhemus Fastrak® affirm that this electromagnetic motion tracking system is the most accurate magnetic digitizer available on the market. With a static accuracy of 0.03" (0.08 cm) RMSE[1] for the X, Y, or Z receiver position, and 0.15° RMS for receiver orientation, they assure this technology as the perfect solution for precise computational positioning and accurate space orientation (Polhemus, 2008; Polhemus, 2012). In a study carried out by Surový *et al.* (2016), in which the purpose was to measure the Polhemus Fastrak® and the FastrakDigitizer® software accuracy in reconstructing tree stem surface, they demonstrated that it is possible to acquire accurate stem data surface as long as the specifications described in the User Manual are followed (Polhemus, 2012).

2.2.2. Photogrammetry

In a study conducted by Mikita *et al.* (2016), in which they performed the automatic photogrammetric processing of a point cloud to estimate the measurements of stem DBH and the height of the trees, they obtained results with high precision. They compared these results with the DBH measurements obtained in field using a caliper, detecting an accuracy of less than 1 cm. Furthermore, they found that the deviation of the stem shape from the regular circular shape became lower as the DBH value is increasing, especially in trees with irregular shape (the higher the DBH value, the smaller the error). Mokroš *et al.* (2018), in a more recent article state that after using different CRP[2] data collection methods in order to estimate the DBH, a RMSE between 4.41 cm to 5.98 cm was found.

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[1] RMSE: Root Mean Square Error
[2] CRP: Close-Range Photogrammetry

Surový *et al.* (2016) analyzed the accuracy of the use of terrestrial CRP for stem surface reconstruction. They concluded that the error is concentrated mainly in the bottom and upper parts of the stem due to the decrease of visibility of these parts of the tree, reducing the number of tie points in the image matching process. The RMSE obtained by comparing digital and field DBH measurements was 1.87 cm.

2.3. Summary of the two approaches

Both methods are fully capable of obtaining the desired data for this thesis. Both magnetic digitization, and photogrammetric methods work with generated points on three coordinate axes (X, Y and Z), making possible the measurement of the distance between them.

3. Case study: Obtaining 3D data

3.1. Plant Material

It was decided to work with trees belonging to the Pinaceae family: *Pinus sylvestris*, and *Pseudotzuga menziesii*. Young *P. sylvestris* are conical and have whorled branches; in contrast, mature trees have bare trunks at the base with branches only on the upper part of the trunk (Press & Hosking, 2002). On the other hand, young *P.menziesii* have thin, smooth, and gray barks, with resin blisters; in contrast, the bark is thick and corky on mature trees (Burns & Honkala, 1990). I decided in this study to work with bare trunk trees.

These features enable to produce a good digitization since the absence of branches and groundcover at the lower part of the trunk allows to generate with the Fastrak a 3D photogrammetric model without digital noise.

In the search and the selection of the trees, I counted on the help of Peter Surový[3] with the assistance of a student from the Czech University of Life Sciences Prague. Because it is necessary to provide an electrical connection to the Fastrak, we took into consideration the accessibility to the plot by car. Also, we considered trees with a very low (or null) groundcover.

Due to these considerations, we chose trees within the city and not in a wooded region. The plot was located in the vicinity of the Faculty of Forestry and Wood Sciences of Prague at 278 meters above the sea level. Eight trees were selected. Three out of them were *Pinus sylvestris*, which were labeled from T1 to T3 located in the following coordinates: 50°07'37.7"N 14°22'42.8"E. The remaining five trees labeled from T4 toT8 belong to the species *Pseudozuga menziesii*, located in the following coordinates: 50°07'35.8"N 14°22'46.2"E.

3.2. Methodology

In order to test and compare the different measurement methods described in Section 2.1, I focused in this study on analyzing the perimeter and the diameter at breast height (DBH) values extracted from the sample of trees, which were obtained by each method. The DBH measurement is one of the most used dendrometric references, widely used in forest science and related fields, *e.g.* forest inventories, providing fundamental information about trees and forest stands (Mikita *et al.*, 2016; Mokroš *et al.*, 2018). In this Section, I will describe the guidelines made for each method.

3.2.1. Magnetic Digitization

The electromagnetic digitizer measurement technique applied in this study is the FastrakDigitizer®. In order to make use of this technique, it was required to use the Polhemus Fastrak®, Polhemus Stylus, and the FastrakDigitizer® software installed on a laptop. In addition, to make a correct use of the Fastrak, it must be operated by at least two or more persons for a proper operation and correct data acquisition. For that reason, I was assisted by a student who was monitoring the software while I was taking measurements.

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[3] Prof. Dr. Surový, Faculty of Forestry and Wood Sciences, Czech University of Life Sciences, Praha.

The 32 bits FastrakDigitizer® software (version 1.0.) used was previously installed on a Dell laptop and connected to Polhemus Fastrak® via USB port. The Polhemus Fastrak® consist of a System Electronics Unit (SEU), a transmitter, and a receiver. The SEU is the Fastrak's main device and contains the required input and output connectors for the transmitter, the receiver, and the laptop (Polhemus, 2012). The transmitter is a device connected to the SEU and provides the spatial reference to the receiver by generating an electromagnetic field. It is recommended to place it on a fixed non-metallic surface or support close to the receiver (Polhemus, 2012). The receiver is an output device connected to the SEU whose position and orientation is measured relative to the transmitter. This device is built inside the Stylus which has a push-button switch that when pressed, effects data output (Polhemus, 2012). In this way, points are generated automatically by the Fastrak and the software, and displayed on the laptop screen.

A power supply was requiered for the system to operate: 100-240 VAC; 47-63 Hz, and single phase at 15 watts (Polhemus, 2012). This was provided by a car that we parked about four meters away from each tree. This distance is recommended because otherwise the Polhemus transmitter or receiver may be affected by nearby large metallic objects while digitizing, thus creating distortion of the electromagnetic field and negatively affecting the system performance (Polhemus, 2012). We placed the Fastrak components according to the recommendations of its manual. The Transmitter was placed near the tree to digitize and away from any metallic object. Since the System Electronics Unit (SEU) can be placed at any convenient location near the power source and the host computer (Polhemus, 2012), we placed it near the Dell laptop. By using some adapters, we connected the Fastrak and the laptop to the power source. We connected all the input and output cables and controls required for its operation as indicated. The set-up of the Fastrak is simple and intuitive, so there was no need of user calibration and in a matter of minutes it is ready to use (Polhemus, 2017).

As a first step, I located and marked a point with an adhesive tape on the north face of the trees at an approximate height of two meters. Then, the next point was placed and marked approximately 20 cm below the previous point on the west face of the tree. The following points where marked in the same way turning counterclockwise locating it in a cardinal point, until the ground was reached – see figure 1.

Once all the marks were made, I placed the tip of the stylus (transmitter) over each of them and started to record its position into the Fastrak by simply pressing the bottom located on the stylus. Each point generated had its own X, Y, Z coordinates and was automatically displayed in the Cylinder Data Grid in the FastrakDigitizer® software, as shown in figure 3. With the digitization of the cylinders of all trees (from T1 to T8) finished, we started digitizing the stem circumference of each tree.

Teamwork was key in achieving this part of the work. Firstly, we located the starting points on the north face of the trees. In a similar way as the procedure of the previous evaluation, the highest point was located at an approximate height of two meters. Then, the following starting points were located 15 or 20 centimeters below the previous one, until reaching the ground, see figure 2.

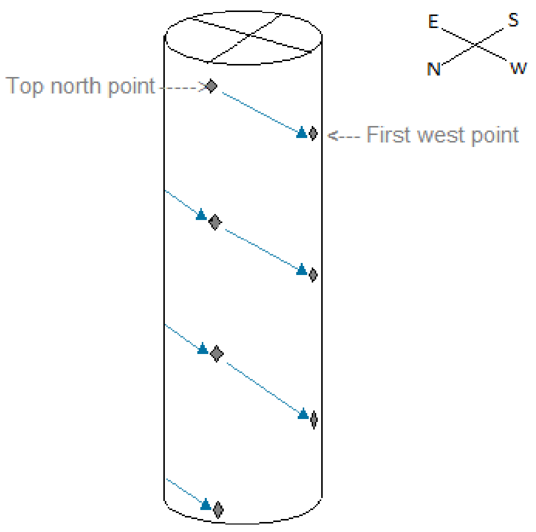

Figure 1. Illustration of the point-marking procedure on a tree stem for the cylinder acquisition.

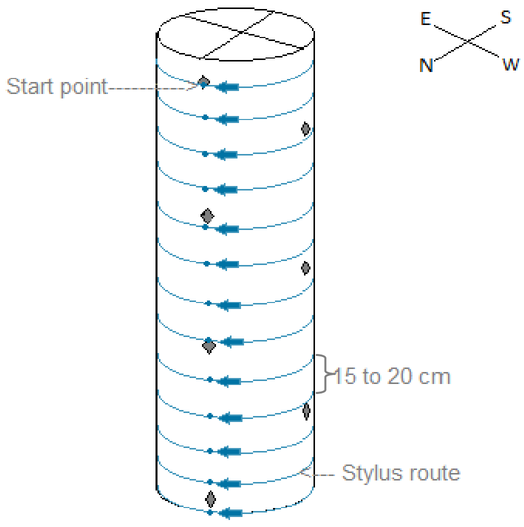

Figure 2. Illustration of the Stylus route for the stem circumference digitization.

Every time we had to digitize a circumference, I placed the stylus on the stem surface, awaiting a voice command ("start!") from my assistant, who would press the record button. Then, I proceeded to surround the tree stem with the stylus, whose tip I kept in direct contact with the bark. Thus, the software generated a sequence of points that represents the circumference of the stem. Each time the circumference was completed, I should pronounce a voice command ("stop!"), and my assistant had to press the respective button, see figure 3.

As a result, we obtained a large list of points with their respective X, Y and Z position values, as well as their 3D representation displayed automatically on the screen, see Figure 4.

After all this data was obtained, I sent them to Peter Surový for further processing. From eight trees, only T4 and T6 were suitable for the analysis. We discarded the other six trees due to possible errors committed that I will discuss in section 5.

In order to obtain the perimeters from T4 and T6, I selected all the points from the Point Data Grid, then in the toolbar I run the option Create Mesh giving as a result a three-dimensional model of the tree stem, see figure 5. Then, I selected the Horizontal Cuts option and run the Process One option, obtaining cuts at different heights. These cuts, shaped like rings, were added to the Data point Grid, see figure 6. I selected all the points at the height corresponding to the DBH (Z = 130 cm), and then run the Circularity of Selection option, obtaining immediately the Total Area, Total Length and Circularity values. The Total Length value represents the Perimeter value of the cut, while the Circularity value indicates how close the shape of the cut is to the generated circle. Circularity values range from 0.0 (polygon) to 1.0 (perfect circle) (Ferreira & Rasband, 2012). I entered the Total Area and the Total Length data into an Excel table, see table 1.

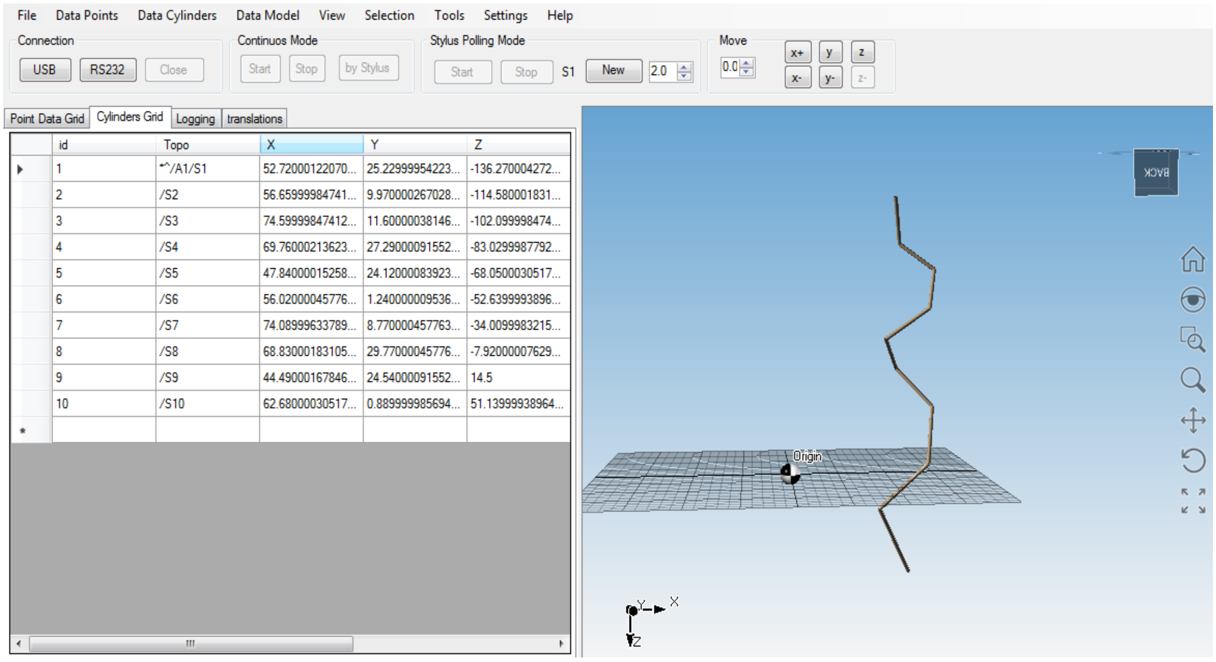

Figure 3. View capture from FastrakDigitizer® software, showing the Cylinder Data Grid and the 3D representation of the cylinder.

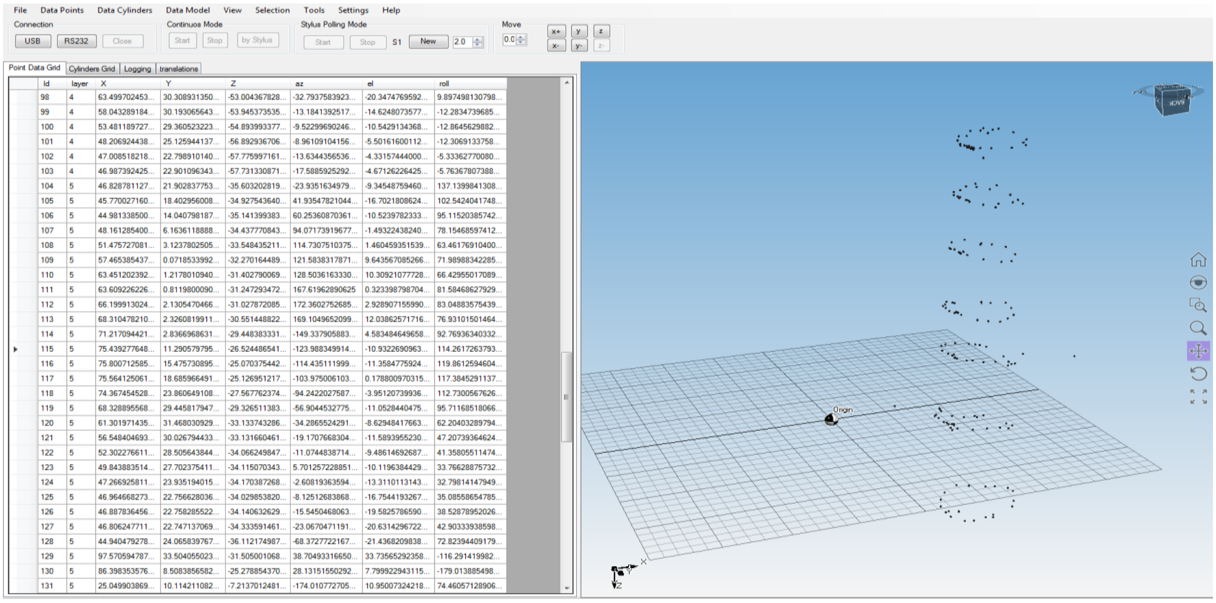

Figure 4. View capture from FastrakDigitizer® software, showing the Point Data Grid and the 3D representation of the points.

To obtain the DBH value I picked the cut corresponding to the DBH (Z=130 cm), then I selected a pair of two opposite points, being the longest and narrowest sides of the cut (marked in red in figure 6). From the Point Data Grid, I took the X and Y values from each point. By placing the X, Y and Z values in the Distance Formula in 3-Dimensions, it was possible to find the distance between these points:

$$D = \sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2]}$$, where:

- D is the distance between two points,
- (x_1, y_1, z_1) are the coordinates of the first point,
- (x_2, y_2, z_2) are the coordinates of the second point.

Finally, the DBH was obtained from each tree by averaging both distances. The DBH values were entered in table 1.

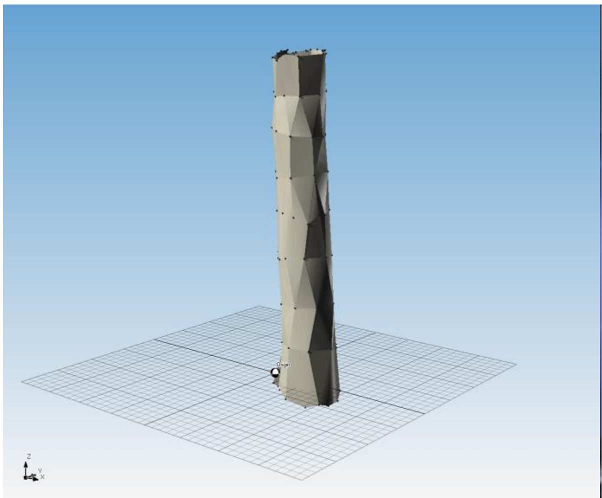

Figure 5. View capture from FastrakDigitizer® software, showing the 3D Reconstruction of T4.

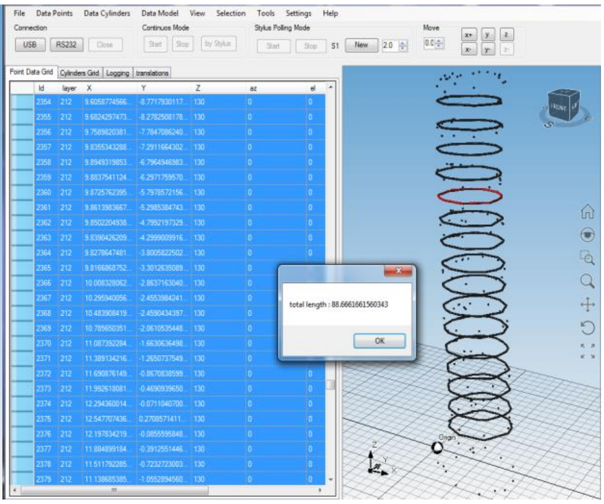

Figure 6. View capture from FastrakDigitizer® software, showing the Horizontal Cuts and the Total Length.

3.2.2. Photogrammetry

As mentioned in 1.3 I used two photogrammetric techniques to collect measurements and perform reconstruction of stems. The first one, Agisoft PhotoScan Professional©, is a software which produces high quality 3D models based on automatic image alignment (Agisoft, 2018a). The second photogrammetric method is a mobile application called Scann3D, this software enables 3D reconstructions based on digital photographs taken directly by a smartphone or tablet (Scann3D, 2017).

3.2.2.1. Agisoft PhotoScan Professional©

As a first step to create a 3D model with Agisoft PhotoScan©, a series of digital photos of the desired object should be taken. As described in the Agisoft Instructor's Manual (Agisoft, 2018a) images for the three-dimensional model reconstruction can be taken with both metric and non-metric digital cameras, as long as they meet the requirements and specifications contained in the manual.

Following the equipment and camera settings guidelines mentioned in chapter two (Agisoft, 2018a) I took the pictures with a 24.3-megapixel APS-C CMOS sensor Sony-α- 6000 camera, setting it as follows: Auto Program, high resolution, 35mm focal length, ISO 100, and an aperture of 0.5EV.

I took an average of 63 photos per tree. To get them I started taking one picture after another while walking in a radius of about two meters around the tree, starting with T1 up to T8 (sequentially). A crucial point for the 3D reconstructions is to place an object with known size into the field of view in order to calibrate the scale of the measurements (Agisoft, 2018a). I used an A4 size sheet of paper as suggested by Peter Surový. I placed the sheet of paper on the ground near the tree as shown in figure 7. The total surface of the stem must be captured within the whole set of photos, to prevent possible “blind-zones” in the reconstruction. PhotoScan is able to reconstruct visible geometry from at least two photos (Agisoft, 2018a).

Once the sets of photos were obtained, I proceeded to copy them to a computer. All the photos maintained their original characteristics (without making edition or other transformation in any way), as indicated in the Agisoft Instructor's Manual, otherwise, errors and inaccurate results could be obtained (Agisoft, 2018a). I used an HP computer with an AMD A8-5545M APU with Radeon (tm) HD graphic card. In order to install Agisoft, I requested and downloaded from its website the Agisoft PhotoScan Professional© Trial version. This version allowed me to use the program for 30 days (Agisoft, 2018b). The PhotoScan software is very intuitive and guides the user to follow a General Workflow. As a first step, I loaded the photos into PhotoScan, then I selected photos that would be used as source for the 3D reconstruction, since the photos are not really loaded in the program until they are selected for processing (Agisoft, 2018a).

Following the workflow, I inspected the photos and removed the useless ones (blurred). Then the photos that were loaded into PhotoScan were aligned by executing the respective command from the Workflow Menu. When the alignment was finished, the sparse point cloud and the computed camera positions were displayed on the screen (Agisoft, 2018a), see figure 7 left. The next step for the three-dimensional reconstruction is to generate a dense point cloud, see figure 7 right. To achieve this, the software calculates depth information based on the estimated position of each camera (photo). The output cloud can be edited as well as classified within PhotoScan (Agisoft, 2018a).

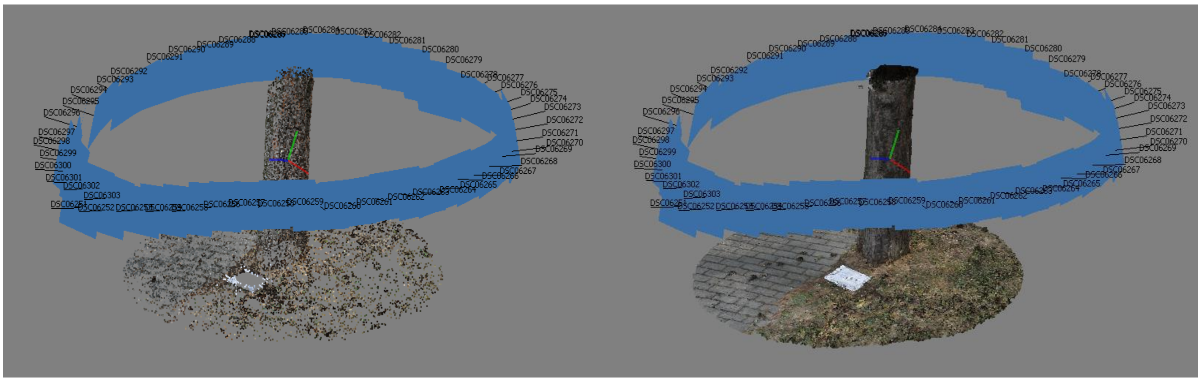

Figure 7. View capture from Agisoft PhotoScan Professional, showing the camera positions (in blue) around T1, with the scale marker on the ground (white A4 sheet). Sparse point cloud obtained from T1 (left). Dense point cloud obtained from T1 (right).

Continuing with the workflow I executed the Create Mesh command, generating a 3D polygonal model, see figure 8 left. This polygonal model is based on the information of the previously created clouds (Agisoft, 2018a). As a last step, I executed the Building Model Texture command. This option improves the 3D model by calibrating the colors and the light variation from every digital photo taken (Agisoft, 2018a), see figure 8 right.

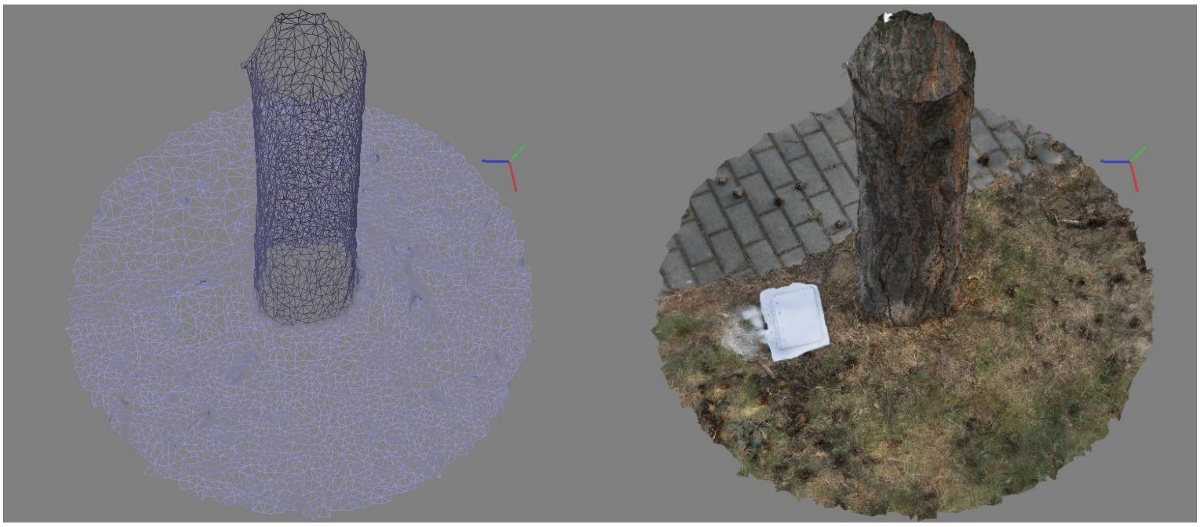

Figure 8. View capture from Agisoft PhotoScan Professional, showing the Polygonal Model of T1 (left) and the output of the Building Model Texture command for T1 (right).

Subsequently, I proceeded to place markers on the edges of the sheet of paper in the 3D reconstruction. Once all the required markers were placed on it, it was possible to rescale the 3D models, optimizing the measurements. Using several tools of the program, I was able to identify and mark the tree at 130 cm height. Then, I continued to mark a series of points at the same height around the tree as shown in figure 9. I obtained the value of distance between each pair of neighboring markers by executing the command Create Scale Bar. The sum of these distances results in the perimeter of the tree at 130 cm. I repeated this process for each tree.

In addition, I took the measurements of two diameters for each tree. By averaging these two values, I obtained the DBH of the tree. Since the tree stems are not perfect cylinders, I took measurements from the narrowest and widest diameters of the stem, see figure 9.

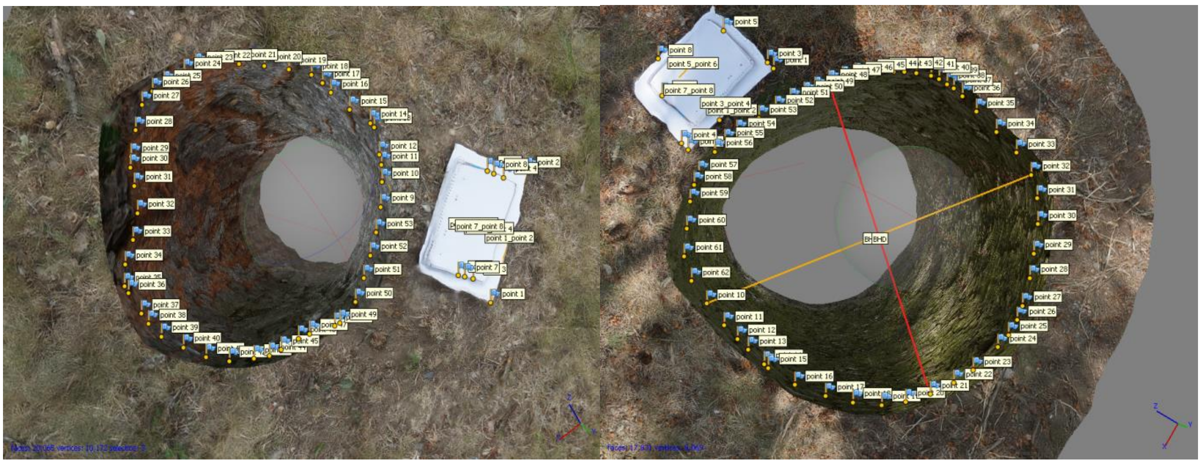

Figure 9. View capture from Agisoft PhotoScan Professional: 3D reconstruction of T3 (left) and T5 (right) viewed from above. The markers that conform the perimeters and the two diameter measurements of T5 are shown.

3.2.2.2. Scann3D

As mentioned in Section 3.2.2, Scann3D is a smartphone application that performs 3D reconstructions by photogrammetric processes. The application can only be installed on smartphones or tablets with Android Operating System version 5.0 (Lollipop) and later versions. Scann3D requires 20 MB of free memory space in order to be installed (Scann3D, 2017). I used a Google smartphone with the application previously installed by Peter Surový. Before starting the evaluation, I became familiar with the application and its use. Since the application is quite intuitive to use, with just a couple of commands a tree is reconstructed. Scann3D has two options when taking photos, Guided Mode and Manual Mode. Because Guided Mode is very sensitive to movement, I decided to work with the Manual Mode.

Being in the plot, I took about 70 pictures per plot tree (T1 – T8), trying to capture the 130 cm height and the A4 sheet of paper placed near the tree. To take the photos I held the smartphone facing and aiming at the tree to evaluate. I took one picture after another moving around the tree in a counterclockwise direction, until it had been photographed completely.

Once the photos were taken, I could see them on the screen in order to verify if I had to discard any blurred photo. The remaining photos were saved as an Imageset within the Application for an immediate or later 3D reconstruction. I repeated the process for the remaining seven trees.

I chose the Imageset corresponding to T1 and then I executed the Make command. It is at this point that the three-dimensional reconstruction begins. Steps like Pairing Images, Geometrical Filtering, Reconstruction Scene, Refining Model, Polishing Model, Coloring Model and Texturing Model are automatically processed on the phone. The resulting model can be displayed directly on the device screen, it can also be saved and shared. However, editing processes are only possible with other software or applications (Scann3D, 2017). I repeated the process for the remaining seven trees.

Once I had obtained and saved all the 3D models under their corresponding names (T1 for tree 1, T2 for tree two and so on), they were exported to a Laptop and then sent to me by email. Looking for some 3D model editing software capable of opening the files created by Scann3D, I found one called MeshLab. Meshlab is a Mesh Viewer software, which supports a variety of 3D file formats enabling to load, view and interactively inspect the models (P. Cignoni *et al.*, 2008), allowing me to make the desired measurements on my pc for each tree.

Using the Selecting File and then the Import Mesh command, I loaded the file .obj corresponding to T1. The 3D model of T1 was displayed on the screen. A required step in order to obtain the correct measurements was to adjust the scale of the model using the Measuring Tool. I measured the distance from side to side of the A4 sheet of paper that I used as a reference, see figure 10. By dividing the real value of the sheet (300 mm) by the distance shown on the screen, I obtained the Scale Factor.

Then, I selected the Transform Scale tool, introduced the Scale Factor and executed it. Next, I started to measure and locate points on the tree stem at 130 cm height. I could not place any marker on the model, so I used the Z-Paint tool to draw black lines around the tree stem at 130 cm height. I used these lines as a guide.

I began to measure once again small distances with the Measuring Tool following the black lines until completion of the perimeter. Every time I made a measurement the distance was automatically saved on the screen, see figure 11. I also took measurements of two diameters to get the DBH.

As a last step, I selected the point to point distances, copied and pasted them in an Excel sheet. Summing the distances results in the perimeter value of T1 in mm. I repeated the whole process for the remaining seven trees. The results are shown in centimeters in table 3.

Figure 10. View capture from MeshLab, showing the raw distance generated from the software without any scale transformation.

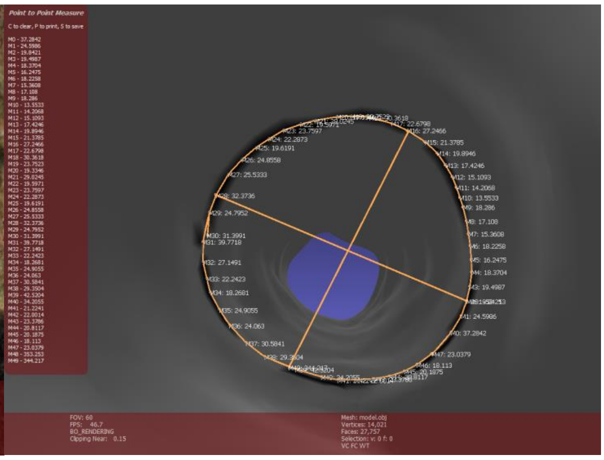

Figure 11. View capture from MeshLab: The markers that conform the perimeters and the two diameter measurements shown in mm.

3.3. Data

Both photogrammetric methods allow exporting or copying the desired data to another software (Excel) in order to perform the required calculation to obtain the measurements of each tree. Also, it is possible to visualize the 3D-reconstruction of them using another third-party software (MeshLab). On the other hand, it is not required to export the data to another software when using the electromagnetic method, since it is enough to make use of the program functions to find the desired measurements. This method also generates a 3D-reconstruction.

3.3.1. Magnetic Digitization

As previously mentioned, the Fastrak Digitizer Software is provided with the necessary tools and commands to obtain the perimeter at any desired height of the tree, in this case at 130 cm height. The data are displayed on the screen as shown in figure 6. The values obtained for each tree can be directly typed into an Excel sheet, see table 1. As I explained in section 3.2.1., the DBH values for T4 and T6 were found by placing the corresponding X, Y and Z values in the following formula:

$$D = \sqrt{[(x_2 - x_1)^2 + (y_2 - y_1)^2 + (z_2 - z_1)^2]}, \text{ where:}$$

- D is the distance between two points,
- (x_1, y_1, z_1) are the coordinates of the first point,
- (x_2, y_2, z_2) are the coordinates of the second point.

The visualization of the 3D model is also possible in its own software, however this reconstruction is based only on the shape of the stem. Thus, it is not able to see details, such as the crust of the tree, colors, the ground, and its visual characteristics, see figure 5.

Table 1. Total Area, Total Length (Perimeter), and DBH from the Tree 4 and Tree 6 obtained by Fastrak Digitizer Software

FASTRAK			
Tree	Total Area	Total Length	DBH
T4	523.88 cm²	88.66 cm	25.42 cm
T6	361.428 cm²	71.46 cm	21.30 cm

3.3.2. Photogrammetry

Agisoft PhotoScan Professional© and the application Scann3D offer a complete 3D-reconstruction visualization on the computer or smartphone screen respectively, see figure 12. In both cases, the generated models can be saved and exported in different formats. Both, Agisoft and Scann3D, offer the possibility to edit and examine the models using third-party software.

The perimeter and DBH measurements obtained by Agisoft can be directly typed in an Excel sheet, see table 2. On the other hand, the data obtained by Scann3D should be opened in a third-party software (MeshLab) for a further edition and examination. The measurements obtained by MeshLab (perimeter and DBH), see figure 11, can be copied and pasted into an Excel sheet to proceed with the evaluation, see table 3.

Table 2. Total Length (Perimeter), and DBH (at 130 cm height) from the trees obtained by Agisoft PhotoScan Professional©.

Agisoft PhotoScan Professional©		
Tree	Total Length	DBH
T1	113.02 cm	33.23 cm
T2	110.9 cm	33.86 cm
T3	83.41 cm	24.62 cm
T4	87.71 cm	22.24 cm
T5	117.01 cm	35.03 cm
T6	76.98 cm	23.76 cm
T7	81.83 cm	25.21 cm
T8	66.32 cm	18.31 cm

Table 3. Total Length (Perimeter), and DBH (at 130 cm height) from the trees obtained by Scann3D+MeshLab

Scann3D + MeshLab		
Tree	Total Length	DBH
T1	111.21 cm	34.83 cm
T2	96.94 cm	29.81 cm
T3	84.23 cm	26.34 cm
T4	88.64 cm	24.36 cm
T5	114.5 cm	37.05 cm
T6	72.22 cm	24.02 cm
T7	80.65 cm	25.34 cm
T8	64.75 cm	19.45 cm

Table 4. Perimeter from each evaluated tree obtained by Agisoft PhotoScan©, and Scann3D+MeshLab. Also, the absolute differences between them are shown.

Tree	Agisoft PhotoScan	Scann3D+MeshLab	|**Δ**|
T1	113.02	111.21	1.81
T2	110.9	96.94	13.96
T3	83.41	84.23	0.82
T4	87.71	88.64	0.93
T5	117.01	114.5	2.51
T6	76.98	72.22	4.76
T7	81.83	80.65	1.18
T8	66.32	64.75	1.57

Table 5. DBH from each evaluated tree obtained by Agisoft PhotoScan©, and Scann3D+MeshLab. Also, the absolute differences between them are shown.

Tree	Agisoft PhotoScan	Scann3D+MeshLab	|**Δ**|
T1	33.23	34.83	1.6
T2	33.86	29.81	4.05
T3	24.62	26.34	1.72
T4	22.24	24.36	2.12
T5	35.03	37.05	2.02
T6	23.76	24.02	0.26
T7	25.21	25.34	0.13
T8	18.31	19.45	1.14

3.3.3. The three cases together

In Excel, I created a new table in which I placed and arranged the data from the tables 1, 2 and 3, in order to compare them, see table 6. As T4 and T6 were the only two trees whose information was obtained by the three methods, I used their information for making comparisons between FastrakDigitizer®, Agisoft PhotoScan Proffesional© and Scann3D+MeshLab.

Table 6. Total Length (Perimeter), and DBH from the Tree 4 and Tree 6 obtained by FastrakDigitizer®, Agisoft PhotoScan, and Scann3D+MeshLab.

	FASTRAK		Agisoft PhotoScan		Scann3D + MeshLab	
Tree	Total Length	DBH	Total Length	DBH	Total Length	DBH
T4	88.66 cm	25.42 cm	87.71 cm	22.24 cm	88.64 cm	24.36 cm
T6	71.46 cm	21.30 cm	76.98 cm	23.76 cm	72.22 cm	24.03 cm

Table 7. Average DBH (left) and Perimeter (right) difference from Tree 4 and Tree 6 obtained by FastrakDigitizer®, Agisoft PhotoScan, and Scann3D+MeshLab. The standard errors of the mean are also shown.

	FASTRAK - Agisoft		FASTRAK - Scann3D+MeshLab		Scann3D+MeshLab - Agisoft	
	DBH	Perimeter	DBH	Perimeter	DBH	Perimeter
mean	2.82	3.24	1.90	0.39	1.20	2.85
sem	0.36	2.28	0.84	0.37	0.92	1.92

3.4. Analysis

In order to analyze the correlation between the values obtained from Agisoft and Scann3D+MeshLab and TO see how similar they are, I performed a linear regression from the perimeter data (Table 2), and DBH data (Table 3), the graphs are shown in Figure 12 and Figure 13. Although both measurement techniques are photogrammetric, it can be seen in the graphs that the values have a slight difference, and have a fair fit on the line. In both analyses, the farthest point from the line belongs to the tree T2.

For the Perimeter analysis (Figure 12), the linear model obtained has a R^2=0.9374 with a significant p-value of 7.834 x 10^{-5}. Alternatively, for the DBH analysis (Figure 13), the linear model obtained has a R^2=0.8924 with a significant p-value of 0.0004. Thus, the analysis of the Perimeter has the best-fitted values.

In order to analyze the variance of values among each measurement technique, I worked with the absolute differences of the values obtained from each tree by the Agisoft PhotoScan© and the Scann3D+MeshLab (table 4 and 5), by estimating their mean and their standard error of the mean. For the perimeter (Figure 14), the average difference between both methods is 3.44 with a standard error of 1.57. On the other hand, for the DBH analysis (Figure 15), the average difference is 1.63 with a standard error of 0.44.

In the same way, in order to analyze the variation of the values among the three measurement techniques, I worked with the absolute differences of the values obtained from each tree (table 6). Each pair of techniques gave absolute differences and was evaluated by estimating their mean and their standard error of the mean. All this information is shown in table 7.

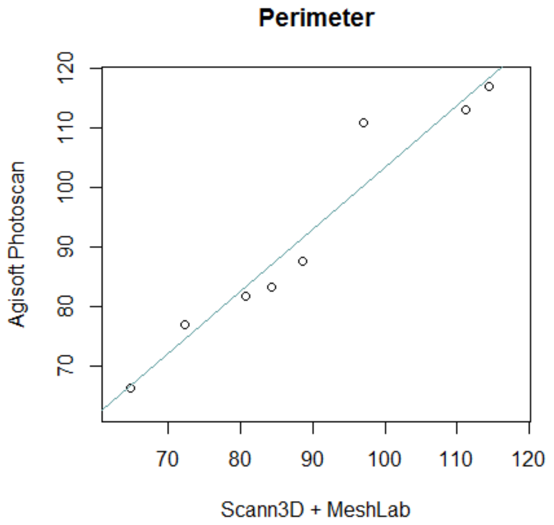

Figure 12. Graph showing the correlation of the Perimeter values obtained by both photogrammetric methods in a linear regression. Y = 1.0406x-0.6151.

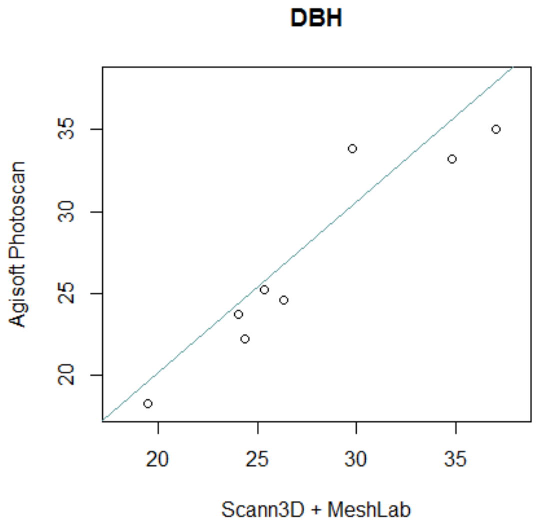

Figure 13. Graph showing the correlation of the DBH values obtained by both photogrammetric methods in a linear regresion. Y = 0.9921x-0.4003.

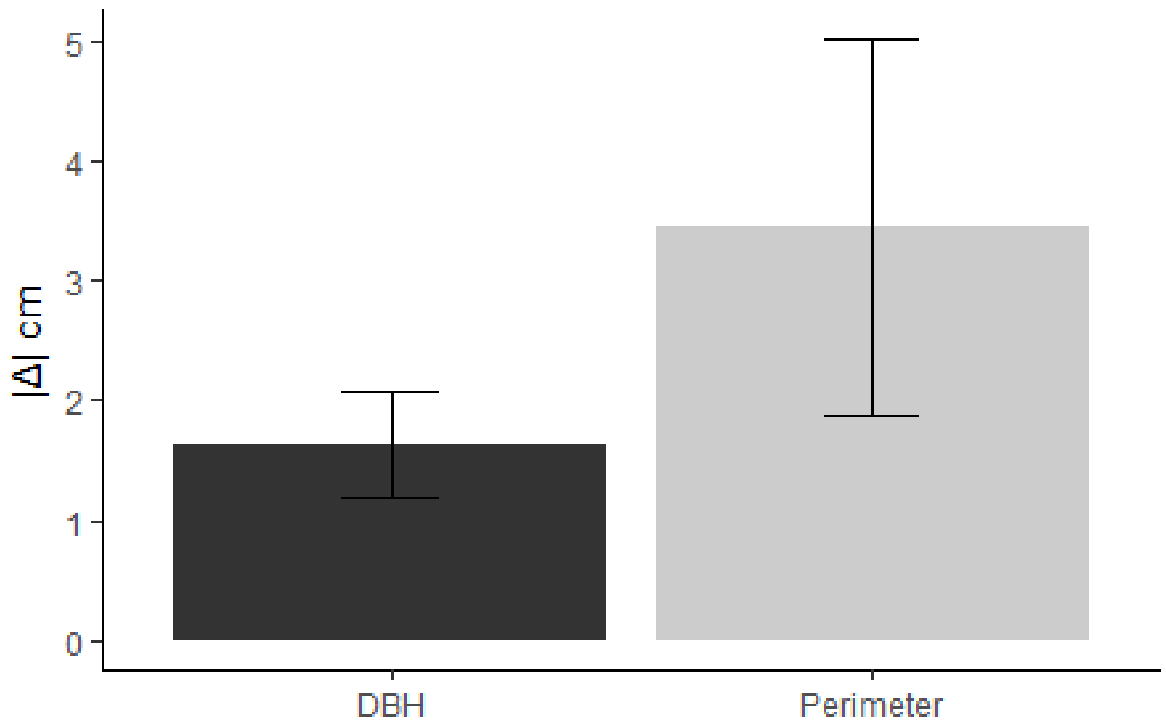

Figure 14. Bar graph showing the average DBH (left) and Perimeter (right) difference between Agisoft Photoscan and Scann3D+MeshLab. Standard errors of the mean are also shown.

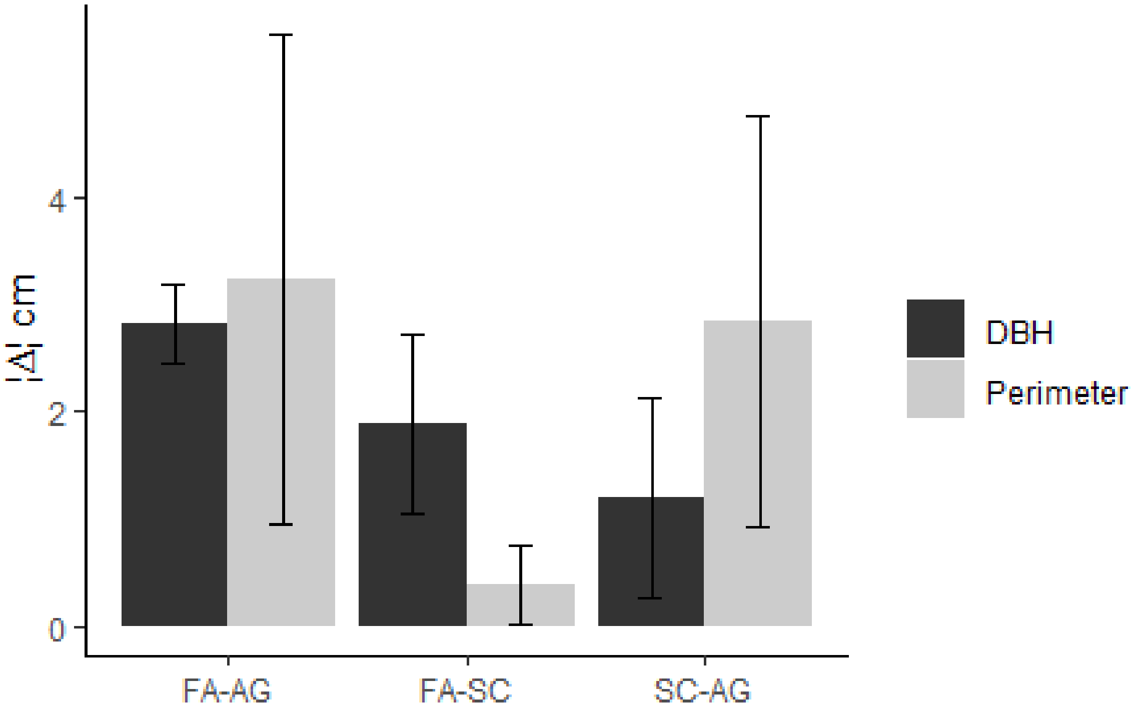

Figure 15. Bar graph showing the average DBH and Perimeter difference between FastrakDigitizer (FA), Agisoft PhotoScan (AG), Scann3D+MeshLab (SC). Standard errors of the mean are also shown.

3.5. Evaluation

3.5.1. Magnetic Digitization

Some considerations should be taken into account before starting the digitization procedure. An electrical power source will always be needed for the Fastrak and the host computer. The power supply must be uninterrupted and last long enough to work without interruptions, and avoid possible loss of time and data.

A previous explanation and a practical demonstration of the software, as well as the technology behind reflects crucial advantages for an efficient work. Using the software might be a challenge for beginners. Moreover, the FastrakDigitizer® 1.0 version tends to crash, causing unsaved data to get lost. To avoid this situation, it is recommended to open and close the program every time a new tree will be digitized. In addition, due to the fact that the software does not have an undo command, the whole process has to be redone if an undesired command was run.

It may be considered that a current error for untrained persons can be not to place properly the Source near the tree. This Source has a range of 1.5 meters, in order to measure tree surfaces above 1.5 meters it is necessary to raise the Source on some non-metallic surface. By not doing this, noise will be generated.

Once the plot selection is done and before work commences, one must be aware of the existence of near metal structures and remove them, otherwise noise could be generated, negatively affecting the digitization. When digitizing, it is recommended to work together with another person. Teamwork facilitates the workflow and reduces the chances of making mistakes during its operation. The data obtained can be easily exported to Excel as well as transformed into text data.

3.5.2. Agisoft PhotoScan Professional©

Here some considerations about Agisoft for a three-dimensional reconstruction:

There should be enough memory space available in the camera for the amount of photos planned to be taken, likewise the batteries must previously be fully charged. Otherwise, the workflow will be negatively affected in terms of efficiency and efficacy, causing waste of time.

The host computer, on which the software will be installed, must comply with a series of requirements regarding: memory space, processing speed, graphics card, and compatibility with the software.

Weather conditions should be checked prior to scheduling the date and time of taking the photo shots. Aspects such as luminance, rain, and wind have a significant influence on the visual results of the three-dimensional reconstruction.

The software is integrated with a wide range of tools and commands allowing us to create a 3D model from digital photographs without any obstacles. However, as every generated model is a 3D scene and is displayed on a 2D plane screen, a number of commands are required in order to move around the model. This procedure becomes tedious and takes a dominating amount of time.

The time it takes to generate a reconstruction, taking into consideration quality, depends on the number of photos used for the model, and also their image resolution.

E.g. obtaining the complete 3D model of T1 took around 6 hours. Nevertheless, depending on others factors it can take up to approximately 14 hours.

Once the model has been created, direct edits can be made, markers can be placed, distances can be measured and no third party software is required.

3.5.3. Scann3D + MeshLab

It is recommended to have a smartphone with enough memory space, good camera resolution and enough battery charge in order to take the photos without interruptions. This allows to save time and to improve the workflow.

Scann3D is a fairly intuitive application. With simplified controls and modes of use, this application is characterized by being uncomplicated. However, it requires practice when using the guided mode due to its sensitivity to movement. Generating a couple of 3D-reconstructions of test trees not only increases the chances of success on the following models, it also guarantees a smooth work while using the application.

The environment around the object to be reconstructed must meet certain requirements, such as good light exposure and avoidance of shadows. The object should be clearly distinguished from the background in each shot.

Scann3D performs a three-dimensional reconstruction based on an Imageset in a relatively short time. This can usually vary between ten and twenty minutes depending on the number of photos and on the characteristics of the smartphone.

E.g. obtaining the complete 3D model of T1 took around 16 minutes. The Imageset for T1 contained 65 photos.

It is not possible to edit the generated model within the application, however, the generated data can be exported in many formats. If a file format change is required, third-party software is available to perform this action.

MeshLab offers the option to edit these formats. As any other 3D-model editing program, MeshLab is complex and hosts a wide range of tools and editing commands, it is recommended to be instructed by others, to watch tutorials or to explore its functions by oneself.

4. Conclusions

4.1. Comparisons

In this Section, we will present the considered aspects to find out which of the three methods is most certainly the optimal. The following aspects were studied in this thesis: visualization, ergonomics, economy, and working time. Nevertheless, it is not intended to evaluate the precision of each measurement technique since it would then be necessary to increase the number of sample trees and to perform measurements with a caliper.

4.1.1. Visual aspects

The visual aspect in this thesis is understood as the visual attributes of the 3D-recreation of the trees (T1-T8) such as color, shape, surface, depth, image quality, and others. These will be evaluated.

As can be seen in figure 5, the model generated by Polhemus Fastrak® does not have image data and cannot show the visual attributes of the trees. Only a gray recreation of the tree shape is generated, besides, the background does not interfere in the 3D-recreation of the tree T5.

On the other hand, as can be seen in figure 16, both Agisoft PhotoScan© and Scann3D offer a good 3D-recreation with most of the visual attributes.

Because the tree was photographed on different days, at different time of the day, and with different weather conditions, a comparison is not possible due to the clear difference in brightness. However, the sharpness and image quality are much better in Agisoft, even the roughness of the tree stem can be noticed.

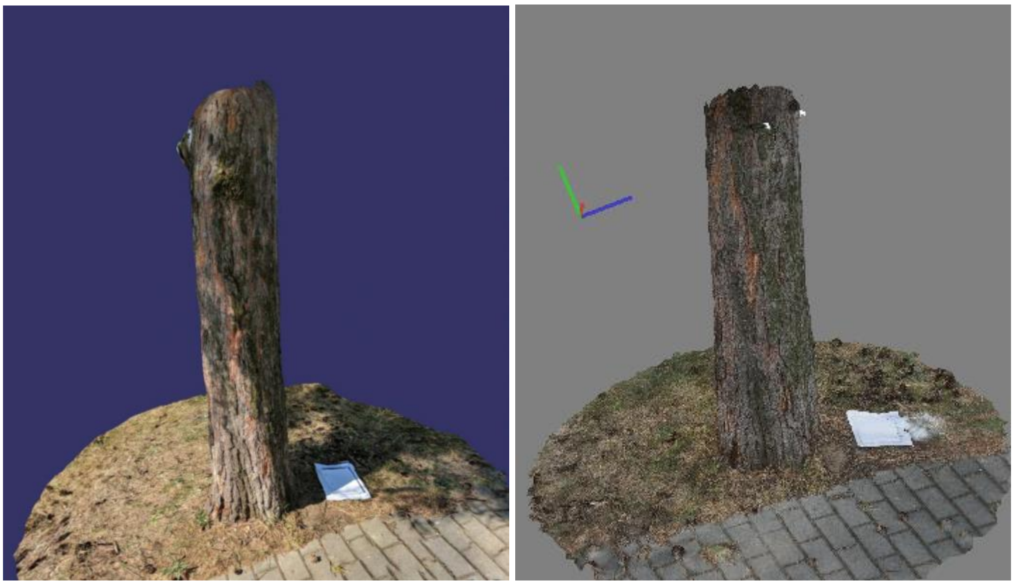

Figure 16. View capture from Scann3D (left) and PhotoScan (right), the 3D reconstruction of T1.

4.1.2. Ergonomics

The Polhemus Fastrak® is usually stored and carried in a protective case, together they weigh approximately 2 kilograms. To set up the Fastrak, the operator must read, understand and follow the instructions given in its manual in order to avoid damaging the equipment. The process of unpacking, assembling and turning on the equipment takes just a few minutes. The most demanding part while setting up the Fastrak is to connect the SEU to the transmitter, the power supply, and the receiver because there are many specific cables to connect. Once the system is set up, no further user calibration is needed. While digitizing, it is inevitable to be in contact with the tree. Furthermore, to obtain the desired points, it is needed to move around the tree, bend down to digitize areas near the ground, and embrace the tree with the risk of staining the clothes with resin. As mentioned above, this method is sensitive since missing one of these considerations would lead to an error during the acquisition of the data and/or affect the processing of the digitization. This results in the amount of time and effort invested to be wasted, having to do the evaluation again.

Prior to working with Agisoft PhotoScan, a series of digital pictures should be taken. The photo shooting process is simple and effortless. If the camera is light and allows to visualize the image by rotating its screen, it will be not necessary to bend down to take pictures of the lower part of the tree, making the process easier. However, maintaining concentration, focus and stability are the key to reduce blurry pictures, which could affect the digitization.

Working with Scann3D is much more simple, intuitive and very comfortable compared with the others. Being a mobile application, it gives the feeling of taking simple pictures as people are used to do it every time. Moreover, while the 3D reconstruction process is running, it is possible to keep the application in the background and run others. Scann3D does not stop working.

4.1.3. Economic aspects

In order to make comparisons between the three techniques, I will assume the equipment and software as new acquisitions.

Fastrak as a commercial product is offered at a purchase price of about $6,350.00, depending on the Distributor Company[4]. Moreover, the Stylus is sold separately, whose price varies between $900.00 and $1,100.00 depending on its size and features. Furthermore, a host device, as a laptop, is required to run the evaluation. The laptop must have one of the following operating systems installed: GUI/SDK 2000/XP/7, and a 2.0 USB port. The average price for a laptop with these characteristics is about $600.

These prices are relatively high and at this point it could be assumed that the photogrammetric method is much more affordable. However, in the case of Agisoft we could face elevated prices. Starting with the digital camera, prices may vary depending on the model and features; *e.g.* the camera used in this thesis was a Sony-α- 6000 with 24.3 megapixel, and an APS-C CMOS sensor, that has a current price of about $580.00. In addition, a laptop is needed with

[4] http://www.vrealities.com/products/magnetic

high processing capacity, and meeting the requirements for a proper functioning of the software. The price also depends on the brand. An average price for a suitable computer is about $1,900.00. Once the equipment is acquired, investment in the software is also needed. Although Agisoft PhotoScan offers a 30-days free trial license, it is recommended to buy the software if a long-term work is to be perform[5]. The Agisoft PhotoScan Professional Edition stand-alone license costs $3,499.00 and the Standard Edition $179.00.

On the other hand, Scann3D runs on smartphones and is only available for the Android operating system. A smartphone with Android 5.0 operative system or higher versions, with a good integrated camera, costs around $300.00. The Scann3D application can be downloaded free, or purchased from the App-Store[6]. The freeware version is the Standard edition whose quality preset is the most basic, while conversely in order to obtain the high and ultra-quality preset a subscription is required, about $6.95 per month or $47.54 per year. In addition, the output generated by Scann3D can be edited through a third-party program, MeshLab[7]. MeshLab is an open source software that allows processing and editing three-dimensional triangular meshes produced by other devices like Scann3D, thus the download is costless.

4.1.4. Time of Process

The setup of the Polhemus Fastrak® took several minutes in order to get all its components perfectly placed for an adequate operation. It took approximately 15 minutes to digitize a tree stem with the Polhemus Fastrak®. On the other hand, it took between 5 and 10 minutes for both photogrammetric methods to shoot the photos of the tree stem. Aspects such as micro-relief of the soil around the tree, and the groundcover may make the work difficult while taking the pictures.

According to the references presented in section 2 and 3, with the Polhemus Fastrak® the data points are generated instantly, but then, further processing is required (made by Peter Surový). Once this process is performed, by executing few commands within the FastrakDigitizer® software, the Perimeter (total length) can be obtained as well as the point coordinates used to calculate the DBH. In contrast both photogrammetric techniques, Agisoft PhotoScan©, and Scann3D in addition with MeshLab, needed much more time to generate a point cloud, also the entire digitization workflow, including the selection of points and the acquisition of the desired measurements took a long time (between 10-20 minutes for Scann3D and up to 6 Hours for Agisoft PhotoScan©).

Both photogrammetric techniques require working at a computer. The skills of the user such as finding tie points, positioning markers, skillfully navigating in a 3D recreated field, and other related actions, influence the perception of difficulty, making it relatively complex and challenging.

[5] http://www.agisoft.com/buy/online-store/
[6] https://play.google.com/store/apps/details?id=com.smartmobilevision.scann3d&hl=es
[7] http://www.meshlab.net/ - download

4.2. Overall conclusions

In terms of operation, the electromagnetic technique FastrakDigitizer® generated the measurement almost automatically using its own software, the FastrakDigitizer® software. But it is not until the processing of the data that it can be noticed if the obtained points are useful or not for further evaluations. If the points are not useful, the whole digitization process must be completely redone. On the other hand, the photogrammetric technique Agisoft PhotoScan Professional© required a previous complex workflow, including a manual selection of the points in the generated 3D model in order to obtain the distance between them. Similarly, the other photogrammetric technique Scann3D also required a manual process to obtain the measurements. In this case, using a third-party software (MeshLab) is involved. In contrast with the previous techniques, this application generated the 3D model automatically and immediately, but without the possibility to edit and examine the data.

Between both photogrammetric techniques, if the goal is to obtain a three-dimensional visual reconstruction in the shortest amount of time, the best choice will be Scann3D. However, it should be taken into account that it only provides visualization without the possibility to edit and examine it in the application, therefore, distance data are not available.

On the other hand, if the goal is to obtain distance information as well, it is much favorable to make use of Agisoft PhotoScan. Despite it takes much more processing time than Scann3d, this software generates clearer reconstructions, allowing to more accurately place marks for scaling, thus reducing the chances of error. Moreover, in comparison to Scann3d, the point cloud generated by Agisoft does not require third party programs in order to measure the distance between points.

When it comes to obtaining the fastest and most precise results of Perimeter and DBH, the magnetic digitization is the best option. This is due to its fluid workflow, not depending on the light intensity or the environment around the object to digitize. The results are precise if the manual instructions are followed to the letter, thus reducing technical problems and potential human error.

5. Critical reflection

5.1. Limitations of the study

Because there were missing measurements from six trees, which were evaluated by the Polhemus Fastrak, the comparisons between the data acquired with the three technologies were limited to only two sample trees, T4 and T6. These measurements could not be redone by two main reasons: first, the tree plot is located in another country (Czech Republic), and secondly, the measurements could not be redone in Germany due to lack of time, and because the photogrammetric data was already analyzed.

5.2. Problems

5.2.1. Obtaining Data

The Points Data generated by Polhemus Fastrak for T1, T2, T3, T5, T7 and T8 could not be used for this thesis. The required processing to Points Data for producing corrected measurements within the software was not achieved. A possible cause for this situation was: noise generated inside the electromagnetic field due to an unnoticed metallic object close to the source that was never removed; and another cause would be human error while manipulating the technology and/or the software.

5.2.2. Analysing Data

No problems were encountered during the data analysis.

5.2.3. Other problems

The official Scann3D developer's website is out of service, therefore it is impossible to obtain information at first hand in real time. I found that the last recorded access to the website: http://scann3d.smartmobilevision.com/ was made in April 2018 by Di Paola & Inzerillo (2018). Besides, I could not find any literature that was not on the Internet.

5.3. Discussion of open issues

This thesis did not intend to compare the accuracy between all the techniques, because otherwise DBH and perimeter measurements with a caliper or a measuring tape would have to be performed, and then these values would have to be compared with the data obtained by the digitization techniques.

On the other hand, as mentioned in section 3.4 in the figure 12 and 13, it can be seen that the farthest point from the regression line belongs to the tree T2. Apart from human error, another explanation for these results could be the stem shape of this tree. Because a branch scar is located over the 130 cm height presenting a protrusion on the stem surface, it seems to be inevitable to obtain an error in the measurement due to its irregular surface.

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7. Statement of good practice

I submit this thesis titled “A Comparison between Photogrammetric Measurement and Measurement with the Electromagnetic Digitizer for Acquisition of Stem Surface” in partial fulfilment of the requirements for the Degree of Bachelor of Science in Forest Sciences and Forest Ecology at the Georg-August-University Göttingen.

In accordance with § 8 para. 5 of the Bachelor Examination Regulations of 31. 10. 2012, I hereby declare that this thesis is my own work and that I have correctly acknowledged the work of others by including full references for all sources in the bibliography.

Monday, 01 October 2018

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