
PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
UNIVERSITY OF AIN-TEMOUCHENTBELHADJBOUCHAIB
FACULTY OF SCIENCE AND TECHNOLOGY
DEPARTMENT OF AGRO-FOOD



THESIS

For obtaining the Master's degree
Field: Natural and life science
Sector: ecological science
Specialty: plant ecology and environment
By:
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THEME

CONTRIBUTION OF PHOTOGRAMMETRY IN THE
CALCULATION OF THE EXACT SURFACE OF PLANT
LEAVES

SUSTAINED ON: 06/2022

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Session Year: 2021-2022

REPUBLIQUE ALGERIENNE DEMOCRATIQUE ET POPULAIRE
MINISTERE DE L'ENSEIGNEMENT SUPERIEURE ET DE LA RECHERCHE
SCIENTIFIQUE

Université d'Aïn-Témouchent Belhadj Bouchaib – UATBB-
Faculté des sciences et de la technologie
Département de l'Agroalimentaire



MÉMOIRE

Présenté en vue de l'obtention du diplôme de Master

Domaine : Sciences de la nature et de la vie

Filière : Ecologie environnement

Spécialité : Ecologie végétale et environnement

Par :

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THEME

Apport de la photogrammétrie dans le calcul de surface exacte
des feuilles de plante

Soutenu le .../06/2022

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Année universitaire: 2021-2022

Contribution of photogrammetry in the calculation of the exact surface of plant

شكرو عرفان

بسم الله الرحمن الرحيم

الشكر و الثناء لله عز وجل الذي أعانني وأنار لي دربي و شد من عزمي

لإكمال هذا البحث

قال رسول الله صلى الله عليه وسلم: « من لم يشكر الناس لن يشكر الله » .

أتقدم بأسمى عبارات الشكر و الثناء لأستاذي الفاضل " قدور حكيم " الذي

تفضل بإشرافه على هذا البحث,الذي له الفضل بعد الله عز وجل لما قدمه لي

من دعم و توجيه و إرشاد مع ما لقيت منه من رحابة صدر و بشاشة

وجه,اسأل الله أن يجازيه خير الجزاء على صبره علي وان يكتب صنيعه في

موازين حسناته.

الإهداء

إذا كان الإهداء جزءاً من الوفاء فانا اهدي هذا البحث:
إلى ذلك الصرح العظيم الذي علمني الخلق الكريم إلى من حصد الأشواق
ليمهد لي طريق العلم والمعرفة ومن أحمل اسمه بكل افتخار صاحب الفضل
العظيم...

أبي الغالي

إلى أول من نطق باسمها اللسان وترتاح عند رؤيتها العينان إلى معنى الحب
و الحنان إلى من كان دعائها سر نجاحي و حنانها بلسم جراحي...
* أمي الغالية *

إلى بضعة من أمي وأبي ملاذي وقوتي وسندي بعد الله سبحانه و توائم
روحي من عشت معهم أجمل ذكرياتي و لولاهم ما عرفت معنى الأخوة...
أخواتي "جوهر" "وداد" "مريم"

إلى ملاكي الصغير ابن أختي "نضال"

إلى كل من أحبني بصدق فدعا لي بالتوفيق و السداد إلى من يسعهم قلبي ولم
تسعهم ورقتي وكل من ترك بصمة حب في قلبي...

إلى أحبتي ورفقاء دربي

إلى كل هؤلاء

اهدي ثمرة جهدي

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List of Abbreviation

DTM: Digital Terrain Model.

GCP: Ground Control Point.

GPS: Global Position System.

SFM: Structure from Motion.

TIN: Triangle Irregular Network.

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ABSTRACT:

The analysis and monitoring of certain plants is based on the knowledge of several aspects, namely the geometric parameters, such as the surface, the length or the thickness.

Moreover, it is not so easy to perform these measurements in most cases, mainly due to the complexity of the geometric structure of plants.

In this thesis, the work will be focused on the calculation of the surface of the blade of certain plant leaves chosen arbitrarily, and this by the use of the technique of photogrammetry.

Indeed, two main methodologies have been identified, using vector processing on a single photograph (2D), and raster processing on a plant reconstructed by SfM (3D). The latter is applied to plants not destroyed in contrary the first.

The precision of the surface obtained depends on several parameters depending on the processing approach; we quote: the CGP, pointing defect, the contrast of the object and EMQ for the case of 3D.

Keywords: photogrammetry; SfM, Raster, Vector, surface.

RESUME :

L'analyse et le suivi de certaines plantes repose sur la connaissance de plusieurs aspects, à savoir les paramètres géométriques, comme la surface, la longueur ou l'épaisseur.

Par ailleurs, il n'est pas aussi facile d'effectuer ces mesures dans la plupart des cas, due essentiellement à la complexité de la structure géométrique des plantes.

Dans ce mémoire, le travail sera focalisé sur le calcul de la surface du limbe de certaines feuilles de plante choisie arbitrairement, et ceci par l'utilisation de la technique de la photogrammétrie.

En effet, on a dégagé deux méthodologies principales, en utilisant un traitement vectoriel sur une seule photographie (2D), et un traitement Raster sur une plante reconstruit par SfM (3D). Cette dernière est appliquée sur des plantes non détruit contrairement à la première.

La précision de la surface obtenue dépend de plusieurs paramètres suivant la démarche de traitement ; on cite : les CGP, défaut de pointage, le contraste de l'objet et EMQ pour le cas de la 3D.

Mots-clés : photogrammétrie;SfM, Raster, Vecteur , surface.

ملخص:

يعتمد تحليل ومراقبة بعض النباتات على معرفة عدة جوانب ، وهي المعلومات الهندسية ، مثل السطح أو الطول أو السماكة. علاوة على ذلك ، ليس من السهل إجراء هذه القياسات في معظم الحالات ، ويرجع ذلك أساساً إلى تعقيد البنية الهندسية للنباتات. في هذه الأطروحة، سيركز العمل على حساب سطح نصل أوراق نباتية معينة تم اختيارها عشوائياً ، وذلك باستخدام تقنية القياس التصويري . في الواقع ، تم تحديد طريقتين رئيسيتين ، باستخدام معالجة المتجهات على صورة واحدة ثنائية الأبعاد(D2)، و المعالجة النقطية على نبتة أعيد بناؤها بواسطة SfM (D3). يتم تطبيق هذا الأخير على النباتات التي لم يتم تدميرها على عكس الأولى. تعتمد دقة السطح التي تم الحصول عليها على العديد من المعلومات اعتماداً على نهج المعالجة؛ نذكر: GCP ، خطأ في التأشير ، تباين الكائن و EMQ لحالة 3D. الكلمات المفتاحية: المسح التصويري ، SfM ، النقطية ، الأشعة ، السطح .

GENERAL INTRODUCTION

GENERAL INTRODUCTION

There are many situations in life or science in which we must measure coordinates distances, areas or volumes.

In ecology the leaf is the main organ of plant photosynthesis, and leaf area is an important factor in measuring plant photosynthesis and other plant mechanisms. Accurate measurement of leaf area for plant growth and the interaction between the plant and the growing environment have an important significance. The measurement accuracy and reliability of plant leaf area have been greatly improved from the original traditional method to the computer image processing technology using photogrammetry.

Photogrammetry is the technique that allows to measure the shape and dimensions of an object to be reconstructed from photographically recorded perspective of this object.

Since the change from analog photogrammetry to digital photogrammetry, the latter has known a multitude of applications in very varied fields (Industrial, agriculture, engineering, scientific, etc....) Hundreds of related photo-based applications have become accessible and within reach for everyone via cell phones.

Academically, photogrammetry has become closely linked with computer science (computer vision, robotics, programming and image processing).

In addition, there is an emphasis on the use of photogrammetry for industrial objects compared to natural ones, namely those related to plant species.

This can be explained by the complex geometric nature of plants which is quite difficult to model.

As a result, we are content with taking ordinary photos which cannot be used as a metric or measurement document on the target plants.

But with the advent of the technique of three-dimensional reconstruction by stereoscopy in aerial photogrammetry, it has become possible to have the DEM (digital terrain model) and therefore the altitude at each point by pair of overlapped photos.

GENERAL INTRODUCTION

Aerial photogrammetry has recognized a remarkable development since it presented advantages on its acquisition geometry. If we know the altitude of the plane, the parameters of the metric room (photogrammetric camera), the percentage of overlap between the photos taken; unknown parameters of the scene (terrain) will be quite simple for their definitions.

Even without stereoscopy, that is to say the use of a single photo, it is possible to have very precise results on the planimetric plan of the terrain.

Alas, this is not the case for land shots, we do not know the distance that separates us with the photographed object, the shot can tend towards the horizon, we use devices of which we only know their brand and their resolution! and for stereoscopy, we have no information on the percentage of overlapping photos.

In short, we cannot project the geometric formulas of aerial photogrammetry to the terrestrial one. This slowed down this axis until the change from analog to digital in photogrammetry, and the production of powerful computer machines.

It has become possible to calculate the camera-scene distance after calibration and knowledge of the internal parameters of the camera, we can also not worry about the shooting angles except to ensure by visual estimation a good overlap between the photos.

Measure in photos means also measure without a physical contact to the object. Therefore, if you have very smooth objects like liquids, sand or clouds, photogrammetry will be the tool of choice.

To finally have an assembly of all the photos in a three-dimensional product which can be zoomed, panned and rotated freely on the three axes.

What are the theoretical concepts related to this new technology?

- What are the acquisition methods for having such a product?
- Can this technique be applied for measuring leaf area with high accuracy and with or without destruct the plants?

The answers to these and other relevant questions are our work objective for this thesis.

The thesis is subdivided to five chapter :

The first one is about basic concept of photogrammetry in general (History, definition; type etc).

GENERAL INTRODUCTION

More details will be found in the second chapter especially about external and inner shooting parameters.

The third chapter discuss the case of the 3D reconstitution, and how to obtain such model.

The fourth chapter gives examples of the applications of photogrammetry nowadays, especially in vegetation domain.

Finally, the last chapter is devoted for the application carried out with two vectorization approach using four different software in order to calculate the area of certain leaf of different plant and trees. the 3D approach is also developed in this chapter.

CHAPTER 1 :
BASIC CONCEPT OF PHOTOGRAMMETRY

1. History:

In the early 18th century Dr. Brook Taylor published his treatise on linear perspective, and soon afterward, J. H. Lambert suggested that the principles of perspective could be used in preparing maps.

The actual practice of photogrammetry could not occur, of course, until a practical photographic process was developed. This occurred in 1839, when Louis Daguerre of Paris announced his direct photographic process. In his process the exposure was made on metal plates that had been light sensitized with a coating of silver iodide. This is essentially the photographic process in use today.

The first actual experiments in using photogrammetry for topographic mapping occurred in 1849 under the direction of Colonel Aime Laussedat of the French Army Corps of Engineers. In Colonel Laussedat's experiments kites and balloons were used for taking aerial photographs. Due to difficulties encountered in obtaining aerial photographs, he curtailed this area of research and concentrated (Bank, 2015)

His efforts on mapping with terrestrial photographs. In 1859 Colonel Laussedat presented an accounting of his successes in mapping using photographs. His pioneering work and dedication to this subject earned him the title "father of photogrammetry."

Topographic mapping using photogrammetry was introduced to North America in 1886 by Captain Eduard Deville, the Surveyor General of Canada. He found Laussedat's principles extremely convenient for mapping the rugged mountains of western Canada. The U.S. Coast and Geodetic

Survey, now the National Geodetic Survey, adopted photogrammetry in 1894 for mapping along the border between Canada and the Alaska Territory. (Bank, 2015)

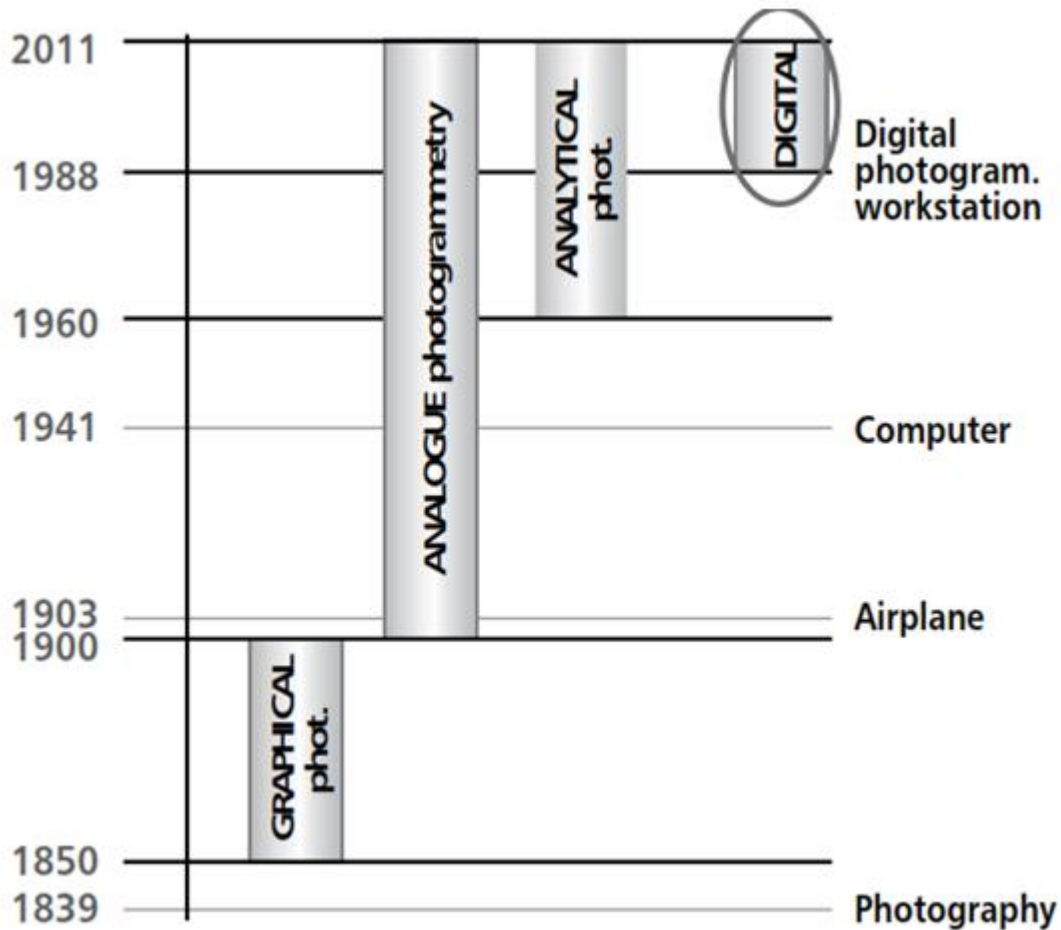


Figure 1: Phases of photogrammetric development as a result of technological innovations.(Balenović, 2011)

2. Definition of photogrammetry:

Photogrammetry has been defined by the American Society for Photogrammetry and Remote Sensing as the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena. As implied by its name, the science originally consisted of analyzing photographs, however the use of film cameras has greatly diminished in favor of digital sensors. Photogrammetry has expanded to include analysis of other records, such as digital imagery, radiated acoustical energy patterns, laser ranging measurements, and magnetic phenomena. In this text both photographic and digital photogrammetry are emphasized since they share many of the same principles, but other sources of information are also discussed.(Wolf, 2014)

The formal definition of photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through the process of recording, measuring, and interpreting photographic images and patterns of electromagnetic radiant energy and other phenomena. In many instances, the use of photogrammetry can be more efficient, less labor-intensive, and more cost-effective than other types of field 3D data collection, resulting in products that have a level of detail, accuracy, range, and price that is difficult to match with other technologies. As described previously, the main component necessary for a photogrammetric project is a series of overlapping stereoscopic images. The stereo images may be captured by a large variety of cameras at almost any height or platform (from tripod to earth-orbiting satellite). (Bank, 2015)

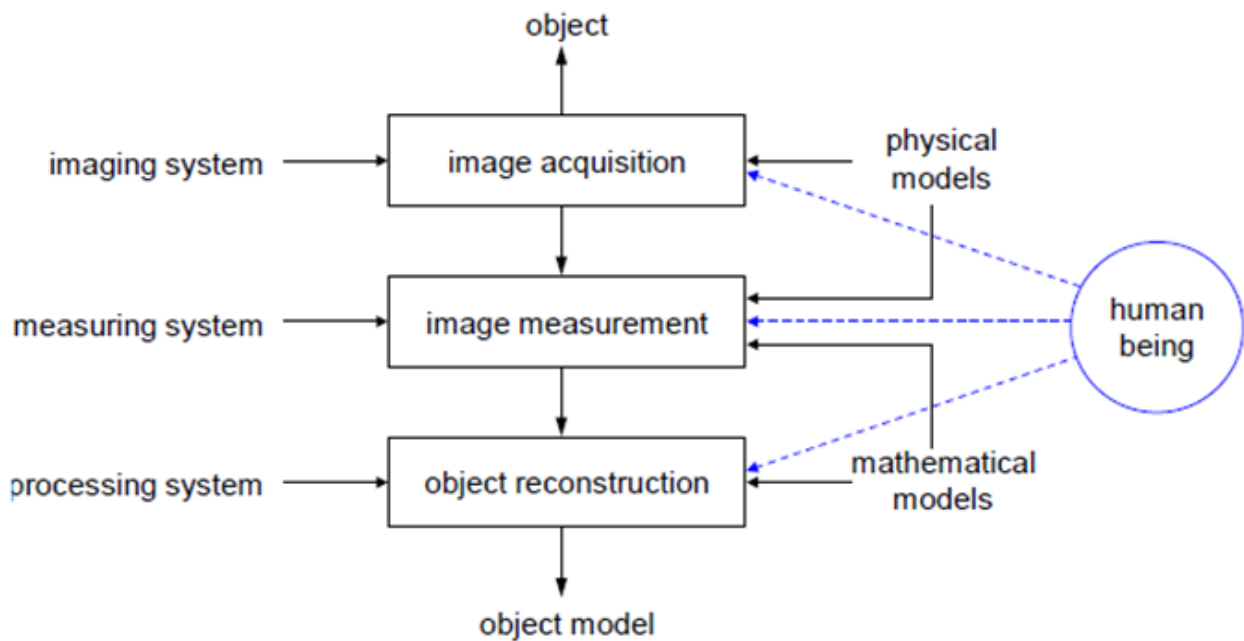


Figure 2: The photogrammetric process from object to model. (Thomas, 2013)

3. Objective

Photogrammetry is used in surveying and mapping by using photography. In order to measure distance between any objects we can use photogrammetry. By using photogrammetry software's, we can create 3d renderings with the help of images captured. During early days it is mostly used for topographic mappings but now a day it is been used in several number of other ways. It is the

first remote sensing technology used to determine the geometric properties about objects using photographic images. The basic principle of photogrammetry is triangulation. Taking

photographs from minimum two different locations that is line of sight can be developed from each camera to points on objects.(Dvivedi, 2020)

3.1. What is image?

The word image, from Latin imago, designates the visual representation of an object by different means or media, drawing, digital image, painting, photography...

At this stage, one realizes the multitude and variety in the basic material. (Vd, 2010)

3.2. What is a photo?

Short for photograph, a photo is a picture taken by a camera, digital camera, or Smartphone that is capable of producing a hard copy or digital copy. (hope, 2020)

4. Types of photogrammetry

The most widely recognized approach to characterize photogrammetry depends on the situation of the camera that takes the photos to be examined. There are three essential kinds of photogrammetry dependent on the camera position: Space photogrammetry; Aerial Photogrammetry and Terrestrial or Close-Range Photogrammetry

4.1. Spatial:

In this branch of photogrammetry, the satellites are used to take photographs. With the development of modern-day satellite, a global coverage of satellite imageries is possible in lesser time with a high-resolution data. (Singh)

4.2. Aerial:

In this kind of photogrammetry the camera is mounted on an aircraft which can take many photographs of the area from different edges (see figure below). For this, an exactness photogrammetric camera is utilized to get top-notch pictures, which is mounted on a flying machine, UAVs or automatons. Every now and again satellite pictures are utilized too. The Aerial

CHAPTER 1: BASIC CONCEPT OF PHOTOGRAMMETRY

photogrammetry model is utilized for geographical examinations, land and soil studies, structural designing for urban improvement, coordinations, military knowledge, and others. (Singh)

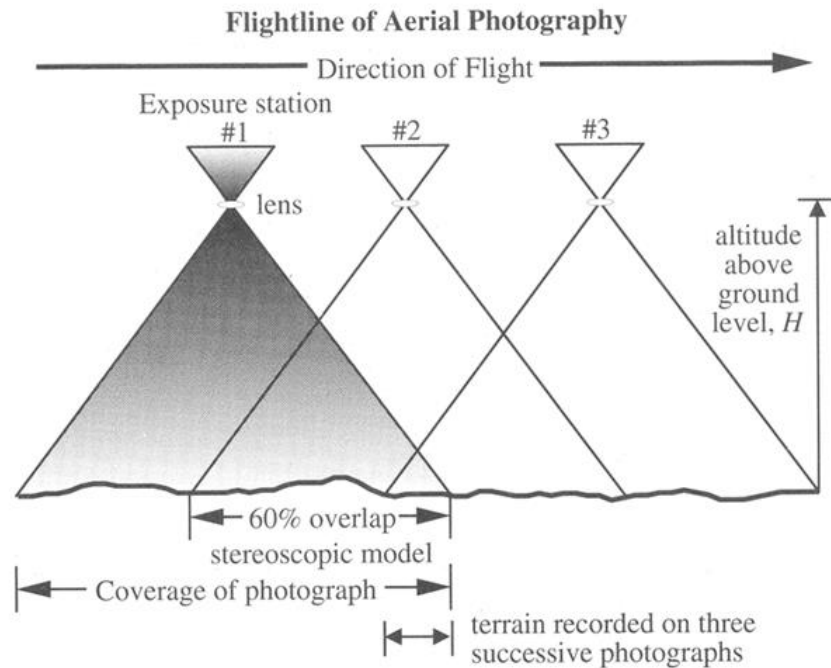


Figure 3 : A single flightline of vertical aerial photography with 60 percent overlap obtained at three exposure stations H meters above-ground-level.



Figure 4: photogrammetry aircraft and equipment used.(F. Gervaix, 2010)

4.3. Aerial photogrammetry with drones:

The professional use of drones in many filed is becoming increasingly popular. Although many are content to simply expand their field of vision through the device. (LBPROFORT, 2020)



Figure 5:Photogrammetric drone. (LBPROFORT, 2020)

4.4. Terrestrial:

It is also called as close-range photogrammetry. Terrestrial photogrammetry is one of the important Branches of the science of photogrammetry. In this photogrammetry it deals with the photographs taken with cameras located on the surface of the earth either by handheld cameras or fixed to tripods or any other specially designed mounts. The principle of terrestrial photogrammetry is similar to that of plane table surveying. (Dvivedi, 2020)

When ground-based cameras are employed, the term terrestrial photogrammetry is used. This term has been historically applied to the system of surveying and mapping from photographs taken at ground stations. Terrestrial photogrammetry can be further classified:

- As close-range photogrammetry if the camera-object distance is somewhere between 1 m to 100 m.
- As macrophotogrammetry if the camera-object distance is in the 0.10 to 0.01m range.
- As microphotogrammetry when the photos are exposed through a microscope. (Assoc. Prof. Dr. Dursun Z. SEKER)



Figure 6 :Camera mounted on tripods. (Bank, 2015)

5. Structure from Motion:

The SfM approach was initially developed by the computer vision community to obtain structural information and estimate camera position based on multiple images. The approach relies on pixel correspondence between images and, unlike older photogrammetry algorithms, no pre-calibration of the camera is necessary. To make the process easier, the surfaces of the imaging object should have distinct features, either natural (e.g. sharp edges, discoloration, bolts, or rails) or artificial targets. A minimum of 60% overlap between images is necessary, in both the longitudinal and transversal directions.(Popescu, 2019)

SfM is a photogrammetric technique that is based on both these principles: the binocular vision and the changing vision of an object that is moving or observed from a moving point . SfM is used for estimating 3D models from sequences of overlapping 2D images.

It gained popularity in recent years due to its ability to deal with sets of unordered and heterogeneous images without prior knowledge of the camera parameters .SfM differs from traditional photogrammetry mainly in three aspects: features can be automatically identified and matched in images at differing scales, viewing angles and orientations, which is of particular benefit when small unstable platforms are considered; the equations used in the algorithm can be solved without information of camera positions or ground control points, although both can be added and used and camera calibration can be automatically solved or refined during the process. SfM can thus automatically deliver photogrammetric models without requiring rigorous homogeneity in overlapping images, camera poses and calibrations.(Iglhaut, 2019)

5.1. Structure from motion Photogrammetry in Practice:

With photogrammetry being a passive technique, results are highly influenced by the input image data.

SfM photogrammetry, employing an automated process to identify and match features by computer vision, is fundamentally dependent on image quality. Sensors, settings and acquisition designs should be considered with great care.

In every circumstance, the camera settings need to be considered to ensure optimal image data is acquired given a set of constraints, namely those from the environment (lighting conditions), the platform (UAV, pole, tripod or handheld) and the camera and lens combination (the exposure triangle, focal length, sensor size). Acquiring high-quality image data has been discussed in O'Connor et al. and Mosbrucker et al., with key rules of thumb including keeping the motion of the camera to a minimum, and increasing ISO (the sensor's sensitivity) to account for potential underexposure. (Iglhaut, 2019)

To apply SfM photogrammetry, important aspects to a successful survey are as follows: the scene is covered with overlapping images from multiple locations and angles (high overlap to increase redundancy and multiple viewing angles of the same object to reduce occlusions and systematic errors), any feature to be reconstructed should be visible in at least three images (five or six images for dense vegetation) and the angular divergence between neighboring images between should not exceed 10–20°, the scenes sufficiently illuminated (constant lighting is preferable, e.g. overcast or cloud-free conditions) and object of interest is fixed (preferably no movement from branches in wind). (Iglhaut, 2019)

6. PHOTOGRAMMETRY PRODUCES:

There are many products of photogrammetry; the following are the main of them:

- Obtaining the coordinates of real world points on objects
- Maps or plans
- Topographic maps
- Orthorectified Imagery
- Digital Terrain Models (DTMs)

Without contacting the surface to be measured, and at a predetermined accuracy, Accuracy is mainly determined by the scale of the photograph. (Seker)

7. Fields of photogrammetry application:

Terrestrial photos were found especially useful for mapping rugged terrain which was difficult to map by conventional field-surveying methods. Although it was known that topographic mapping could be done more conveniently using aerial photos, no practical method was available for taking aerial photographs until the airplane was invented. Following the invention of the airplane, emphasis in topographic mapping shifted from terrestrial to aerial methods. Terrestrial photogrammetry is still used in topographic mapping, but its application is usually limited to small areas and special situations such as deep gorges or rugged mountains that are difficult to map from aerial photography. Other topographic applications of terrestrial photogrammetry are in mapping construction sites, areas of excavation; borrow pits, material stockpiles, etc. Through the years terrestrial photogrammetry has continued to gain prominence in numerous Diversified non topographic applications. Examples of non topographic applications occur in such areas as aircraft manufacture, shipbuilding, telecommunications, robotics, forestry, archaeology, anthropology, architecture, geology, engineering, mining, nuclear industry, criminology, oceanography, medicine, dentistry, and many more. In the field of medicine, X-ray photogrammetry has been utilized advantageously for measuring sizes and shapes of body parts, recording tumor growth, studying the development of fetuses, locating foreign objects within the body, etc.(Wolf, 2014)

8. The principle of photogrammetry:

Photogrammetry is the science and technology of obtaining spatial measurements and other geometrically reliable derived products from photographs.

Photogrammetric analysis procedures can range from:

Obtaining approximate distances, areas, and elevation using hardcopy photographic products with unsophisticated equipments Geometric concepts to generating precise digital elevation models (DEMs), orthophotos, and thematic GIS data. (Sijmos)

- Assumes the camera produces a perfect central projection,
- There must be no deviation of light rays passing through the lens of the camera ,
- The image medium at the focal plane of the camera must be a rigid, planar surface,

CHAPTER 1: BASIC CONCEPT OF PHOTOGRAMMETRY

- The mathematical relationship between the object and the image is known as the principle of collinearity,
- The principle of collinearity embraces the six degrees of freedom of the camera: three translations and three rotations,
- Departures from the central projection can be modeled as systematic errors in the collinearity conditions.(Assoc.Prof. Dr.Dursun Z. SEKER)

8.1. What is the difference between a photo and map?

The big difference between a photograph and a map is that a map represents a vertical “plan” of a region, while a photograph presents a realistic image.

a photo is a picture taken by a camera, digital camera, or Smartphone that is capable of producing a hard copy or digital copy. (Hope, 2020)

MAP:

- Orthogonal projection.
- Uniform scale.
- Terrain relief without distortion (contour lines).
- All objects are represented also the non visible.
- An abstract representation.
- Representation geometrically correct.
- Elements appear displaced in its real position and in different shapes, due to the generalization process.

Photograph:

- Central perspective projection.
- Variable scales.
- Relief displacement in the image.
- Only objects that are visible.
- Is a real representation of the earth surface, no legend needed.
- Representation geometrically not correct.
- Objects appear displaced due to geometric distortions.

(Sijmos)

9. Image and photo Structure:

9.1 Raster:

Raster data are scanned from a photograph or graphic image or are collected by a multispectral scanner, thermal scanner, or radar. The image is composed of rows and columns of numerous picture elements, individually known as pixels. Each pixel has a defined size and specific incident flux value indicating a specific type of information. Radiation intensity is graded from 0 (no reflectance), which exhibits a dark image, to 255 (full reflectance), which exhibits a bright image.

Illustrates a set of raster data aligned in columns and rows of picture elements with a single pixel isplated as the hatched frame.(John G. Lyon, 2002)

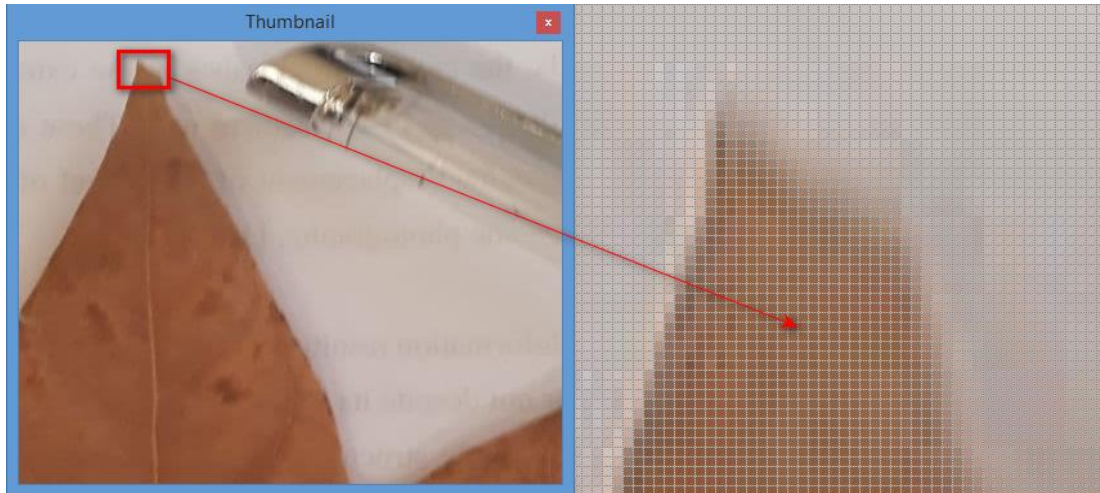


Figure 7:Pixel dimension by zooming in plant leaf.

9.2 pixel:

Is a contraction of the term picture element. Digital images are made up of small squares, just like a tile mosaic on a wall. Though a digital photograph looks smooth and continuous just like a regular photograph, it's actually composed of millions of tiny squares as shown below.(Sijmos)

9.3 Vector format:

Vector data are generated in planar or spatial Cartesian coordinate data strings, as illustrated in Figure below, forming points, lines, and polygons:

- A point is located by a single XY or XYZ coordinate set.
- Lines are composed of a series of points connected by vectors.
- A polygon is a succession of lines enclosing an area. .(John G. Lyon, 2002)

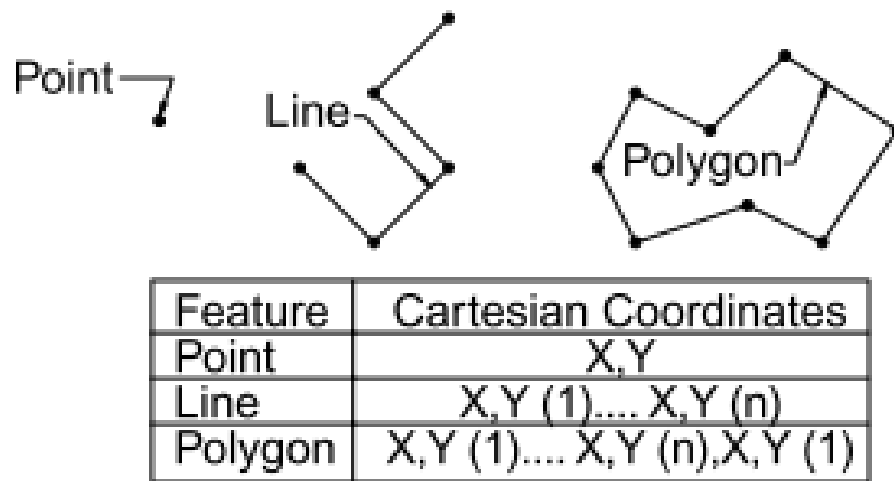


Figure 8 : Vector data format.(John G. Lyon, 2002)

9.4 Raster vs Vector :

	Vector Image	Raster Image
Resolution	Scalable	pixel, device dependent
File Size	Small	large, depends on exported resolution
Usage	<ul style="list-style-type: none"> · Fonts · Logos · Coin designs · laser engravings · T-shirts · Patches · Digital printing (e.g., business cards, billboards) · Lower thirds for video · 2D or 3D computer animation 	<ul style="list-style-type: none"> · Photography · Print Materials
File Formats	<ul style="list-style-type: none"> · EPS · SVG · AI 	<ul style="list-style-type: none"> · BMP · GIF · JPG · PNG · TIFF
Software	<ul style="list-style-type: none"> · Vector-based software (e.g., Adobe Illustrator) 	<ul style="list-style-type: none"> · Raster-based software (e.g., Adobe Photoshop) · Digital cameras · Scanned images

Table 1: comparison between Raster and Vector images.(PAVILION, 2020)

10. Depth and color in raster format:

Each pixel in a raster image stores color information. The amount of information within each pixel is called depth and is measured in bits. Pixels with more depth can store more information and therefore display more colors.

11. Definition of voxel:

Voxel art is basically like pixel art but in 3D. The word voxel is composed of volume and pixel. (Benitez., 2021)

The three-dimensional analogue of a pixel; a volume element representing some numerical quantity, such as the color, of a point in three-dimensional space, used in the visualization and analysis of three-dimensional data. (Benitez., 2021)

12. Definition of spatial resolution:

The spatial resolution meaning the more details can be observed.

The spatial resolution can be summarized by the size of the pixel on the ground (GSD for Ground Sampling Distance, ground sampling size, size of a pixel in object space), expressed in meters or more frequently in centimeters. This spatial resolution is not to be confused with the number of pixels of the CCD matrix. This is an equally important notion, but it is not enough on its own to understand a system. The race for the best spatial resolution is permanent. (Vd, 2010)

CHAPTER 2:
SHOOTING PARAMETERS

1. Introduction:

Photography is the art of capturing light with a camera, usually via a digital sensor or film, to create an image. With the right camera equipment, you can even photograph wavelengths of light invisible to the human eye, including UV, infrared, and radio.

This chapter describes the shooting parameters and how to configure the camera to obtain good results.

2. Photograph acquisition:

It is necessary to lay down the leaves on a white background to ensure that the photograph will have only two colors with high contrast. It is also mandatory that no other objects appear in the photograph, because they may be mistakenly included as part of leaf area. Finally, all photographs must be taken from the same position and height to ensure the scale factor will be the same for all photographs. In this study the height was kept constant at 40 cm from the lens of the camera to the object being photographed. (january, 2019)

3. Camera sensors dimensions:

A camera's sensor dictates the quality of the images it can produce the larger the sensor, the higher the image quality. Bigger image sensors have bigger pixels, which means better low-light performance, reduced noise, good dynamic range, and the ability to obtain more information. (CAPTURE THE ATLAS)

CHAPTER 2: SHOOTING PARAMETERS

	MEDIUM FORMAT	FULL-FRAME	APS-C	MICRO 4/3	1"	1/2.55"
PICTURE						
SENSOR SIZE	53.0 X 40.20 MM	35.00 X 24.00 MM	23.6 X 15.60 MM	17.00 X 13.00 MM	12.80 X 9.60 MM	6.17 X 4.55 MM
CROP FACTOR	0.64	1	1.52	2	2.7	5.62
CAMERA						

Figure 9 : Dimensions of camera sensors of various types.(CAPTURE THE ATLAS)

3.1 CAMERA SENSOR SIZE AND IMAGE QUALITY:

Differences in camera sensor size definitely impact image quality. But it's important to determine what we mean by "image quality." Are we talking about photo quality; how large of a print we can make? Sharpness? Resolution? Dynamic range? Depth of field?

As it turns out, even Smartphone sensor sizes are innately good enough to make prints indistinguishable from a pro-level body leaving aside dynamic range and shallow depth of field. Therefore, we need to dive deeper into more details apart from the generic "Image quality" of a determined camera sensor size.(CAPTURE THE ATLAS)

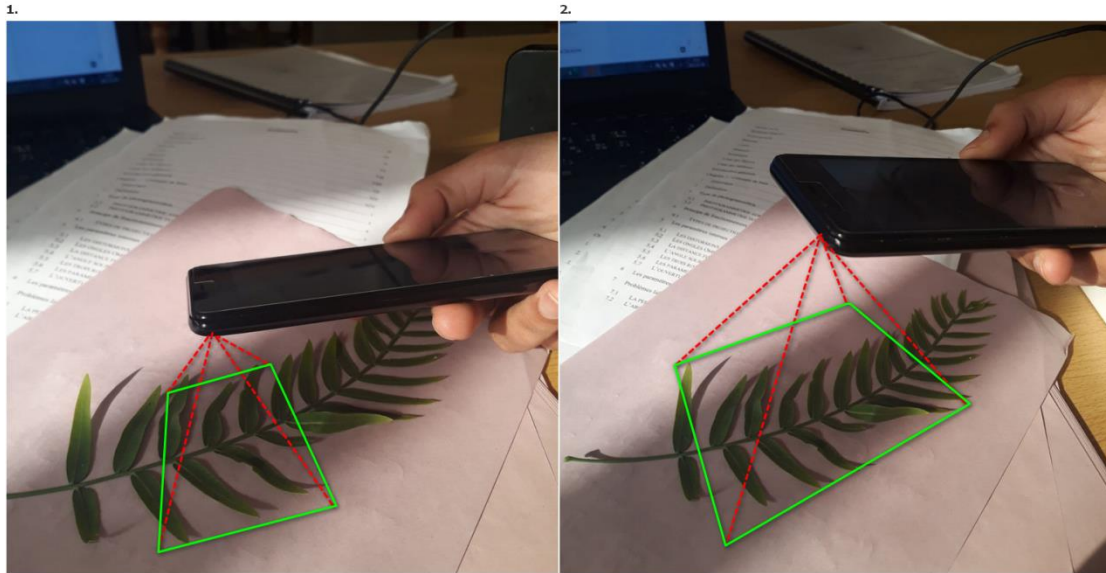


Figure 10 : frame explication.

4. Camera configuration:

The Exposure Triangle comprises aperture, shutter speed, and ISO. These three cameras and lens controls work together to regulate the amount of light that makes it to the light-sensitive surface (aperture and shutter speed) and the sensitivity of that surface. Not only do those three controls affect the light of a photograph, but they also have unique “side effects.” Aperture controls depth of field, shutter speed can blur or freeze action, and ISO can add or subtract film grain or digital noise from an image.(Vorenkamp, 2022)

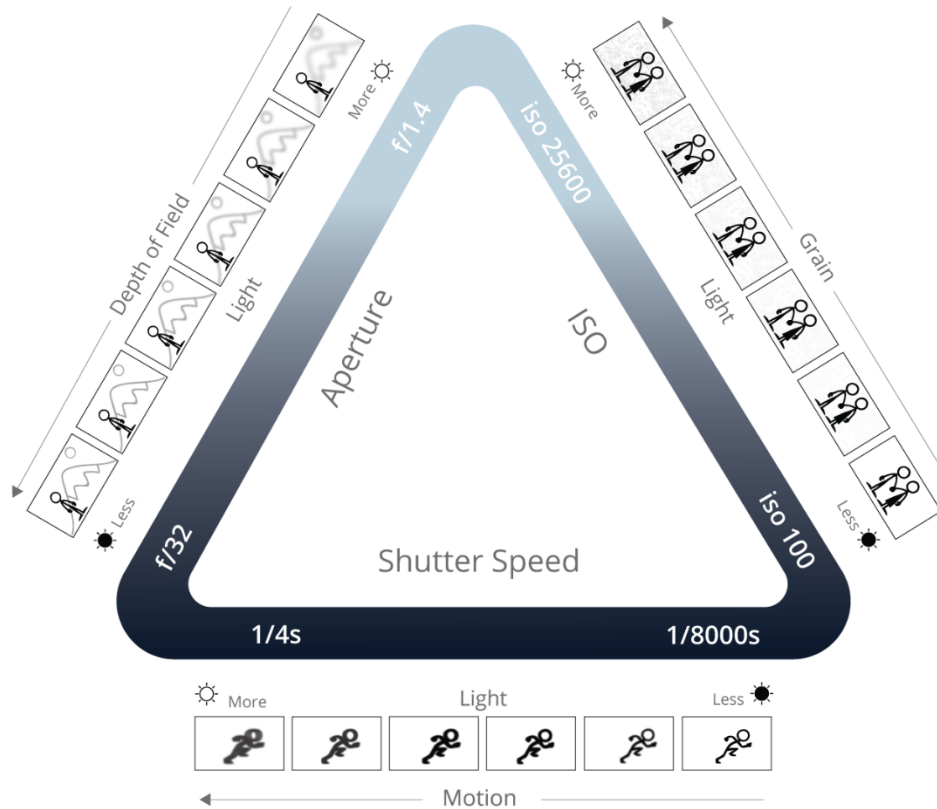


Figure 11 : The exposure triangle.(Vorenkamp, 2022)

5. Environment related parameters:

5.1 Wind:

Taking pictures in the wind is difficult because it makes things move, especially plants, leaves, and can make the camera unstable, producing blurry images.

5.2 Shadow:

Shadows / shading – Shadows and shading ultimately limit the quality of the images and require them to be over-exposed, which degrades the quality of the images. Hence, there is the need for sufficient lighting for all parts of the structure that is to be captured. This is particularly relevant for the abutments or areas on the soffit of the deck.(Chan, 2017)

5.3 Light:

A good lighting gives a good; accurate and harmonious picture.

Natural light photography uses the sun as a light source. The available light from the sun varies with the time of day. A sunny day provides full illumination, while an overcast day may afford texture and nuance to a photographer.

5.4. Background:

The background may affect the images, the many colors or movement in the background reduces the reflection of the true colors of the object and makes it difficult for the programmer to read them.

6. Inner parameters:

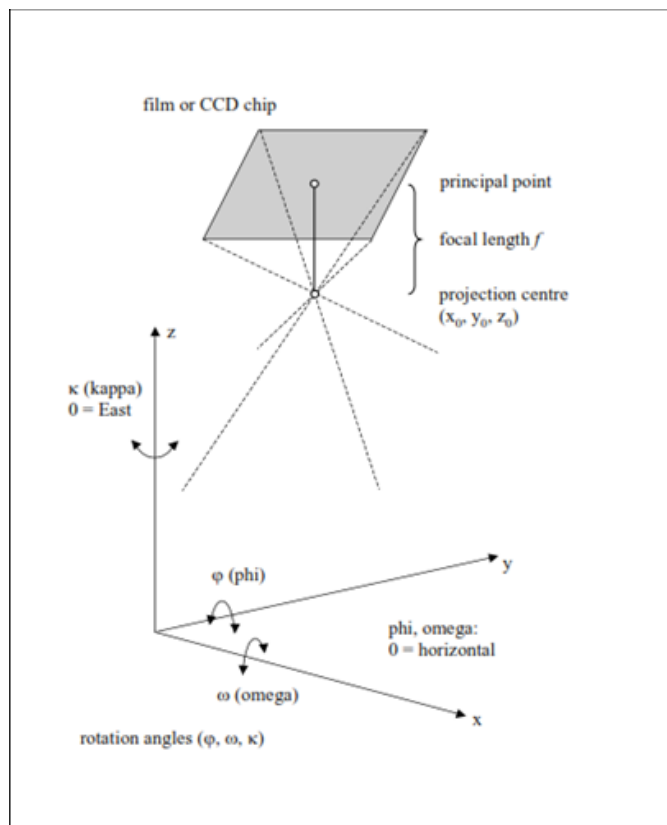


Figure 12: Focal length, projection centre and rotation angles.

6.1 The distortions:

Distortion is a geometric deformation of the various elements that make up the image. It is most often caused by the optical design of the lens. Even high-end models suffer more or less strongly from this phenomenon. Fortunately, distortion can be greatly reduced by understanding how it is generated and how it impacts the images.(valentin, 2022)

6.2 Barrel distortion:

Barrel distortion causes the outer lines of the frame to bend toward the interior of the image. It is often encountered with wide-angle lenses, due to the curved optical elements they incorporate.(valentin, 2022)

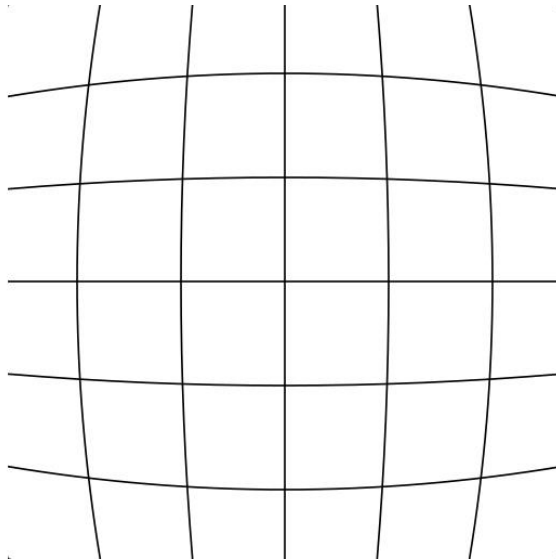


Figure 13 :Barrel distortion causes the outer lines of the frame to bend towards the inside of the image.(valentin, 2022)

6.3 Pincushion distortion:

Pincushion distortion produces the opposite effect to barrel distortion. The straight lines curve this time from the center of the image to the outside of the frame.(valentin, 2022)

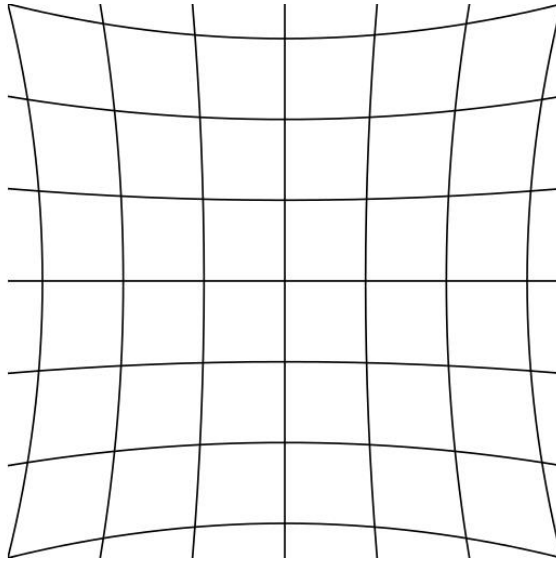


Figure 14: Pincushion distortion causes the internal lines of the image to bend outward from the frame. (valentin, 2022)

6.4 Mustache Distortion:

Mustache distortion is the most severe form of distortion that can affect a lens. It is characterized by the combination of barrel distortion and pincushion distortion. The image thus adopts lines curved inwards, but also towards the outside of the frame. (valentin, 2022)

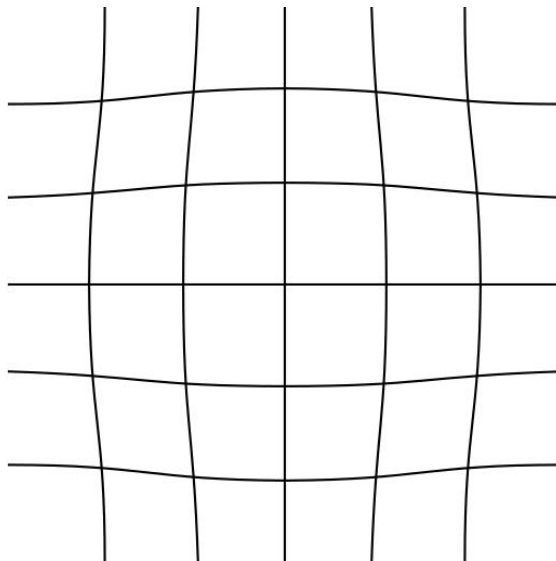


Figure 15: Mustache distortion creates inward and outward curvature of the frame. (valentin, 2022)

6.5 The orientation angles Omega, Phi, and Kappa:

Exterior orientation defines the position and angular orientation of the camera that captured an image. The variables defining the position and orientation of an image are referred to as the elements of exterior orientation. The elements of exterior orientation define the characteristics associated with an image at the time of exposure or capture.

The angular or rotational elements of exterior orientation describe the relationship between the ground space coordinate system (X, Y, and Z) and the image space coordinate system (x, y, and z). Three rotation angles are commonly used to define angular orientation. They are omega (ω), phi (ϕ), and kappa (κ). (Society, 1994)

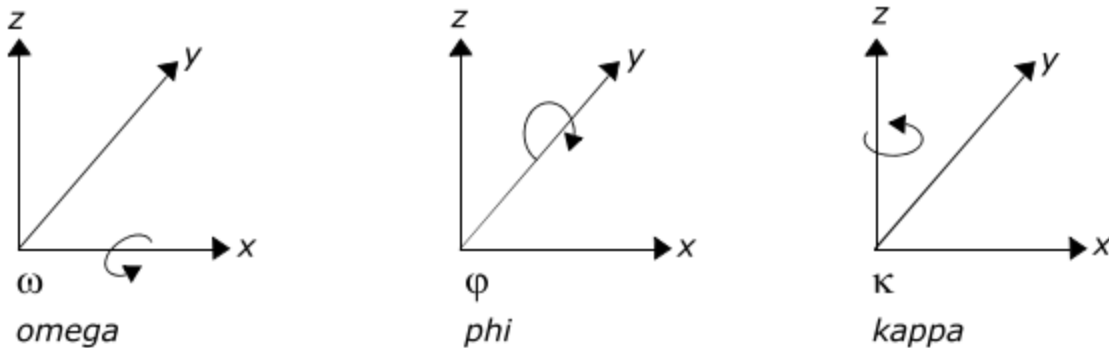


Figure 16 : Omega, Phi, and Kappa.(Society, 1994)

Omega is a rotation about the photographic x-axis, phi is a rotation about the photographic y-axis, and kappa is a rotation about the photographic z-axis. Rotations are defined as being positive if they are counterclockwise when viewed from the positive end of their respective axis.(Society, 1994)

6.6 Focal Length:

Imbedded within the rear lens elements is a point, measurable with optical calibration equipment, known as the rear nodal point. The focal length of a given camera is the finitely measured distance from the rear nodal point within the lens to the focal plane. Focal length is important to the planner in that it is a function of flight height determination. There are several common focal lengths available: narrow angle (12 in.), normal angle (8.25 in.), wide angle (6 in.), and super wide angle (3.5 in.). Image analysis projects may utilize all of these various focal lengths, whereas photo mapping projects use 6 in. predominantly and 3.5 in. to a limited extent. (John G. Lyon, 2002)

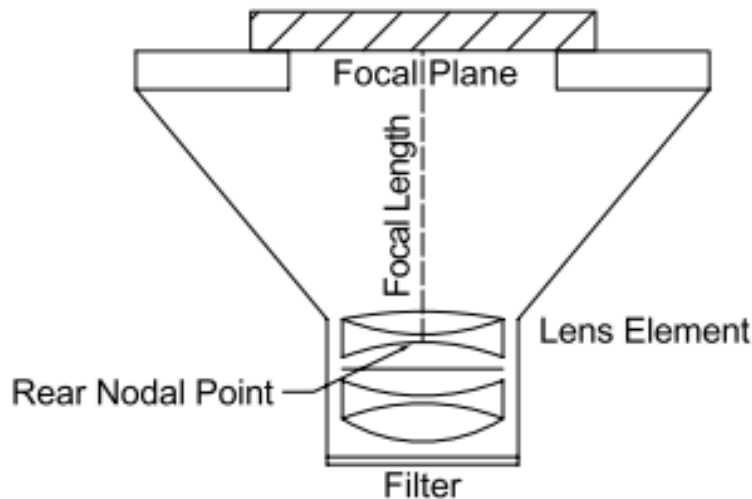


Figure 17 : Focal length of an aerial camera.(John G. Lyon, 2002)

6.7 Solid angle:

The angle subtended at the center of the sphere by the surface of the sphere is called solid angle. This is a three dimensional angle .suppose area of the surface which makes a cone on the center (O)of the sphere is “S” and the radius of sphere is r then solid angle is defined as S/r^2 and represented as Ω The unit of solid angle is Steradian.(Weisstein)

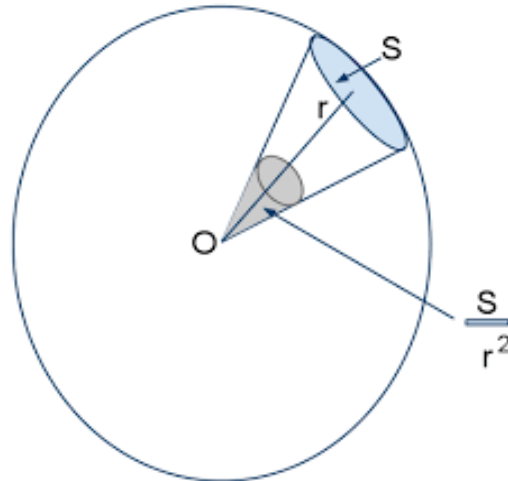


Figure 18 : Solid angle.(Weisstein)

6.8 The three camera rotations:

Horizontal rotation: Named panning; consists in turning the camera from left to right or from right to left without moving the tripod. While if by moving the head quickly we can assimilate visual information, it is not on the screen. If it is too fast, this movement does not give the viewer enough time to assimilate the information. This is why you have to be slow enough when performing such a movement.

Vertical rotation: consists of pointing the camera from top to bottom or from bottom to top without moving the tripod. Again, it is best to perform this movement slowly so that the human brain can assimilate the information.

Rotation around the optical axis: This is the rotation around the remaining third axis.

7. External parameters:

The external camera parameters are different for each image. They are given by:

- The position of the camera projection center in the world coordinate system.
- The rotation matrix that defines the camera orientation with angles.

8. Shooting rules for photogrammetric restitution:

8.1 Overlap:

The methodology for which the images are collected – In order to produce photogrammetric modeling to a high degree of detail and accuracy, there needs to be a minimum of 50% overlap

between each subsequent image. These should be captured in such a way that the images are taken successively, in order to create greater ease of processing and alignment of the images.(Chan, 2017)

8.2 Sharpness:

In photogrammetry, a good image is an image that is not blurred, that is well exposed, and sharp. The use of automatic settings (specifically, automatic aperture, shutter speed and ISO) and automatic focus guarantees, on average, a good image quality. The various settings of each photograph are now well managed by the latest photogrammetric software.(Bauwens, 2017)

8.3 Consistency:

Furthermore, weather conditions out-door should be with minimal shadows and consistent light. A fixed focal length is recommended. The aperture should ensure good depth of field, recommended f8 or f11 if the shooting is at a close distance from the object. The film speed should not be too high as it can add artifacts to the pictures. ISO 100 is appropriate for a bright day while a higher number is needed if it is in low-light conditions. Next thing is the shutter speed which should be at least 1/200th of a second. (Gärdin, 2018)

Before shooting the subject, planning is necessary. For large projects (area greater than 5 m²), one chooses portions that represent most information in each capture. If there are not enough natural marks, targets like monuments are needed as reference points. Also, high-accuracy GPS is useful to establish the coordinates of the control points and the camera. A camera calibration can be done by taking at least two additional photos turned 90 degrees to the previous photos and other two turned 270 degrees at the beginning or end of the stereo shots. This eliminates distortions from the lens with respect to the sensor location. Also, a control for the user defined coordinate system is needed and can be done by adding an object of known dimension, visible in at least two stereo models. (Gärdin, 2018).

CHAPTER3: PHOTOGRAMMETRY
RESTITUTION

1. Definition of restitution:

The photogrammetric restitution systematically combines two images that have been photographed from different points. Each eye observes another image and, if the images are well oriented in the device, a three-dimensional view is obtained. This facilitates the identification and interpretation of certain objects (buildings, for example).

For the actual survey, a floating mark is used which is brought into contact with the point to be measured. The device transforms the x,y coordinates of the point appearing on the photo on the left and on the right into the xyz coordinates of the point which would be measured in three dimensions on the ground. Finally, these xyz coordinates are recorded and processed using graphics software. (La photogrammétrie à l'IGN)

2. PHOTOGRAMMETRIC MODELING:

2.1 Previous Applications:

Advances in the development of images and producing 3-D scene reconstructions have enabled 3-D models to be produced that have a high degree of relative dimensional accuracy. Photogrammetric models utilize the principle of triangulation to identify key points between two different images and triangulate these back to a single viewpoint. This process is able to be undertaken where there is sufficient overlap between images that are taken and hence, sufficient key points of interest. (Chan, 2017)

The predominant application of photogrammetric modeling has been for measuring / quantifying elements, with a large focus on buildings. This involves using photogrammetric modeling as a means of producing a point cloud image for such purposes as:

- Measuring the deflection of individual components and monitoring, including for retaining wall structures through creating a point of reference
- Forming a baseline for a dimensional survey of structures in lieu of detailed design / as-constructed drawings
- Developing into solid models for such applications as virtual reality

However, this process may be taken further, by converting the point cloud model to a 3-D mesh and projecting the original images that were captured (and post processed to produce the model) onto the mesh, with a computing algorithm used to select the relevant images. (Chan, 2017)

3. Geometry of photo pairs:

Suppose we have two images, taken at the same time and from different viewpoints. Such setting is referred to as stereo. The principle behind stereo-based 3D reconstruction is simple: given the two projections of the same point in the world onto the two images, its 3D position is found as the intersection of the two projection rays.(Moons, 2009)

Image matching, digital image correlation (DIC), stereo correspondences problem: all refer to the class of non- contact techniques that utilize two or more digital images depicting (at least partly) the same scene. They deliver a full-field description of the shape, displacements and/or deformation of the object imaged, identifying corresponding image points. Also, the term “optical flow” is commonly used to describe pixel matching between images captured at different times, and is therefore used to address the image analysis performed in matching. More rigorously (and generally), the concept of optical flow was first introduced in psychology and physiology to describe the visual stimulus generated by the relative movement between the observer and the world, and later co-opted by image processing to indicate algorithms or techniques able to estimate the pattern of apparent motion of object or surfaces in a sequence of images.(Forlani, 2015)

3.1 Stereoscopic Vision:

Stereoscopic vision determines the distance to an object by intersecting two lines of sight. In the human vision system, the brain senses the parallax angle between the converging lines of sight and unconsciously associates the angle with a distance. Overlapping aerial photographs can be viewed stereoscopically with the aid of a stereoscope. The stereoscope forces the left eye to view the left photograph and the right eye to view the right photograph. Since the right photograph images the same terrain as the left photograph, but from a different exposure station, the brain perceives a parallax angle when the two images are fused into one. As the viewer scans the entire overlap area of the two photographs, a continuous stereo model of the ground surface can be seen. (Washington, 1996)

The stereo model can be measured in three dimensions, yielding the elevation and horizontal position of unknown points. The limitation that elevation cannot be determined in a single photograph solution is overcome by the use of stereophotography. (Washington, 1996)

a. Lens stereoscope: A lens or pocket stereoscope is a low-cost instrument that is very useful in the field as well as the office. It offers a fixed magnification, typically 2.5X. The lens stereoscope is useful for photo interpretation, control point design, and verification of mapped planimetric and topographic features.(Washington, 1996)

b. Mirror stereoscope: A mirror stereoscope can be used for the same functions as a lens, but is not appropriate for field use. The mirror stereoscope has a wider field of view at the nominal magnification ratio. Since photographs can be held fixed for stereo viewing under a mirror stereoscope, the instrument is useful for simple stereoscopic measurements.(Washington, 1996)

c. Floating mark: Stereoscopic measurements are possible if a floating mark is introduced in the viewing system. Identical half marks, such as a small filled circle or a small cross, are put in the field of view of each eye. As the stereo model surface is viewed, the two half marks are viewed against the photographed scene by each eye. If the half mark positions are properly adjusted, the brain will fuse their images into a single floating mark that appears in three-dimensional space relative to the stereo model. By moving the half marks parallel to the viewer's eye base, the floating mark can be adjusted until it is perceived to lie on the stereo- model surface. At this point, the two half marks are on the identical or conjugate image points of two different photographs. The horizontal position and elevation of the mark can be determined and plotted on a map. (Washington, 1996)

The importance of the floating mark is that all points in a stereo model can be measured and mapped. Thus, indistinct points, such as hilltops, centers of road intersections, and contours can be mapped in three dimensions from the stereomodel.(Washington, 1996)

3.2 Two-view geometry:

From a single image of an unknown scene, no 3D measurements can be derived, because the third dimension (the depth along the ray) is lost during projection. The photogrammetric

measurement principle is to acquire multiple images from different viewpoints and measure corresponding points, meaning image points which are the projections of the same physical object point. From correspondences one can reconstruct the 3D coordinates via triangulation. The minimal case of two views forms the nucleus for this approach. (Schindler, 2015)

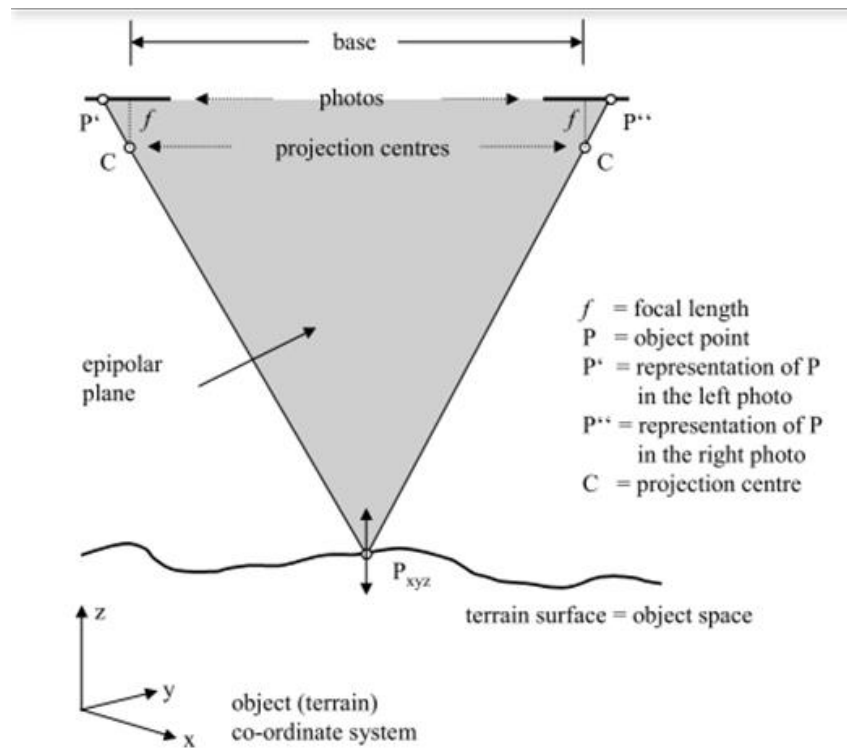


Figure 19:Geometry in an oriented stereo model.(Balenović, 2011)

4. Calibration:

Camera calibration is the process of finding the true parameters of the camera that took your photographs. Some of these parameters are focal length, format size, principal point, and lens distortion.

Camera Calibration is also important for any close range Photogrammetry work. It is a process of determining the characteristics of a camera so it can be used as a measurement device. These characteristics specifications of camera are focal length of the lens (f), CCD format size of a digital camera ,thePrincipal points , and Lens distortions . This description needs to be created only once and is used for every subsequent project done with this camera. (Pal Singh, 2013)

The purpose of camera calibration is to determine the geometric model of the camera described by the interior orientation parameters(Thomas, 2013):

- Spatial location of the perspective center in the image coordinate system;
- Principal distance and image coordinates of the principal point;
- Parameters describing image errors: distortion and sensor corrections.

In other words, the calibration consists in the extraction and the quantification of the errors of the distortion of the camera used. These errors result in the longitudinal, transverse and radial displacement of each pixel of the photo from its true position in relation to the scene photography.

Note that the deformation resulting from the distortion can be remarkable visually on some photographic or not despite its existing in all photography.

Three calibration methods can actually be distinguished. These are characterized by the reference object used and the time and place of calibration.

- Calibration in the laboratory;
- Calibration of the test field;
- Self-calibration.

To overcome this problem which not only hinders the visual aspect but presents a major obstacle for the essential bit of photogrammetry, namely the geometric measurements on the image? We need a whole procedure called calibration before we start taking photographs.

It is therefore the preparation of a scene called a canvas which will serve as a geometric reference for the said operation.

Indeed, the canvas is nothing but printed paper containing a point grid (100 points as shown in the figure below, necessarily equidistant.

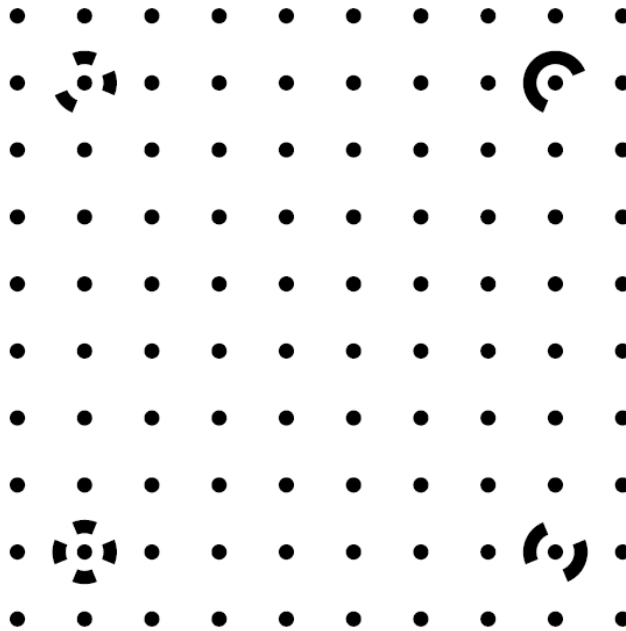


Figure 20 : Photomodeler calibration grid.

This canvas also contains marking points with different symbolization. Practically we must photograph the canvas from these four sides.

On each side we will take 03 photos according to the orientations of the camera, namely camera in ordinary position, in 90° green the left side and in end in 90° towards the right side. In total, we will take 12 photos on the canvas.

The physical size and type of target to be used depends on the chosen imaging setup (camera stations and viewing directions, image scale, resolution) and lighting (light source, direction of illumination).

The difference in the symbol of the marking points will help the program to easily detect the camera positions according to the side and according to its orientation.

The software calculates the transverse, longitudinal and radial displacement for each point and then generates a calibration report specifically for the type of camera used.

This file will be used as a calculation support for each operation performed by the cameras calibrate. That's to say that we are not obliged to calibrate our camera before each photogrammetry operation.

The software puts the relationship between the photos and the saved calibration parameters through the metadata of the images to insert because they necessarily contain in their properties the type of cameras used. See figure below.

Some Photogrammetric software can detect the calibration parameters by a connection to servers which include a database of certain types of cameras already calibrated.

The size of the canvas and relative to the size of the scene envisaged to be photographed. In other words, an A4 size canvas is more than enough for photogrammetry of centimeter-sized objects or a little larger than an A4 sheet.

In other words; the larger the objects; you have to highlight the calibration parameters that are adequate for your size. This presents a tedious task and highlights the use of specific cameras called photogrammetric cameras.

Photogrammetric cameras are cameras whose calibration parameters are known and provided by the manufacturer. Unfortunately, it remains expensive given their specific use.

One of the remarkable things in this type of cameras and that they have a grid of crosses engraved on their ocular devices, these crosses will be visible in all the photos taken of course.

5. Orthophotography:

Orthophotographs are photographs constructed from vertical or near-vertical aerial photographs, such that the effects of central perspective, relief displacement, and tilt are (practically) removed. The resulting orthophotograph is an orthographic project. (Washington, 1996)

Orthophotos and orthophotomaps are widely used for general planning purposes. The complete and accurate display of all features in a project area is an ideal medium for demonstrating terrain features to laypersons. Proposed designs of engineering projects can be super- imposed on the orthophoto map for a vivid understanding of work to be accomplished. Many factors must be considered before deciding on a photomap product instead of a topographical map product. The

intended use of the product needs to be classified exactly, together with the accuracy required and whether height information is required or not. (Washington, 1996)

5.1 Principle of orthophotography:

The working principle of orthophotography is based on photographs taken from the air, generally by means of a drone or an Unmanned Aerial Vehicle (UAV). These photographs are geometrically corrected to represent a uniform scale to facilitate the possibility of measuring aspects such as distances between buildings, streets and other parameters that may be relevant for the specific application. (Center line design, 2021)

6. Point Cloud concept (3D):

The point cloud is the raw product of LiDAR. Its essential characteristics are:

- The points follow the distribution of the system: it can therefore be parameterized and predicted (canvas). It is generally sought to describe a mesh grid as square as possible.
- Stitches generally do not fall on pattern/break lines, even at very high stitch density. Certain particular situations make it possible to detect lines of structures, but there is still a large part of extrapolation.

The information contained in the point cloud is:

- (X, Y, Z) for each point, but not only.
- WGS 84 coordinates (GPS), to be transformed into usual coordinates.
- Separate dots in multiple echoes, one pulse can produce up to five echoes.
- Links between multiple echoes, “first of many”, “intermediate” characteristic, etc.
- Echo intensity, generally expressed in one byte (0 – 255).

Warning: a point cloud is not a DSM! (Vd, 2010)

7. Triangular Irregular Network :

This model is a file which, used in specific software, gives a description of the relief in a given area. It can be established from photogrammetric measurements of points and lines, from

digitized contour lines, from field surveys or using laser measurements from an aircraft (or possibly radar).

Points: a Z height for each position (x,y) Restitution:

- TIN Model /Triangulated Irregular Network = irregular triangulated network (points connected by triangles). (La photogrammétrie à l'IGN)

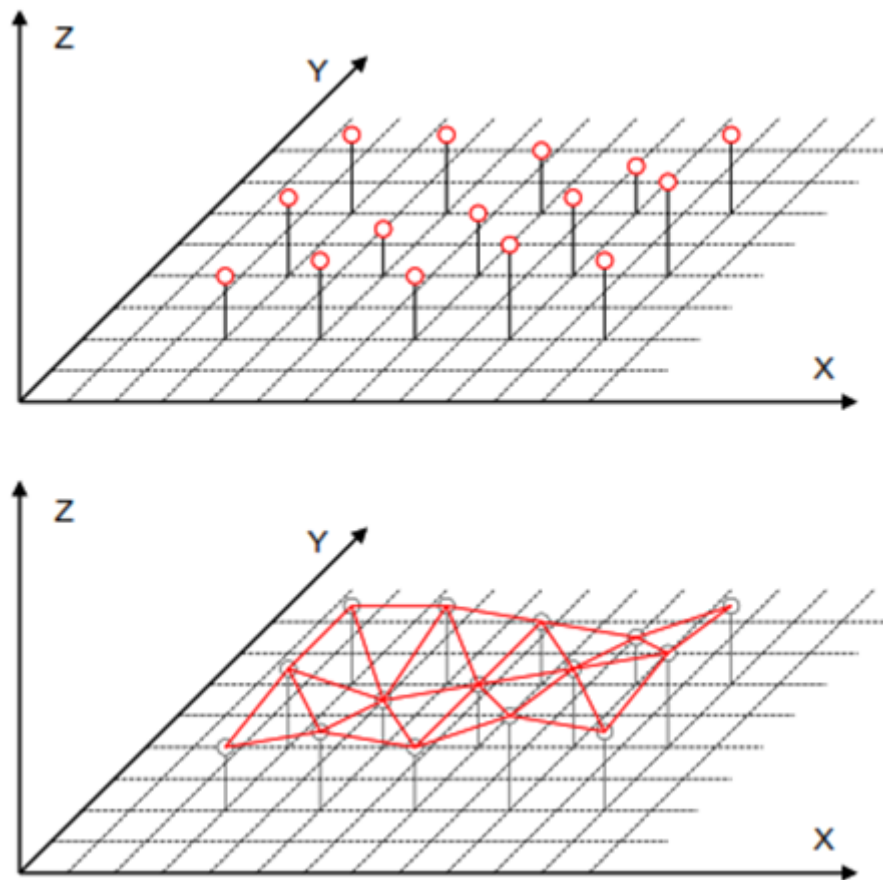


Figure 21 : Triangle mesh from a 3D point cloud. (Thomas, 2013)

8. Treatment steps:

The treatment phase is divided into two parts, a single image section meaning two-dimensional treatment, and a multi-image section meaning three-dimensional treatment

The steps are detailed in the application chapter.

9. Using GPS to identify camera position:

The GPS (Global Positioning System) and the IMU (Inertial Measurement Unit) have become essential elements of photogrammetric missions, both for film cameras and for cameras and other digital sensors.

The GPS intervenes at three levels:

- help with navigation and real-time camera control
- precise determination of the centers of projection in post-processing
- precise determination of the support points on the ground in real time or post-processing.

The IMU operates at two levels:

- Real-time camera orientation control
- precise determination of external orientations in post-processing.

GPS can be used with or without IMU, while IMU requires GPS for operation.(Ragheb, 2011)

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1. Examples of new release in ecology using photogrammetry techniques:

- tree volume

Measurement of tree volume is based on elaboration of 3D model of a tree. The 3D model considers array of central axis points, attributed with diameters measured on images. Possibility of direct measurement of volume increment, particularly interesting element of forest management that is commonly assessed indirectly, is also considered. The idea evolved from interactive work of students from two faculties (forestry and mathematics) and is based on up-to-date experiences acquired on Forestry Photogrammetry Department at the Faculty of Forestry University of Zagreb, and on Photogrammetry Department at the Faculty of Geodesy University of Zagreb. The program was developed by using Borlan DELPHI program package and operates on Windows 95 operating system.(Barrett, 2012)



Figure 22 : tree photograph. (Barrett, 2012)

- Mapping of vegetation.

Here we demonstrate a new atmospheric remote sensing system that enables routine and inexpensive 3D aerial measurements of canopy structure and spectral features, with properties similar to those of LIDAR, but with RGB (red–green–blue) spectral attributes for each point,

enabling high-frequency observations during a season single growth. This "Ecosynth" methodology applies imaging "structure-of-

motion" computer vision algorithms to large sets of low-altitude, highly overlapping (b130 m) aerial images obtained using off-the-shelf digital cameras mounted on an inexpensive (US\$4,000) and lightweight (b2) kg), an amateur class unmanned aerial system (UAS). (Dandois, 2013)

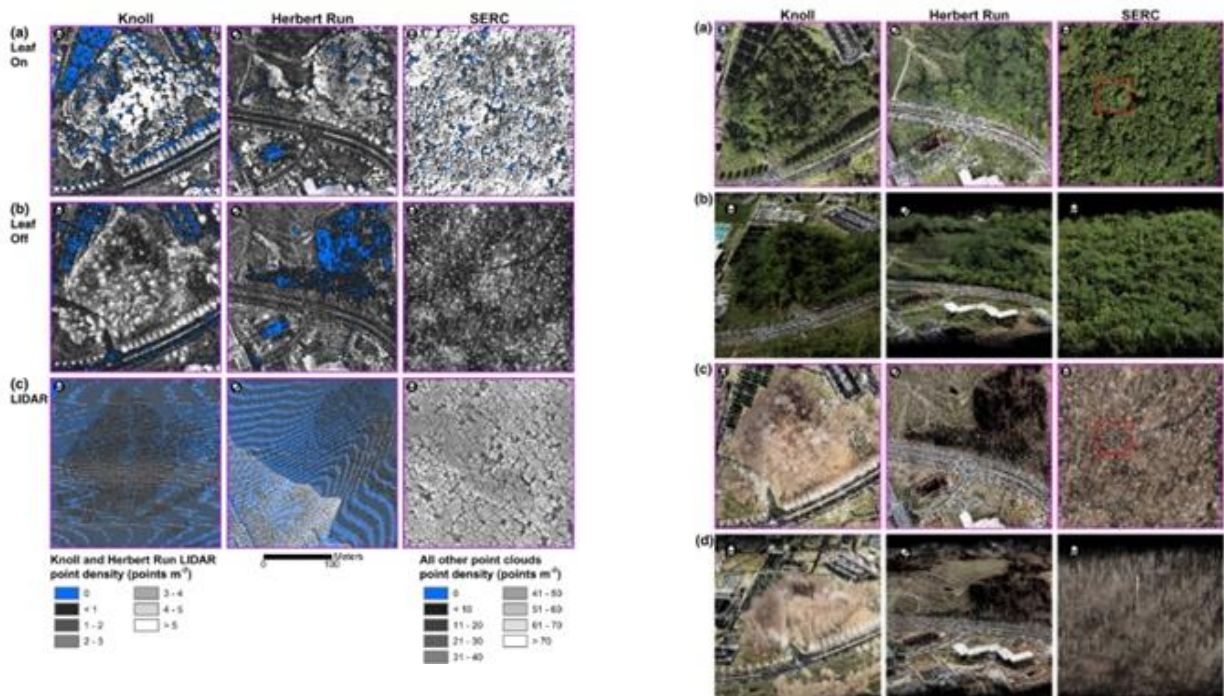


Figure 23: Point cloud density maps from Ecosynth 250 m × 250 m sites. (Dandois, 2013)

Geometric modeling of broad-leaf plants

Photogrammetry was used to obtain a model close to the truth by means of photography ;Realistic rendering of plants has practical value for digital plant research, where plant leaves play an important role in the construction of virtual plants. The fact is that plant leaves are diversified in structure and geometric shape, which usually makes the realistic rendering of plants leaves very difficult. Many existed modeling and simulation methods have been focused on the organs of plant models, in which leaves are modeled using simple 2D polygons and the thickness of leaves are neglected. Such models are far from realistic. This paper proposes a new modeling method of broad-leaf plants, based on the theory of reverse engineering. A leaf model is

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established by acquiring data on the characteristic points from the leaf of the sample part and combining the advantages of Open Gland NURBS functions. (Wang, 2013)

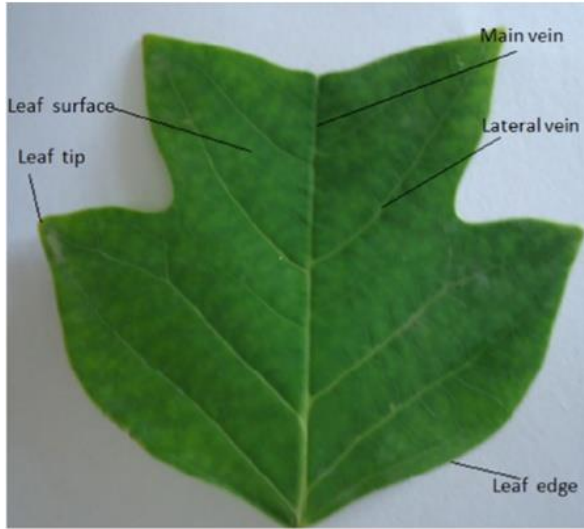


Figure 24 : Structure of the leaf(Wang, 2013)

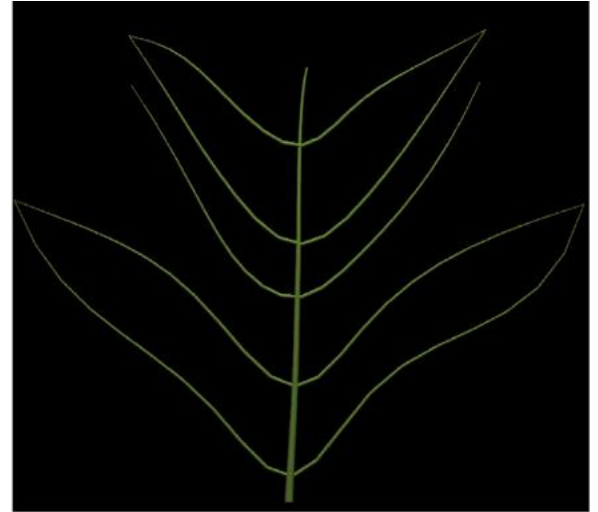


Figure 25 : Leaf veins generated(Wang, 2013)

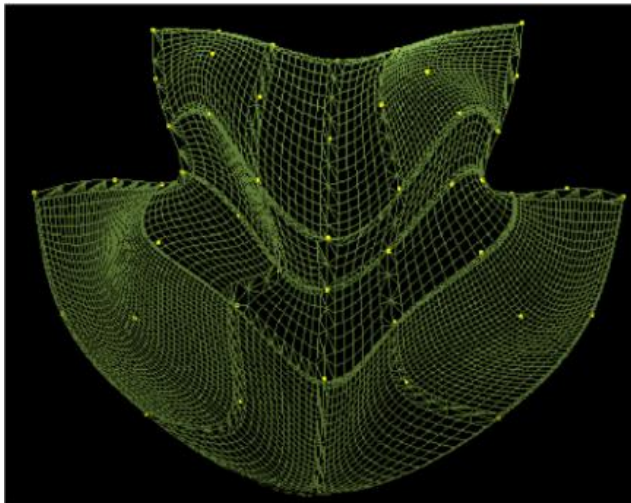


Figure 26: leaf surface mesh.(Wang, 2013)

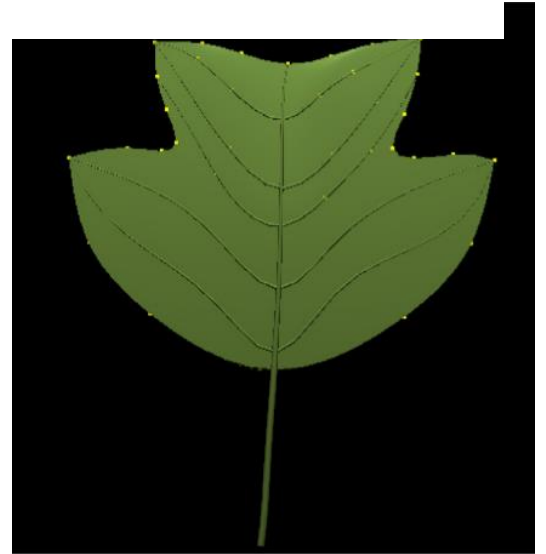


Figure 27 :Synthetic leaf model(Wang, 2013)

Modelization of irregularly shaped tree trunks

Trees of irregular shapes including trees with trusses, flutes, or deciduous roots are frequent in tropical forests. The lack of an international standard for measuring the diameter of such trees leads to a high degree of uncertainty in estimating biomass and tree growth and in monitoring the carbon budget. In this study, they developed a new method based on the ground-based close-range photogrammetry to measure and model irregular stems. This approach is cheap and easy to apply in the field because it only requires a camera and a graduated rod. They validated the approach with destructive cross-sectional measurements along the trunk of three supported trees. To illustrate the broader benefit of this method, they extended the validated approach to an additional 43 trees belonging to two species: *Celtis Moldbraedii* (Ulmaceae) and *En tandophragmacylindricum* (Meliaceae). Based on the 3D models, they calculated the shape indices of each tree, and analyzed the stem morphology of both species. Finally, they analyzed some standard predictors to estimate aboveground biomass. (Bauwens, 2017)

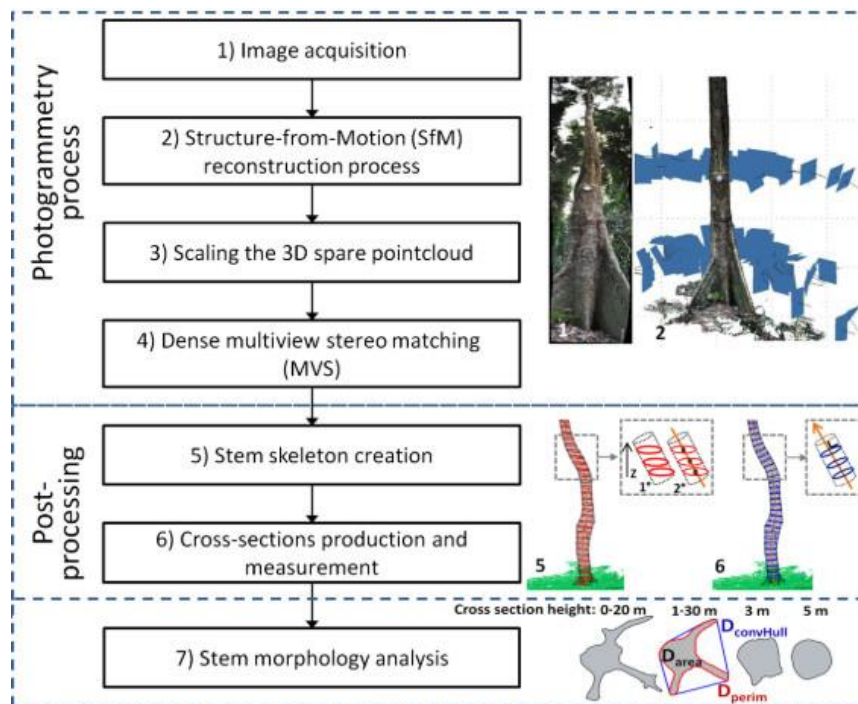


Figure 28 : treatment steps for modelization of irregularly shaped tree trunks.
(Bauwens, 2017)

Street Tree mapping and measurements

In this study, a group of researchers compared site and stem diameter measurements derived from both geospatial-specific SfM mobile photogrammetry and static SfM data. The results from both methods were then compared to field-derived DBH measurements and site measurements. While conducting this study, the aim was to demonstrate the capabilities of portable SfM photogrammetry for the inventory of street trees in urban conditions. (Koeser Roberts, 2019)

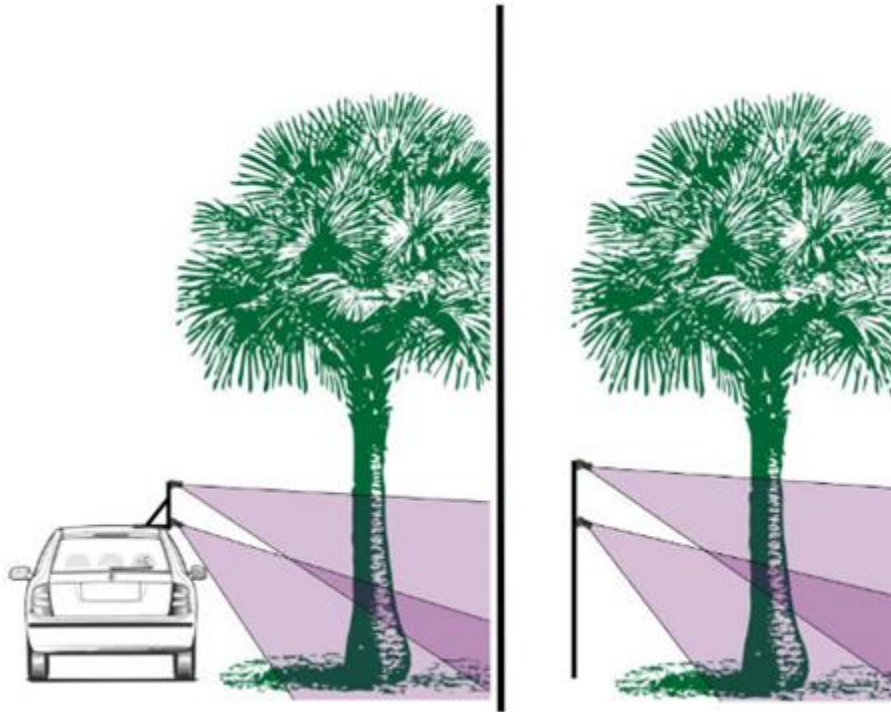


Figure 29 : Schematic of the experimental stereoscopic mobile camera set-up. Representation of image capture with a mobile vehicle (left) and stationary image capture with a surveying pole (right).(Koeser Roberts, 2019)

Forest Inventory Data

In 2019; a group of scientists applied photogrammetry to four forest plots located in Austria and Slovakia, two in each country, selected to cover a wide range of conditions such as terrain slope, shrub vegetation, tree density, age and species. For each forest plot, reference data for forest parameters were acquired by performing field surveys and TLS measurements nearly

simultaneously with the photogrammetric acquisitions. TLS data was also used to estimate the accuracy of the imaging ground elevation.

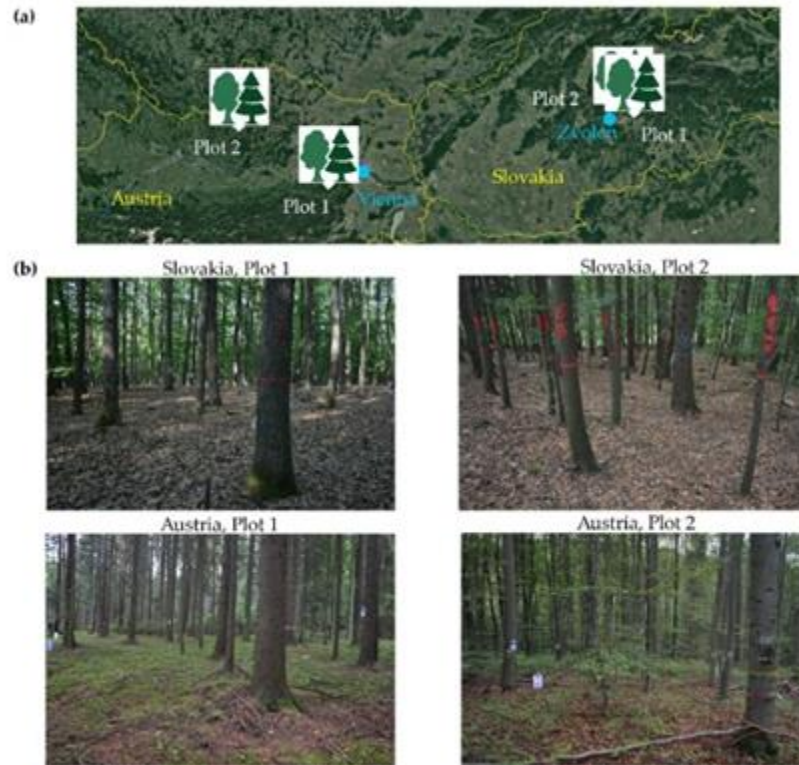


Figure 30 : (a)Overview of the forest plot locations and (b) for each forest plot, a photo illustrating the forest at the time of the survey. (Iglhaut, 2019)

The overall objective of this study is to assess the competitiveness of Ground Photogrammetry based on Structure from Motion (SfM) and matching of dense images to derive tree positions, diameters at chest height, and forest cut trunk curves by means of a consumer level camera.

This study demonstrates that using the approved image capture method, SfM photogrammetry is an accurate solution to support forest inventory for estimating the number and location of trees. (Iglhaut, 2019)

Plant phenotyping:

One of the uses of photogrammetry currently is to study the phenotype to abandon the traditional slow methods High-throughput phenotyping is using computer algorithms and imaging systems to acquire phenotype characteristics for a large number of plants/crops in a relative short period of time.(Price)



Figure 31 : traditional phenotyping vs. photogrammetric phenotyping.(Price)

Leaf area index

Estimation of leaf area index has many benefits, including helping to know the required amount of pesticides for the land, and its calculation has become easy by relying on photogrammetry, LAI. It is the ratio of the total surface area of the top leaf of the crop divided by the surface area of the land on which the crop grows. In this work, a predictive and experimental model was generated regarding the non-destructive estimation of LAI. This model is based on the size and density of tomato plants, i.e. $LAI = \text{function}(\text{density}, \text{volume})$. The size was first obtained by close-range photometry (“real” size) which was later used to select a manual method of tomato bush size measurement that offered a better fit to the “real” size. Plant densities were derived by digital image analysis. Finally, the 'true' LAI was measured in a destructive manner using a leaf area scale. The experimental LAI model provided a coefficient of determination close to 83%. (Aguilar, 2010)

leaf area estimation in maize under different plant growth stages

A continuous determination of leaf area (LA) could help to adjust fertilization, pest management and harvesting. (David Reiser*1)

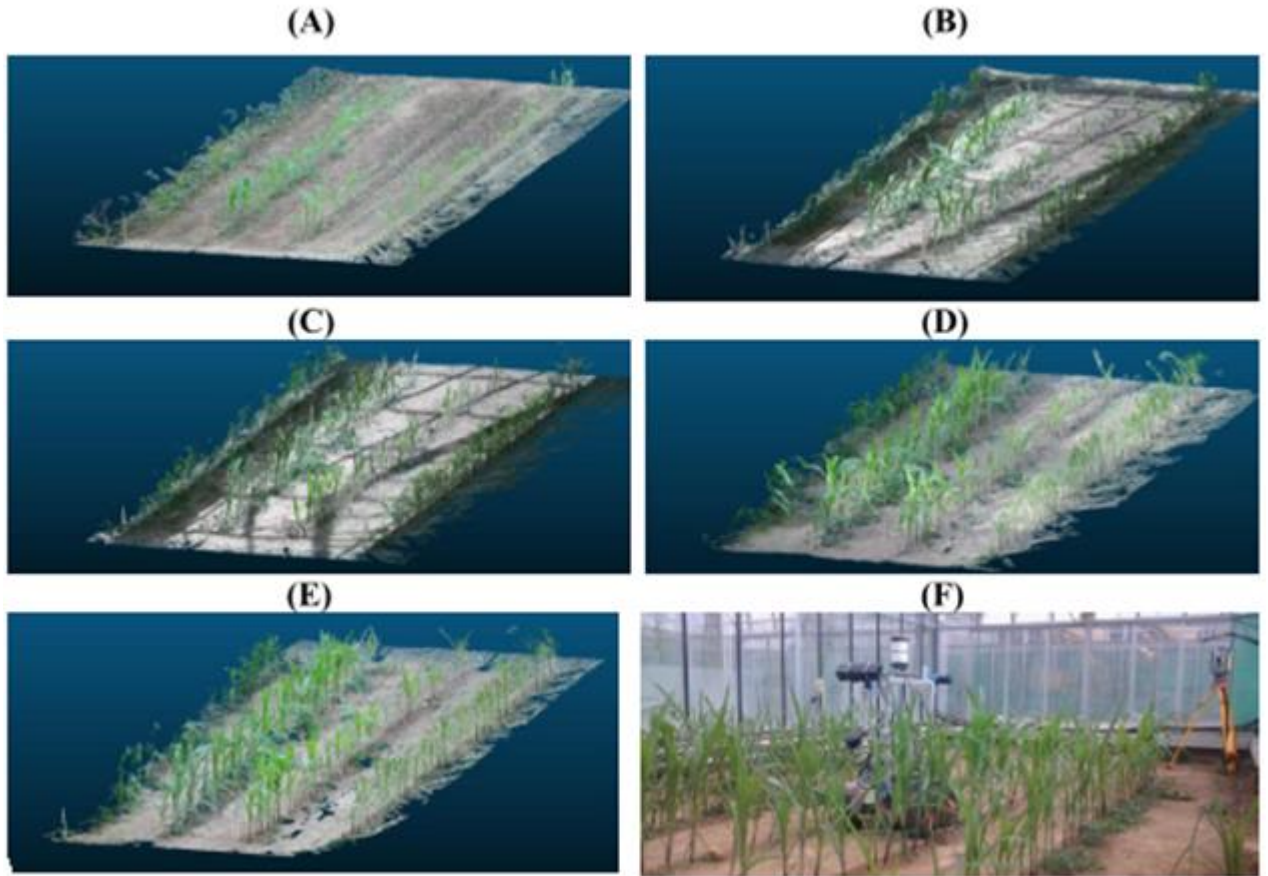


Figure 32 : Visualization of the point clouds generated by pix4D photogrammetry software 40 (A), 49(B), 54(C),62(D) and 69(E) days after seeding.(F) the robot with camera mounting and total station 69 days after seeding.(David Reiser*1)

In this research, a non-destructive measuring method for LA estimation was correlated with results based on the analysis of dense point clouds, gained by photogrammetry. Maize rows were planted and were analyzed weekly over one month, resulting in five different growth stages. For determining the LA out of the resulting point clouds, the plant points were separated from ground points. Afterwards, a point distance filter was applied and the resulting points were counted. The

results showed a high correlation between LA and the filtered point cloud number. The filter distance could be set to a polynomial correlation dependent on the growth stage. (David Reiser*1)

Actual method of measuring leaf surface:

Traditional method still applied to calculate the surface of Leaf plant.

Measuring leaf area using Otsu segmentation:

This study aims to measure the leaf area using image processing techniques that automatically count the grid method to measure the area of a sheet, the otsu method is first required .Later, reduce noise by an average filter and followed by object recognition ,boundary tracking and area filling techniques. (Muhammad haqqiman radzali, 2016)

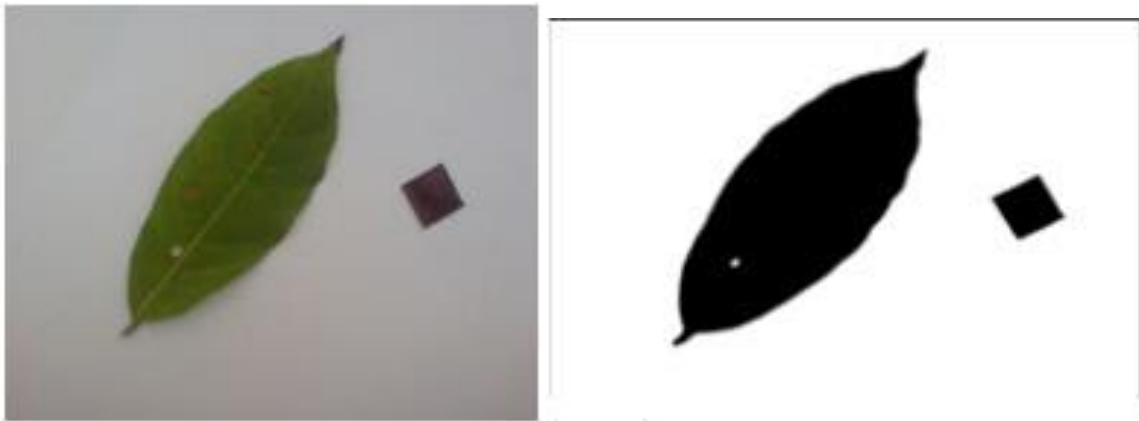


Figure 33 :RGB image(Muhammad haqqiman radzali, 2016)**Figure 34 :Binary image**(Muhammad haqqiman radzali, 2016)

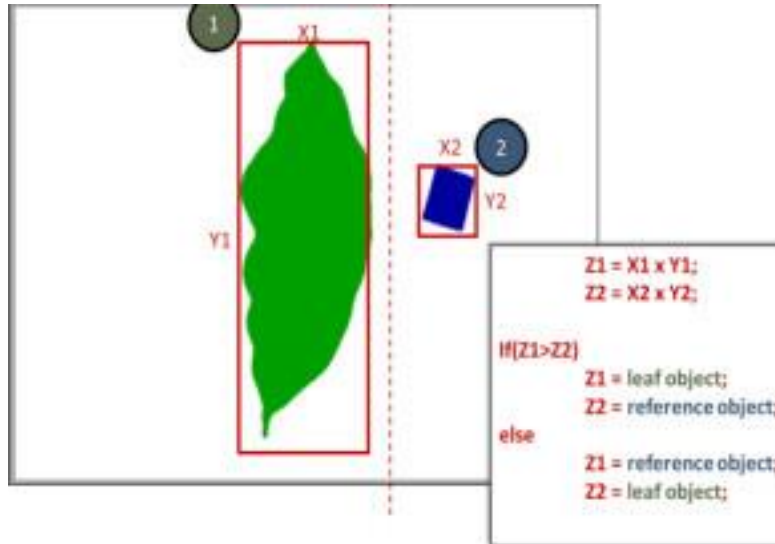


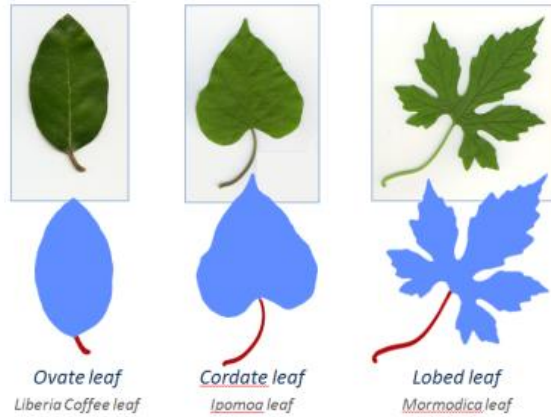
Figure 35: Leaf recognition. (Muhammad haqqiman radzali, 2016)

Calculate leaf area measurement by using segmentation treatment:

The aim was to develop a new method for automatic analysis of the geometry of homogeneous sheets from digital images produced by a flatbed scanner. This work was motivated by two particular aspects:

- Automatic data coupling, in particular the area and the weight of each sheet.
- The automatic removal of the petiole to reduce errors in the measurement of photosynthesis surfaces. (G, Mésures de la géométrie des feuilles, 2012)

Experimental results: simple examples



Experimental results: more difficult

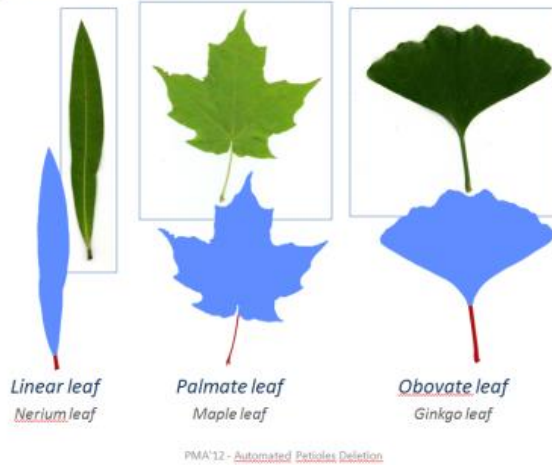


Figure 36 : examples of leaf area measurement by using segmentation treatment. (G, Mésures de la géométrie des feuilles, 2012)

2. Smartphone apps:

Among the applications for smartphones that allow to calculate the surface of the leaves through the captured image, we mention for example, the following:

-
- Easy Leaf Area
- Petiole: Plant Leaf Area Meter
- Leaf Area
- Leaf-IT

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- BioLeaf- Foliar Analysis
- Canopy Cover Free

However, it should be noted that such applications do not give us the desired accuracy in the calculation and do not work in all cases; they can be used for general knowledge, and not for elaborate study.

Chapter5:
APPLICATION

1. INTRODUCTION:

In this chapter we will describe the process for the photogrammetric approach and the proximity of the surfaces of the objects. We will also cite our first tests to fully discuss the margin of error committed to highlight the importance of some technical aspects during shooting and the steps followed in the vectorization and reconstruction.

2. Instruments and software:

We used four software in our case: Photomodeler, GlobalMapper, AutoCAD and Vextractor

We opted for the “Photomodeler” software version 2017; it is a commercial software specialized in the processing of photos for photogrammetric use it has a long history as a leading photogrammetric tool. Photomodeler introduced the concept of a desktop close range photogrammetry product to the world in 1993 and has been a leader in technology since. Many consider photo modeler to be the father of modern desktop terrestrial photogrammetry.

The software interface presents a range of different treatments to choose from its start; namely the development of target points, camera calibration, manual modeling, etc.

Furthermore, the software does not provide us with a global assistant for a new user, despite the existence of assistants in each chosen operation, we consider that the basic concepts of photogrammetry are necessary and specific training on the software is compulsory for the proper handling of this type of professional software.

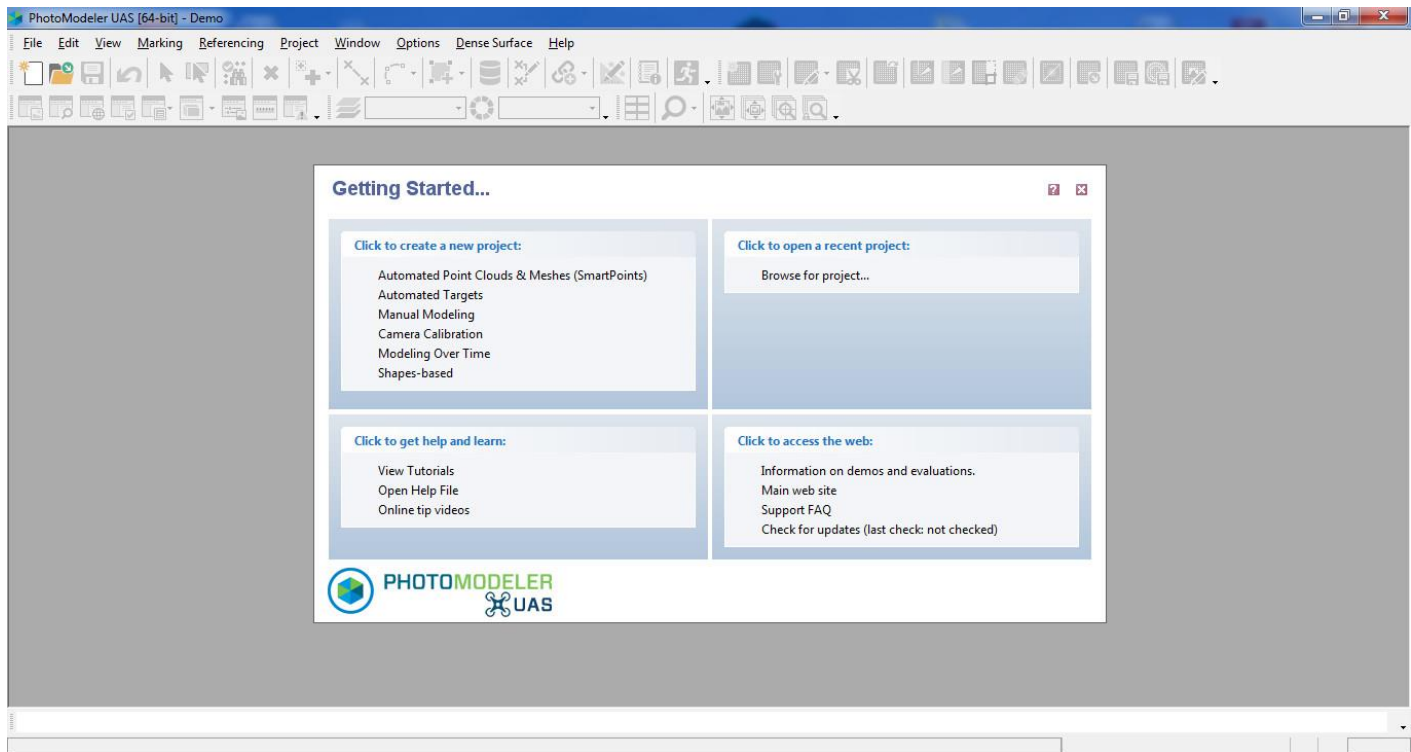


Figure 37 : Start window for the “Photomodeler” software.

We used also Globalmapper not as a geographic information system but as an automatic vectorization and format conversion tool, because globalmapper is known for exporting and importing more than 300 extensions.

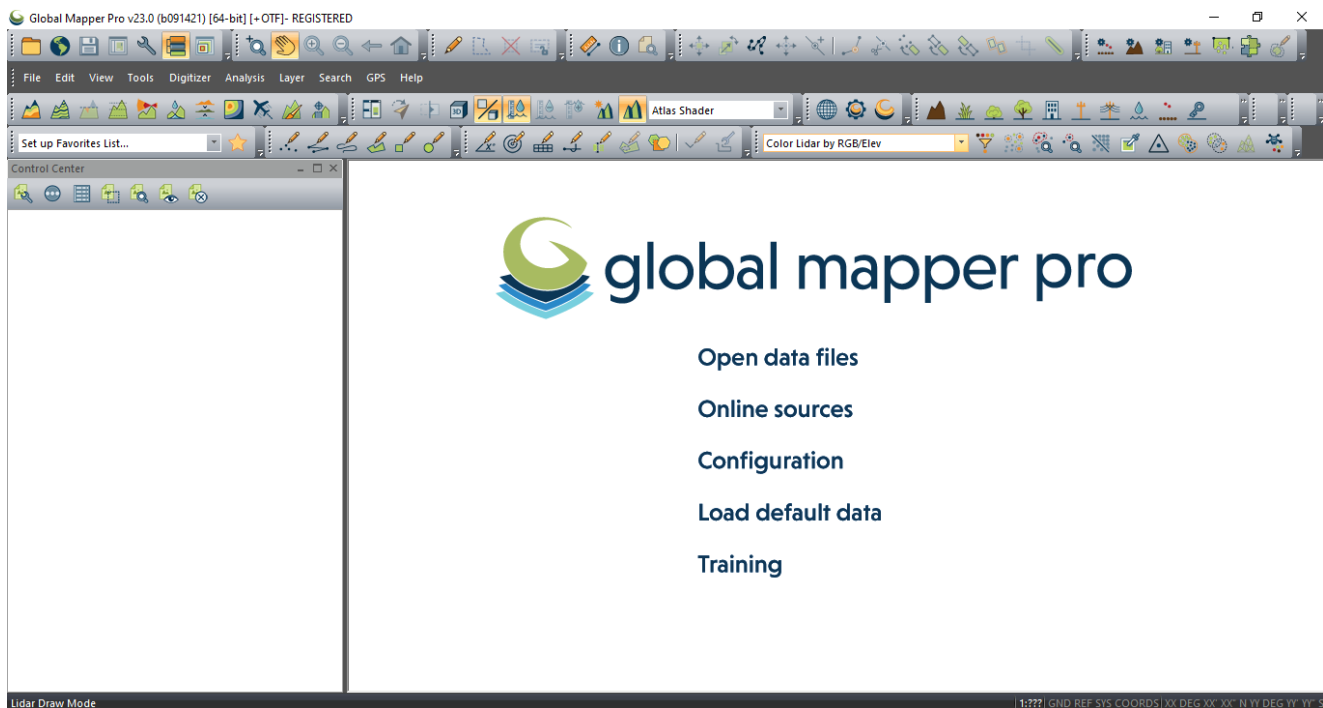


Figure 38 : Start window for the “Global mapper” software.

Autocad is a CAO software, their result are polygons this software allows us to scale easily, but in the automatic vectorization we have too many polygons, so we effect a single polygon to calculate the surface is the perimeter.

The vextractor software is a software specialized in vectorization, that is to say the passage between the Raster and the Vector, it uses different programs, filters and algorithms in order to automatically bring out a more precise vectorization.

Instruments:

Phone mobile: G7 Pro + Infinix smart 3

Camera: we use cameras attached to phones.

Computer: ASUS- PC, processor: Celeron (R) N2840. 2,16GHZ, Windows7, Ram: 2 Go

3. METHODOLOGY:

Our work steps divided into three essential following phases:

Firstly, Pretreatment then acquisition, lastly the treatment:

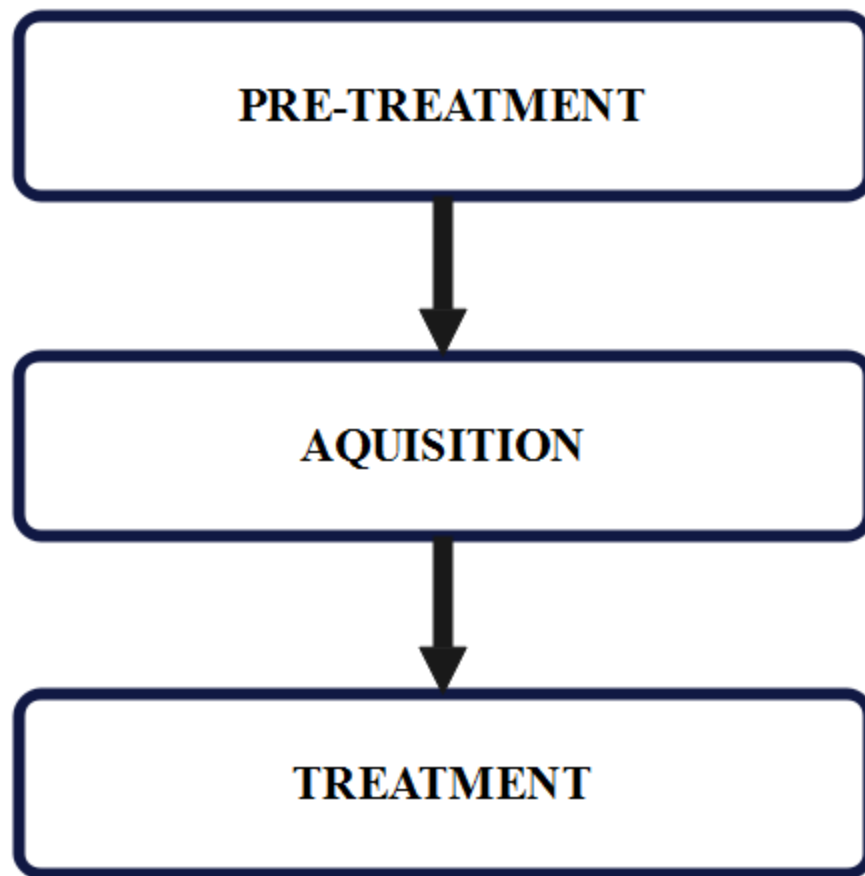


Figure 39 :the phases of photogrammetry.

3.1 Pretreatment:

This is the phase which must precede acquisition, it's about the steps of calibration of the camera we used, we can mention in 6 steps.

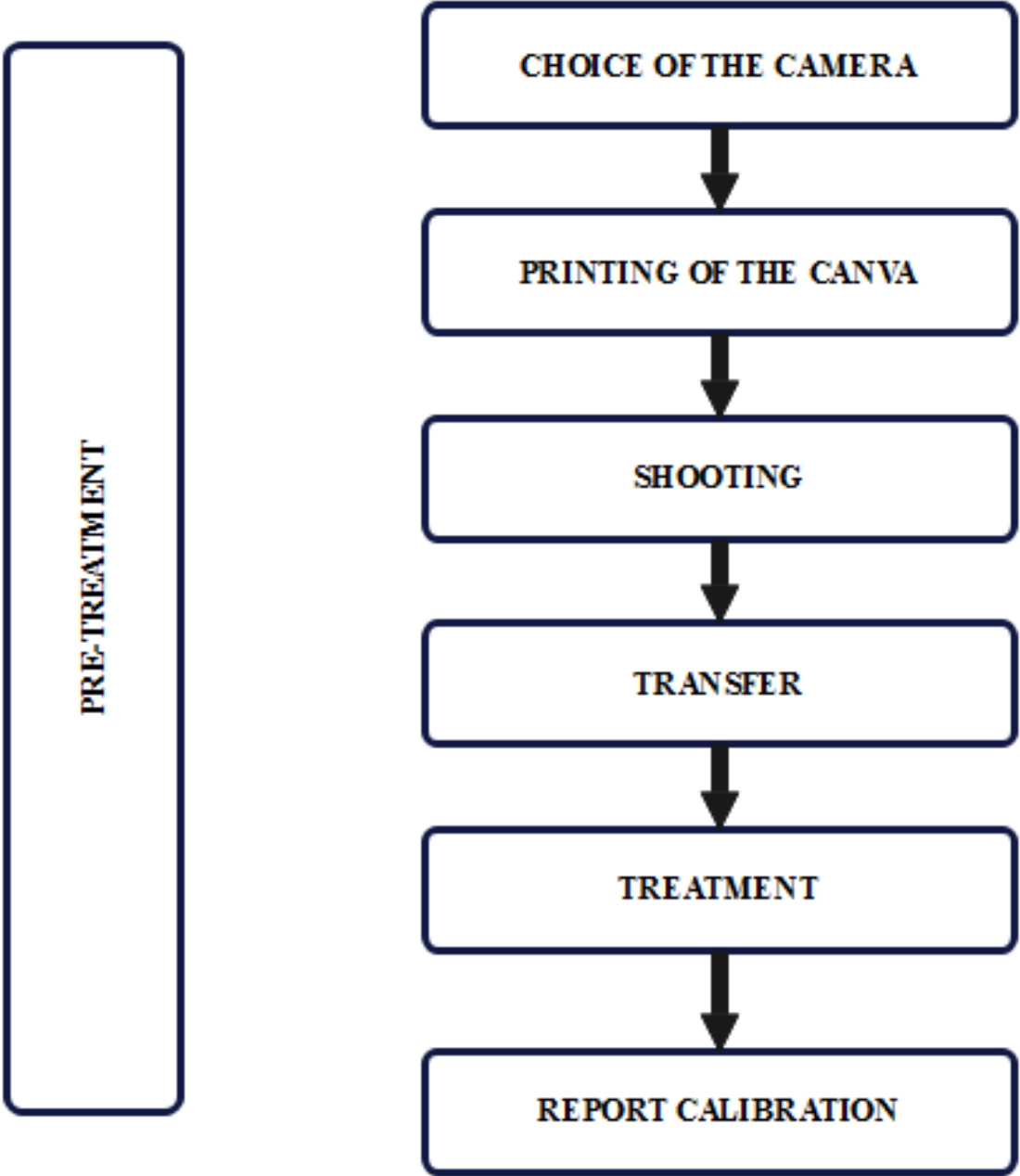


Figure 40:Pretreatment tasks.

3.2 ACQUISITION:

The acquisition part is the field data, in the beginning of this phases we chosen different leaf plant (different shape, area , color and stratification).

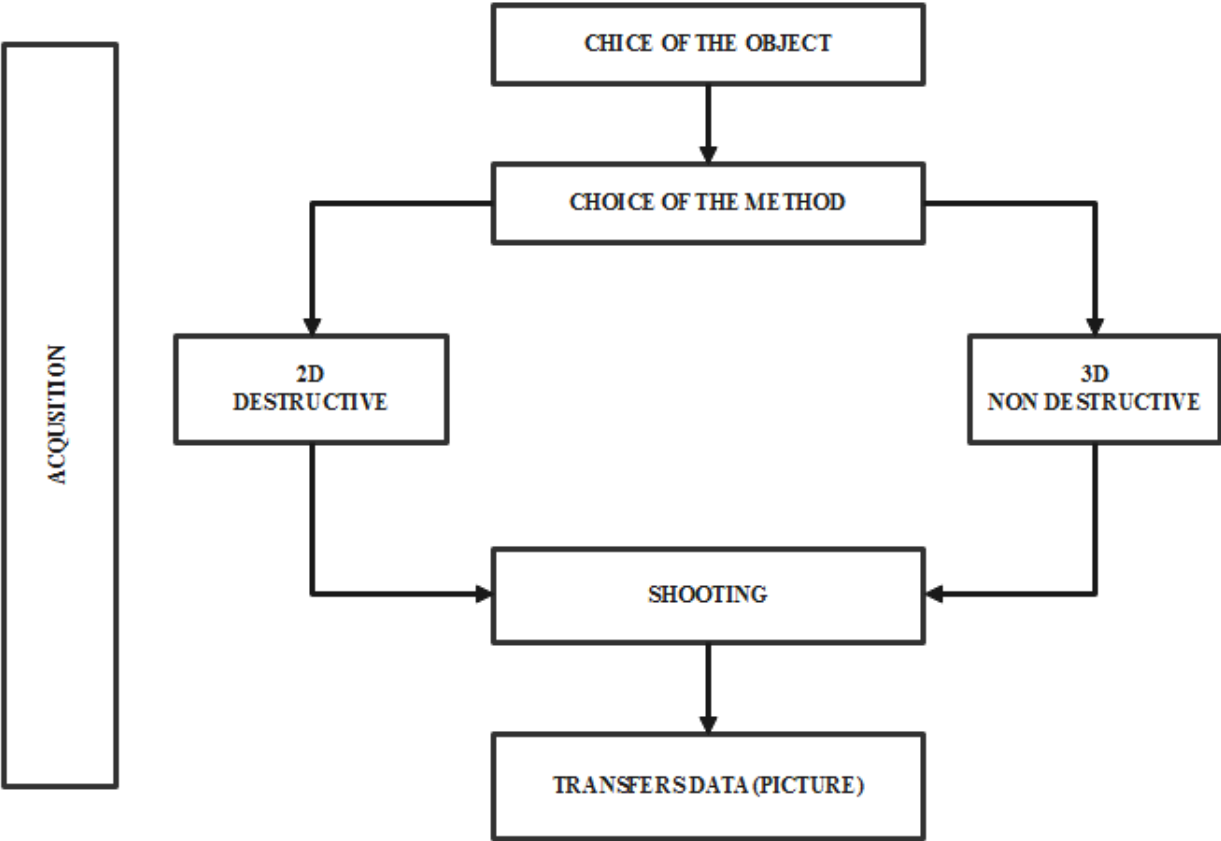


Figure 41 : Acquisition tasks.

3.2.1 Plant leaves used in 2D treatment:

We used different plant leaves in terms of shape, color and stratification.

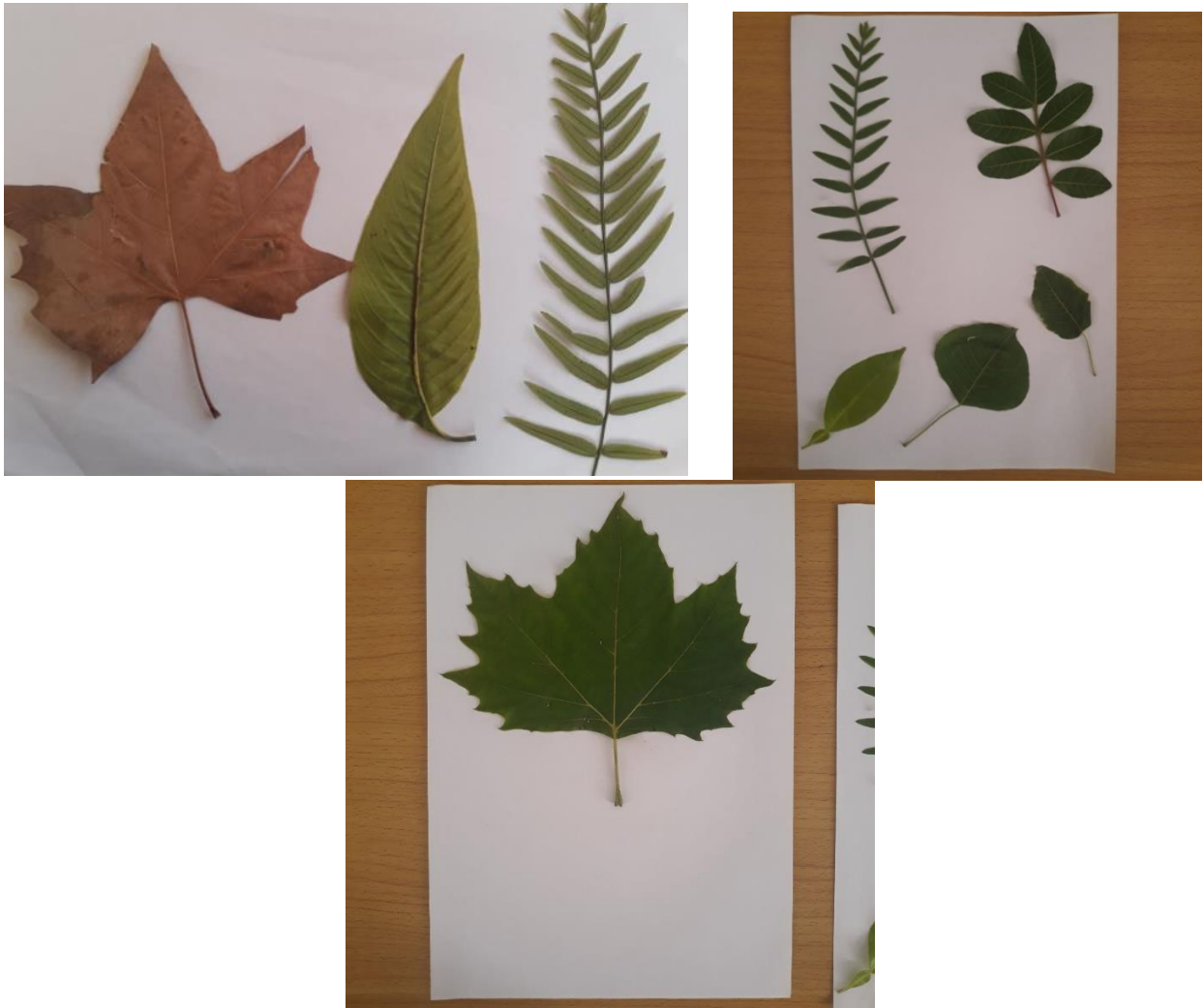


Figure 42 : vertical photos of leaves plants used.

For the 3d images we used a series of images of the leaves of two plant species of different geometric shapes as shown in the figures below:

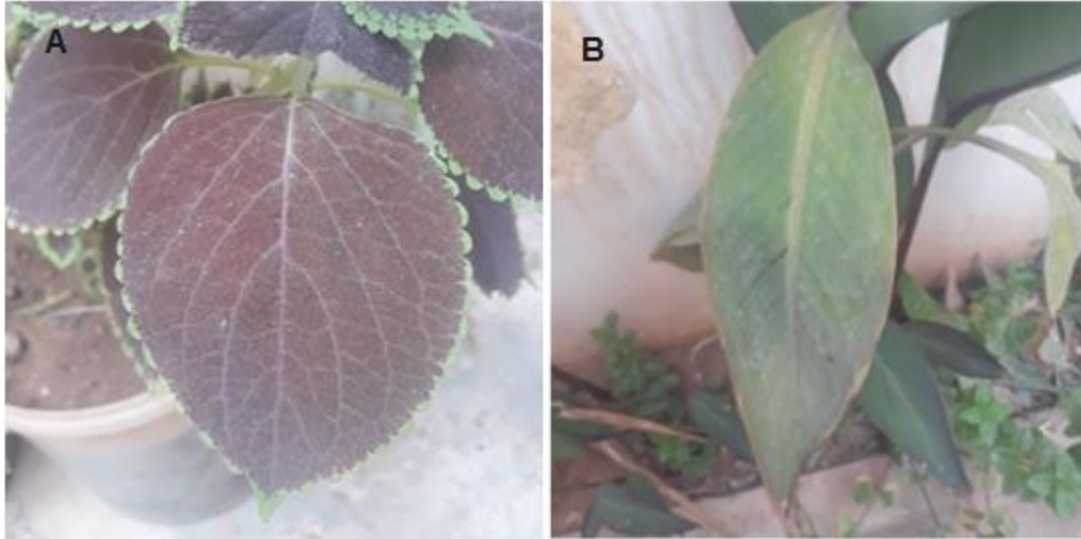


Figure 43 : leaves plants A and B

3.3 TREATMENT:

The treatment phase is divided into two parts: a treatment of two-dimensional images(2D) and also three-dimensional images(3D), that is after data transfer.

3.3.1 2D TREATMENT:

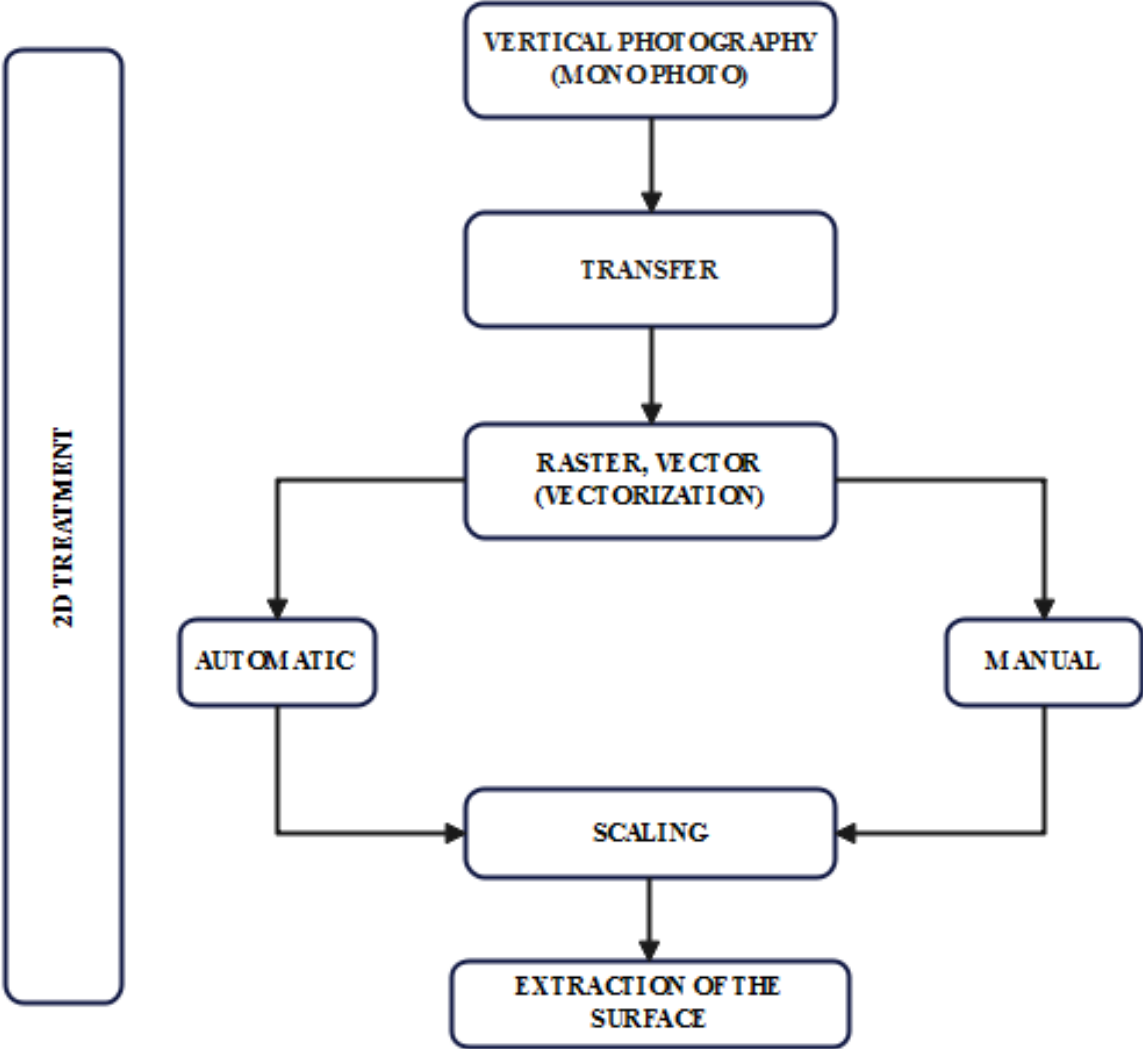


Figure 44 : 2D treatment tasks.



Figure 45 : vertical picture of a plant leaf.

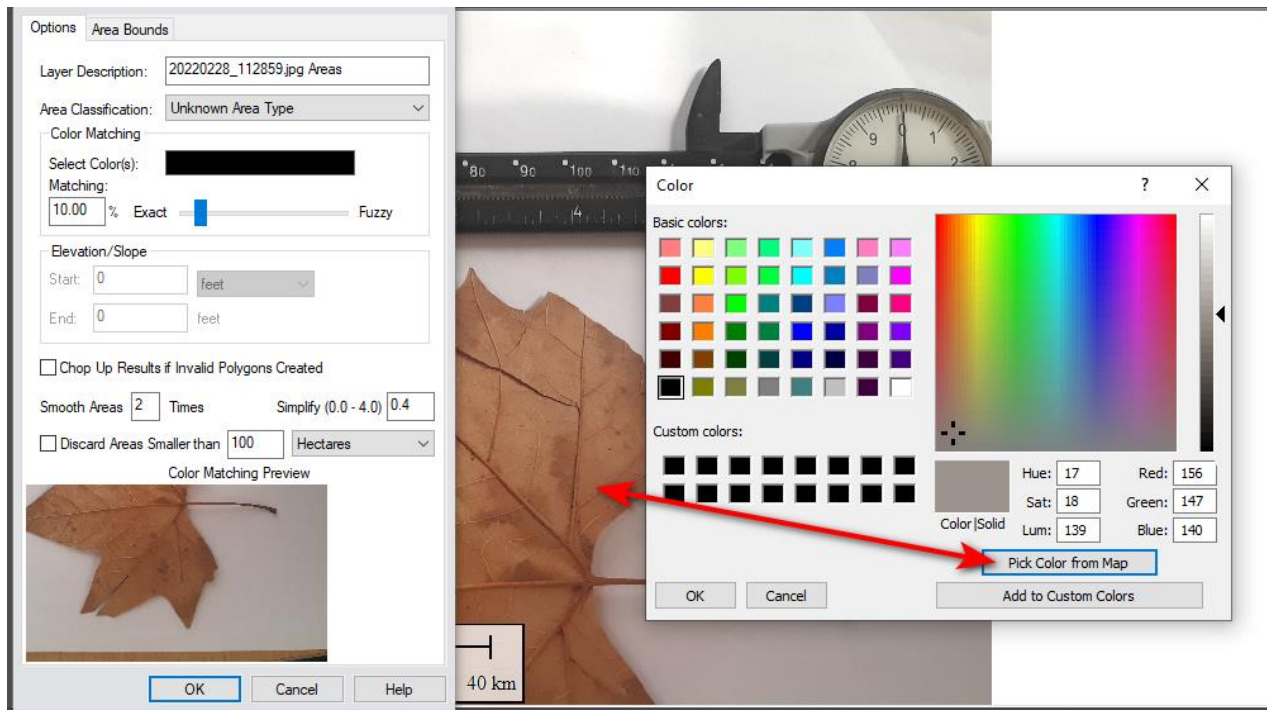


Figure 46 : Setup for the matching color percentage.(GlobalMapper)

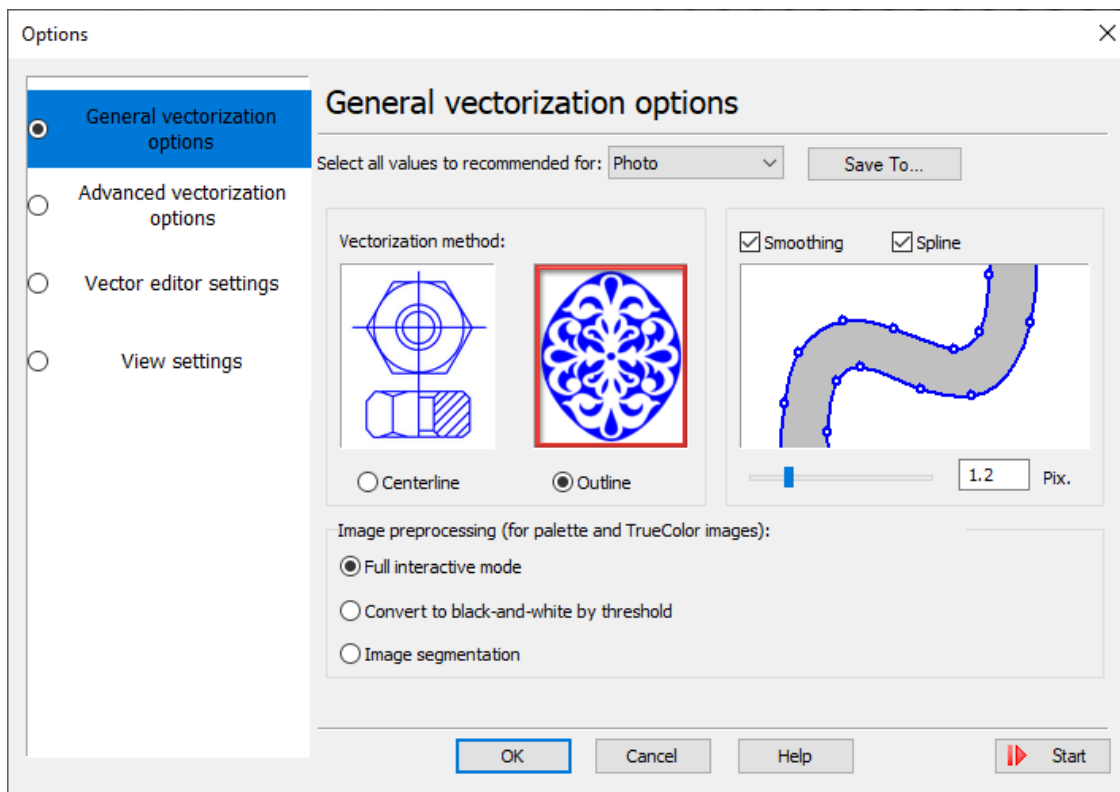


Figure 47 : setup for automatic vectorization (Vextractor)

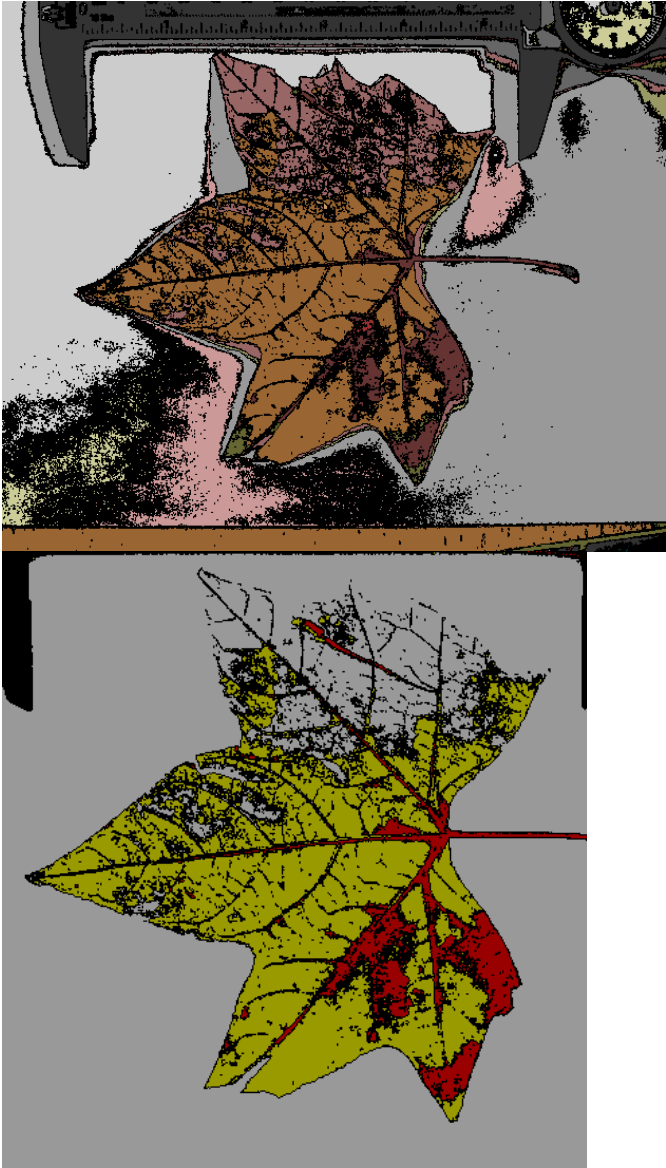


Figure 48 :Automaticvectorization in GlobalMappersoftware by 10% color matching in the photo in left, and 30 %color matching in photo in right.



Figure 49: Automatic vectorization in GlobalMappersoftware by 50% color matching in the photo in left, and 70 %color matching in photo in right.

We vectorized the image automatically with the Raster vectorization tool which takes into consideration the correspondence of two colors, percentage of correspondence then we exported in DWG format for Autocad to allow us to do the scaling which we can't do with global mapper because it's mapping software.

In both cases, we note that parts of the surface of the leaf were not identified and did not merge with the rest of the surface. In 70% of color matching we notice in the image to the extent that the shape of the leaf is not longer clear.

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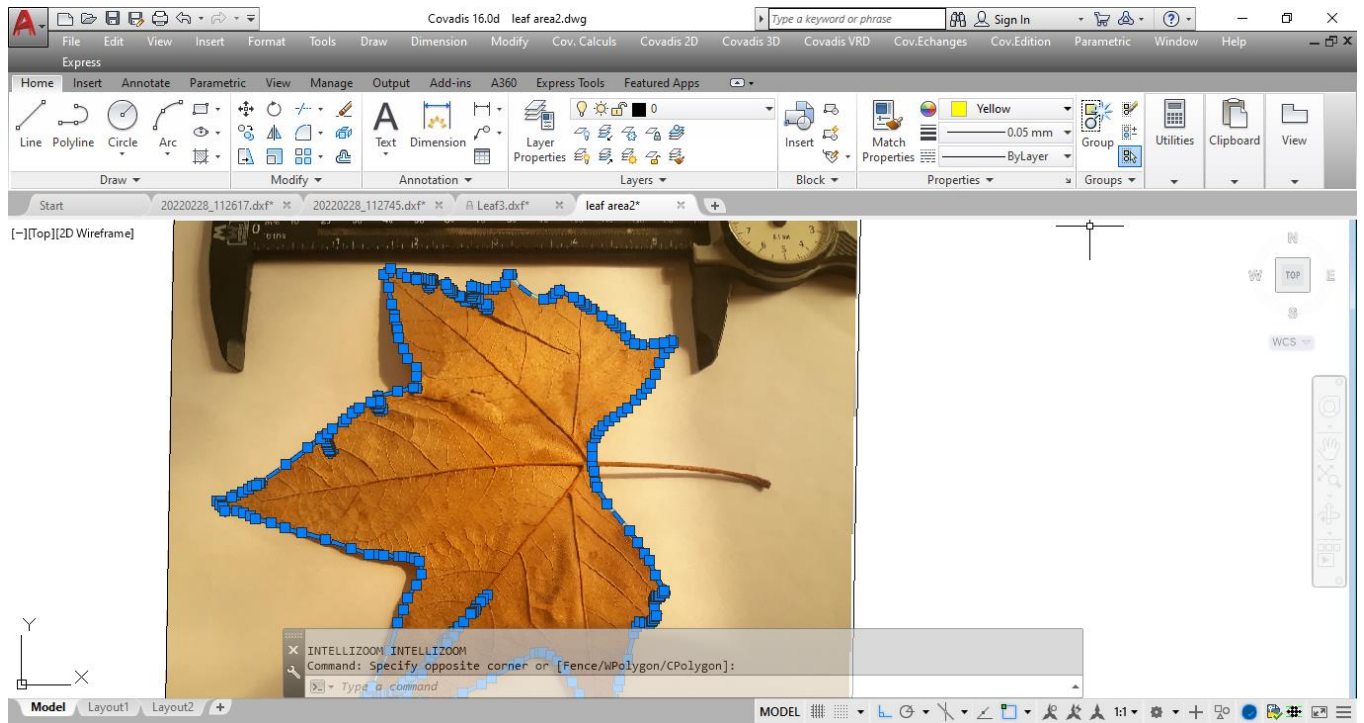


Figure 50 : result of manual vectorization in AutoCAD

This process took about 14 minutes to get the correct and accurate vectorization to enable us to calculate the area of the leaf and to be as close as possible to the real area.

After the process of vectorization, whether automatic or manual, the phase of scaling and calculating the area comes.

Polyline	
General	
Color	Yellow
Layer	0
Linetype	ByLayer
Linetype scale	1.0000
Plot style	ByColor
Lineweight	0.05 mm
Transparency	ByLayer
Hyperlink	
Thickness	0.0000
3D Visualization	
Material	ByLayer
Geometry	
Current Vertex	1
Vertex X	27.7292
Vertex Y	27.2639
Start segment width	0.0000
End segment width	0.0000
Global width	0.0000
Elevation	0.0000
Area	99.6175
Length	68.3978
Misc	
Closed	Yes
Linetype generation	Enabled
COVADIS : longueurs et aires	
Longueur 2D	68.3978

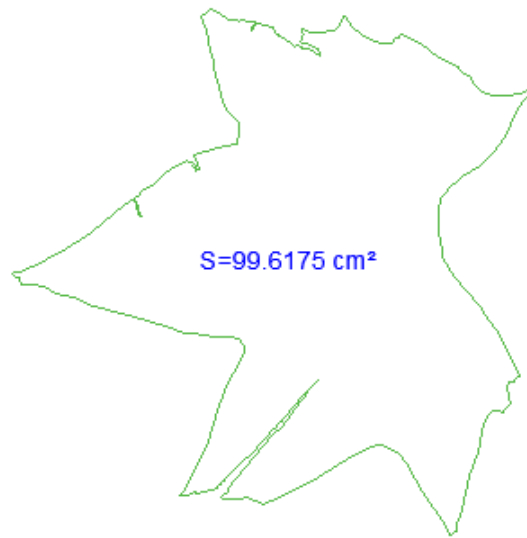


Figure 51 :leaf area result by automatic vectorization.

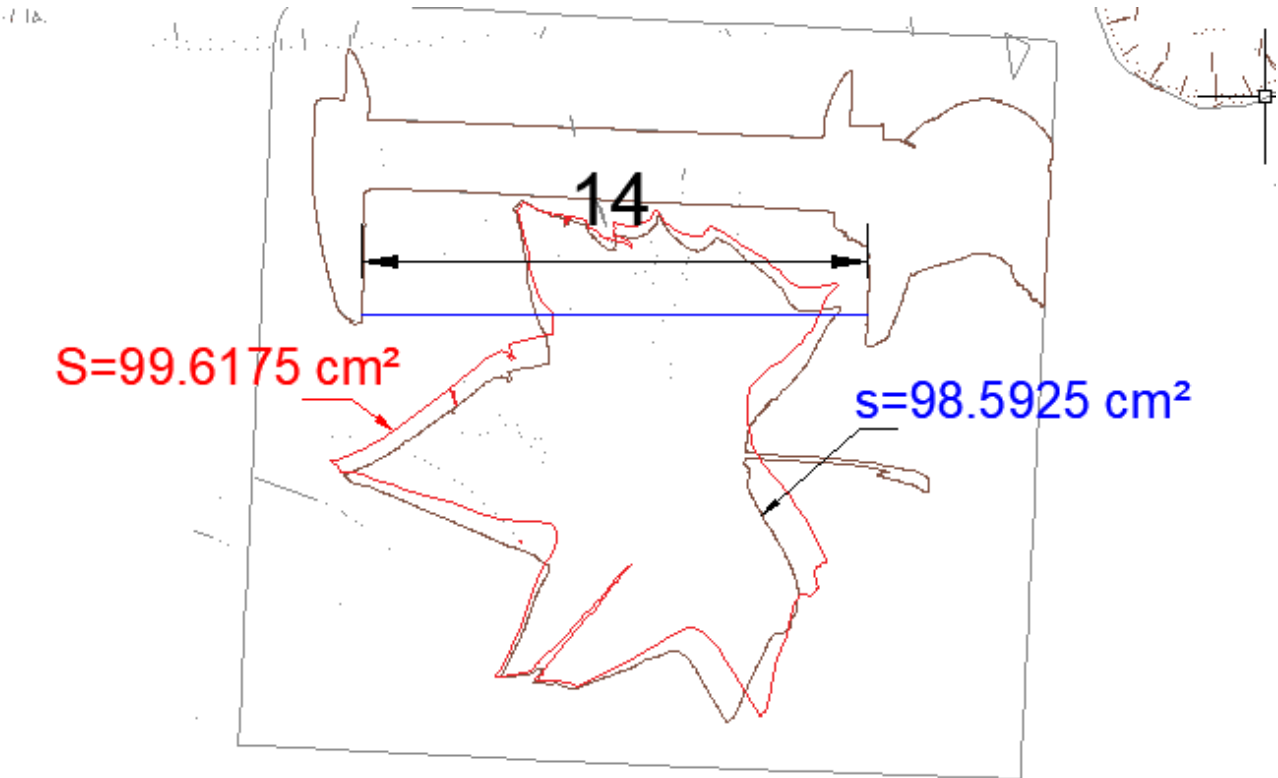


Figure 52 : Area difference between automatic (in black color) and manual vectorization (in red color). 98.97%

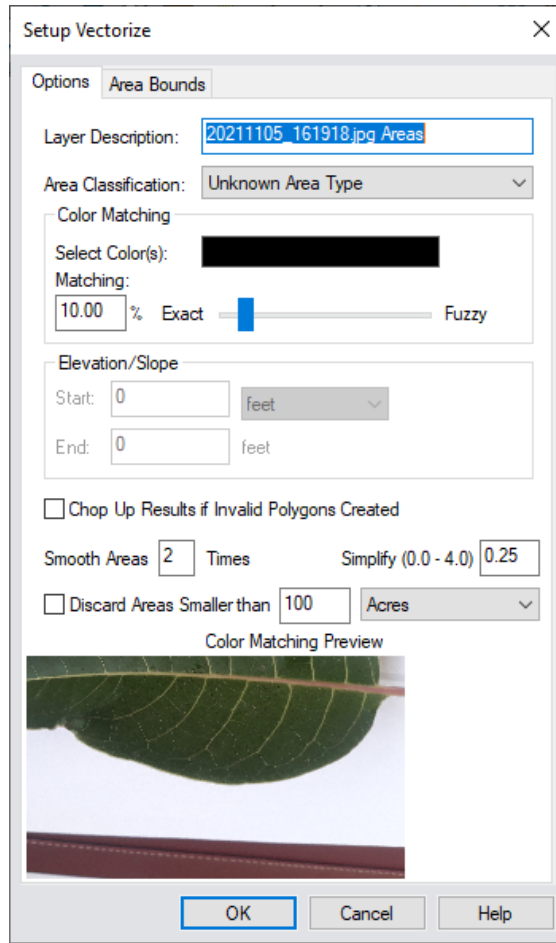


Figure 53 : Setup for automatic vectorization in globalmapper

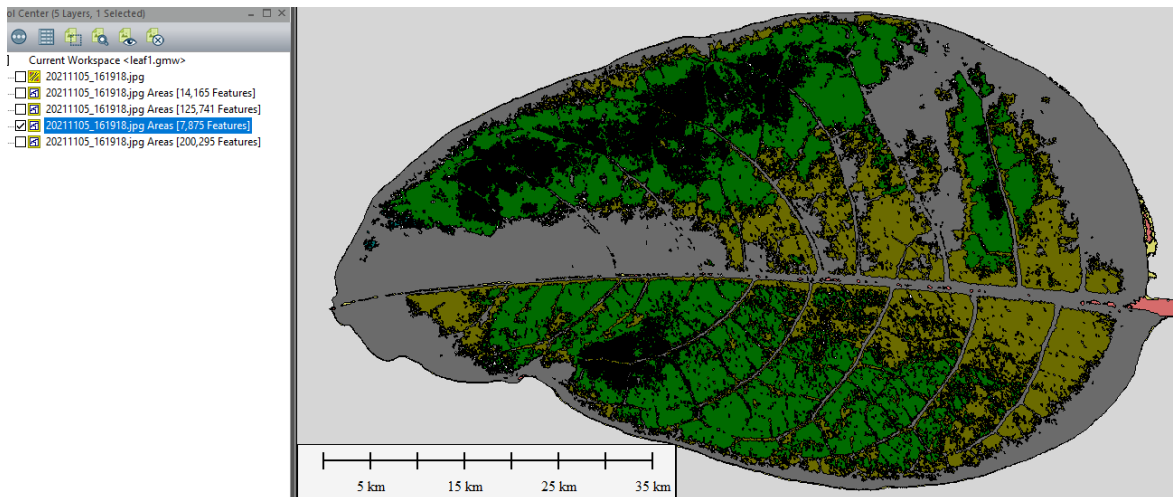


Figure 54 : Automatic vectorization in global mapper.

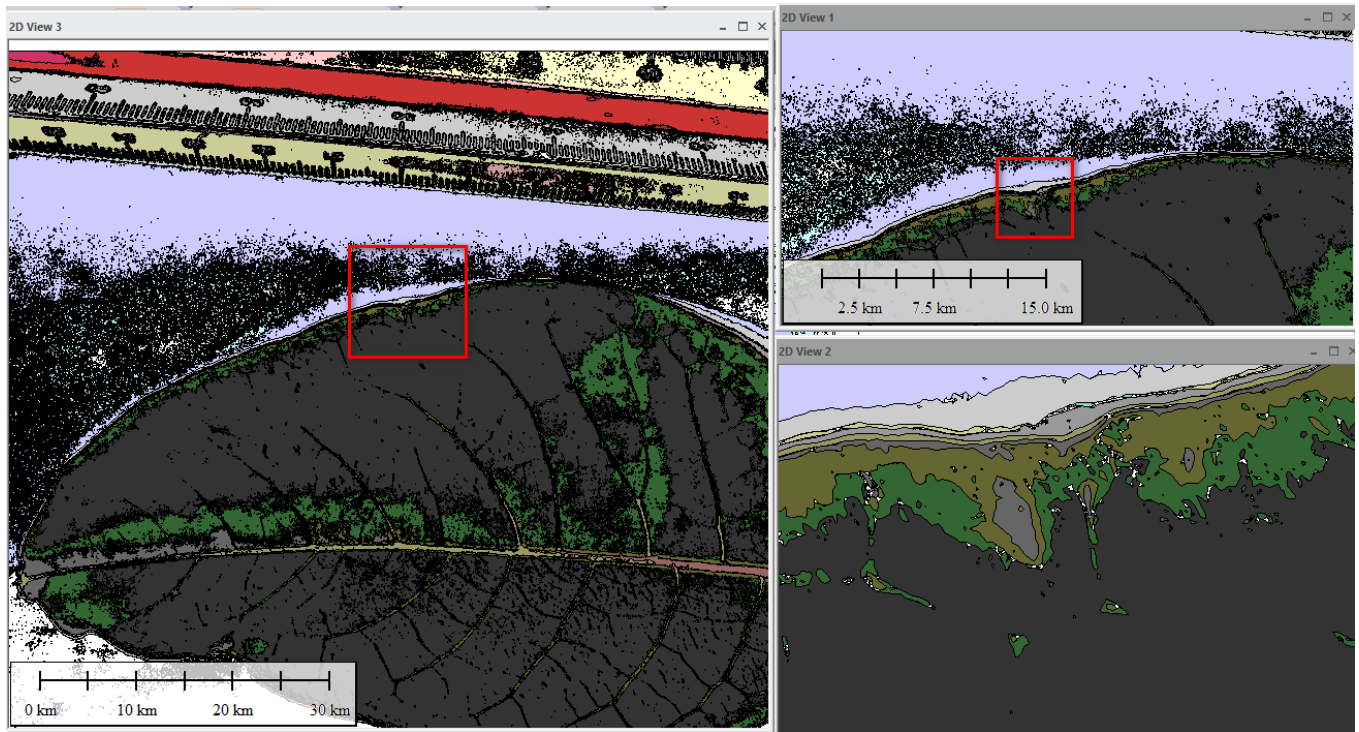


Figure 55 : Zoom in leaf before scaling



Figure 56 : automatic vectorization in vextractor.

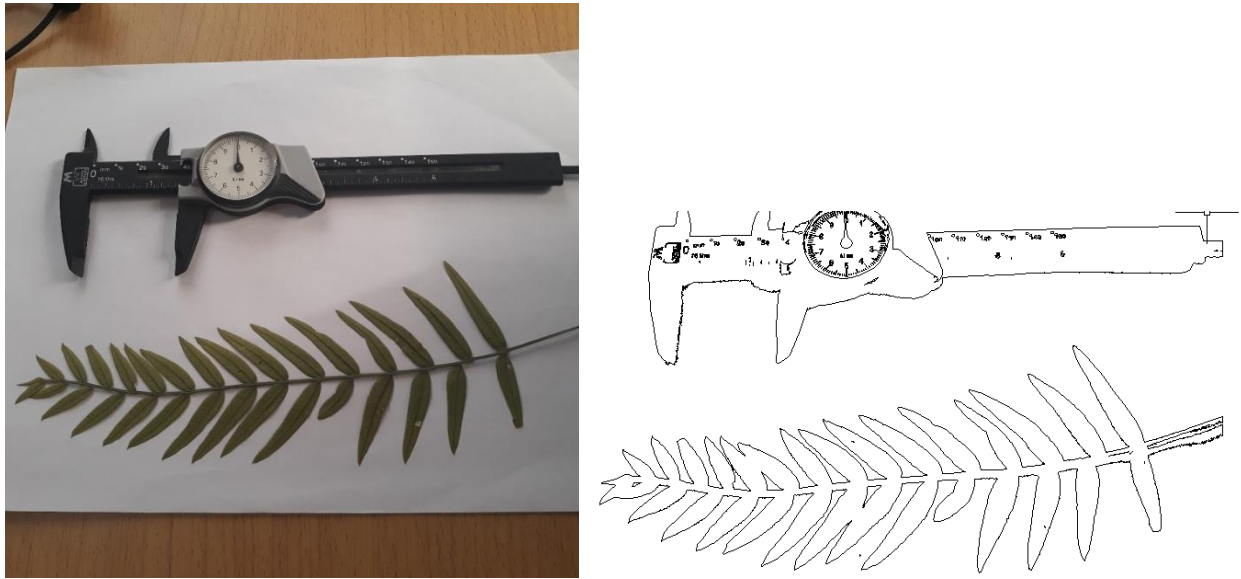


Figure 57 :vertical of photo of leaf plant. Figure 58 : automatic vectorization .

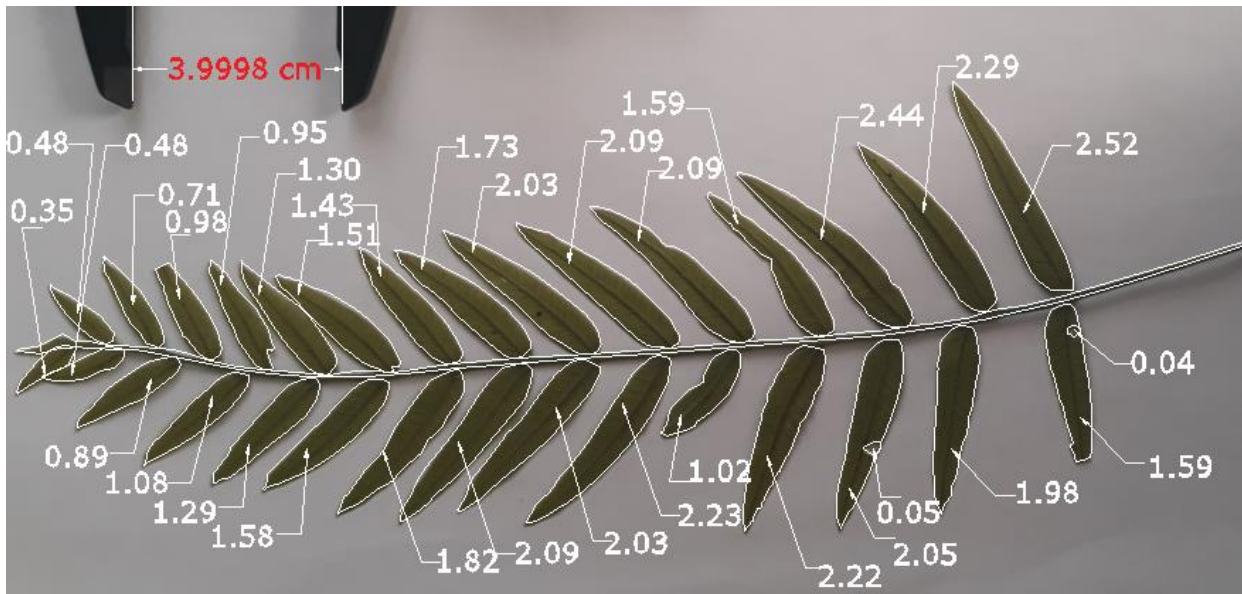


Figure 59 : leaflets areas (cm²) by manual vectorization

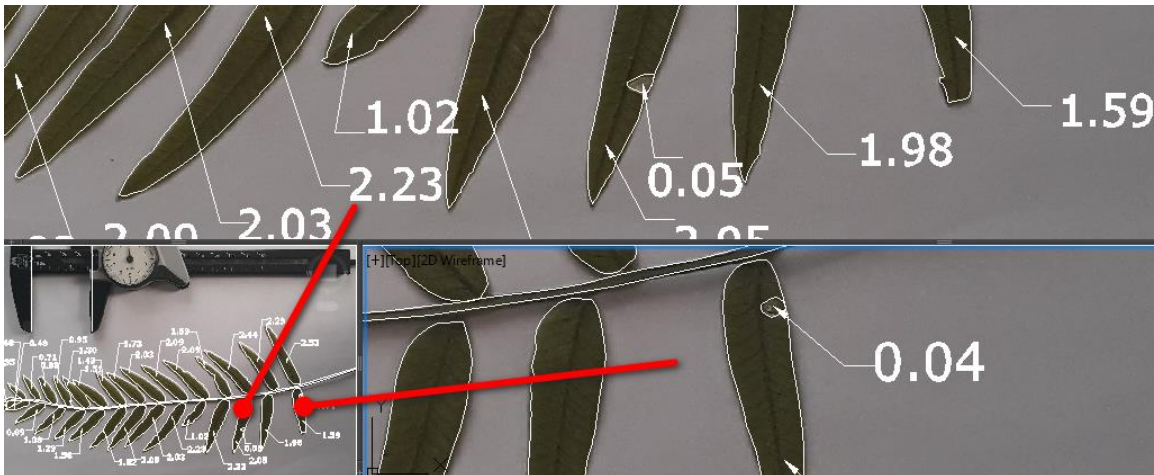


Figure 60 : Small areavectorized manually.

Small area and leaf spots from diseases and more can be picked up, allowing us to closely monitor this deformation .



Figure 61: the area(cm²) with automatic vectorization.

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	MANUAL VECTORIZATION	AUTOMATIC VECTORIZATION	
ORGAN	Leaflets	Leaflets	Rod
AREA inCm ²	47,02	58,933	9,6194

Table 2: difference between areas result by manual and automatic vectorization

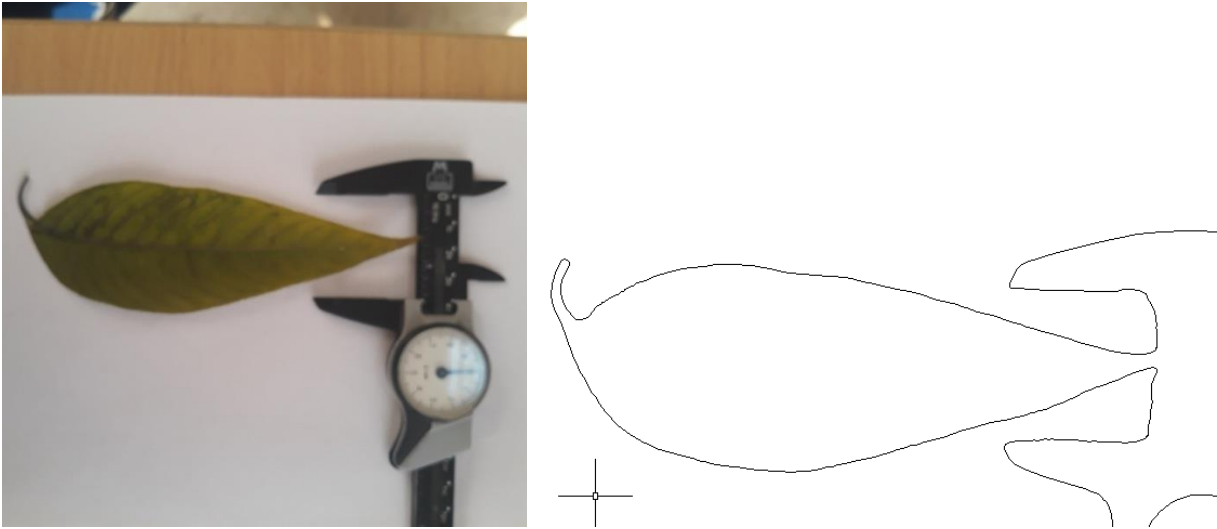


Figure 62: The result of automatic vectorization

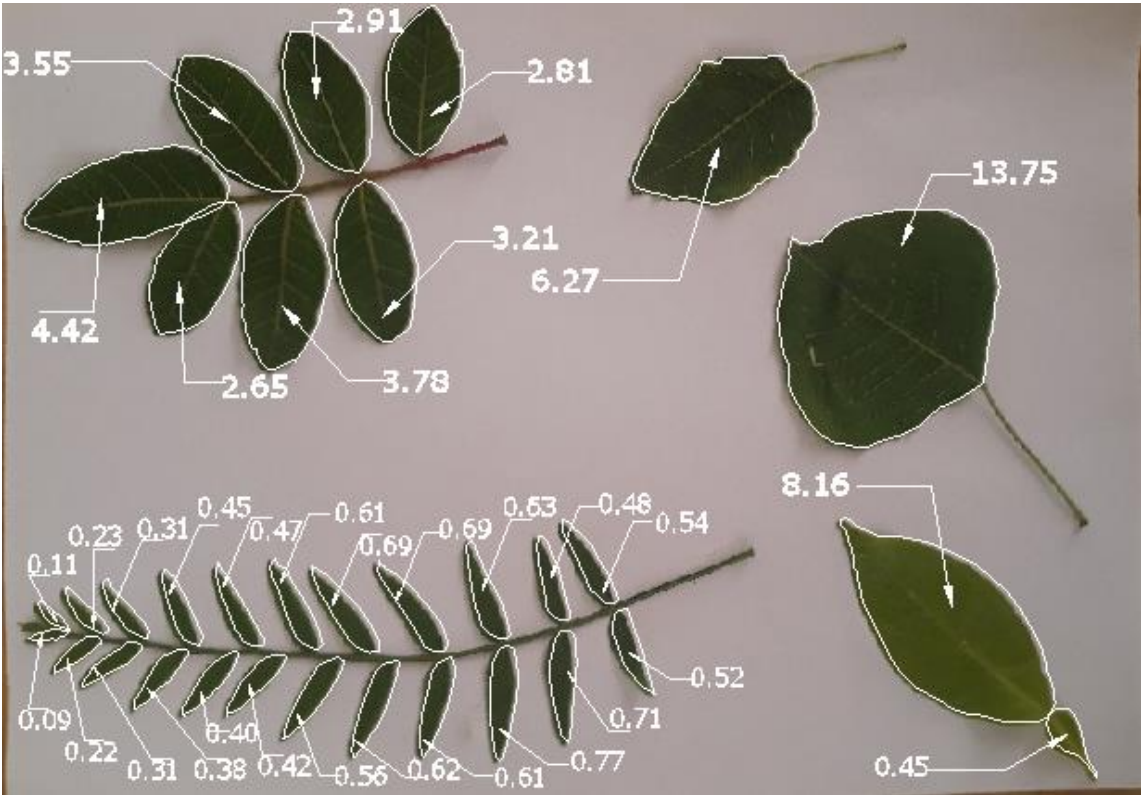


Figure 63 : Areas of different leaves by manual vectorization.

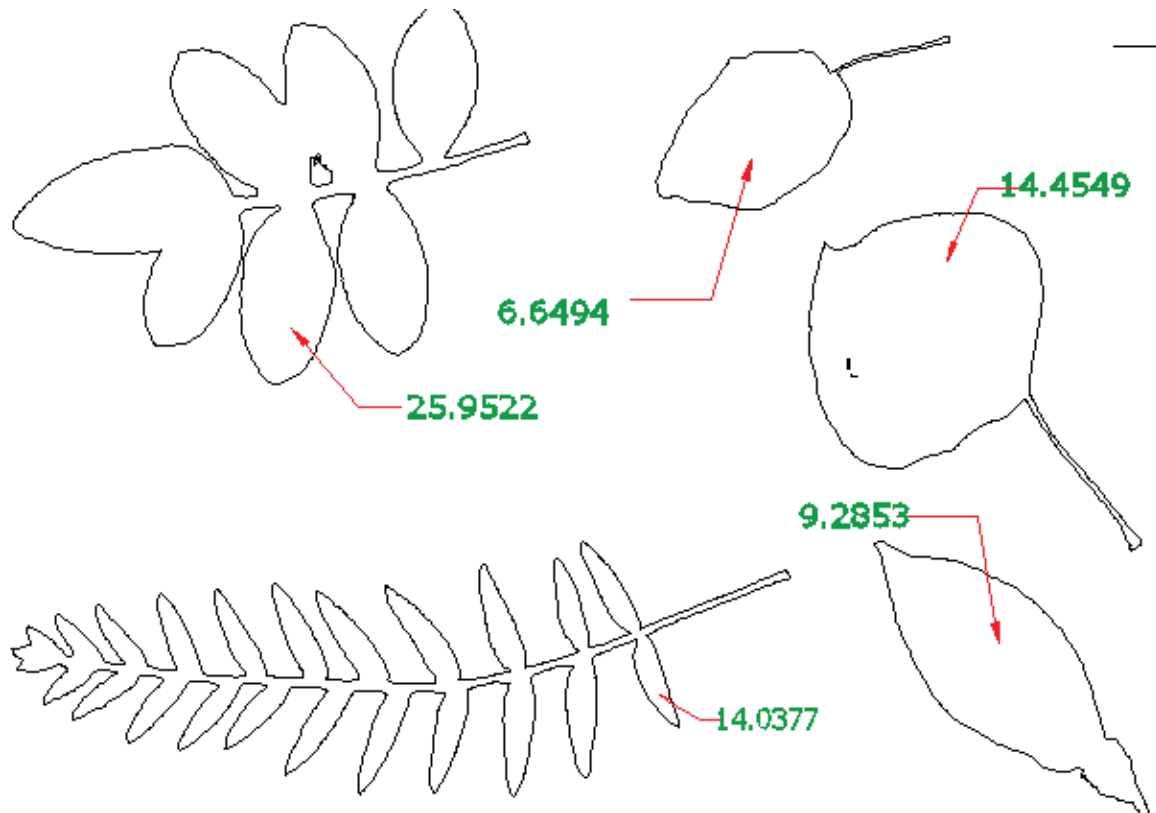


Figure 64 : leaves areas by automatic vectorization.

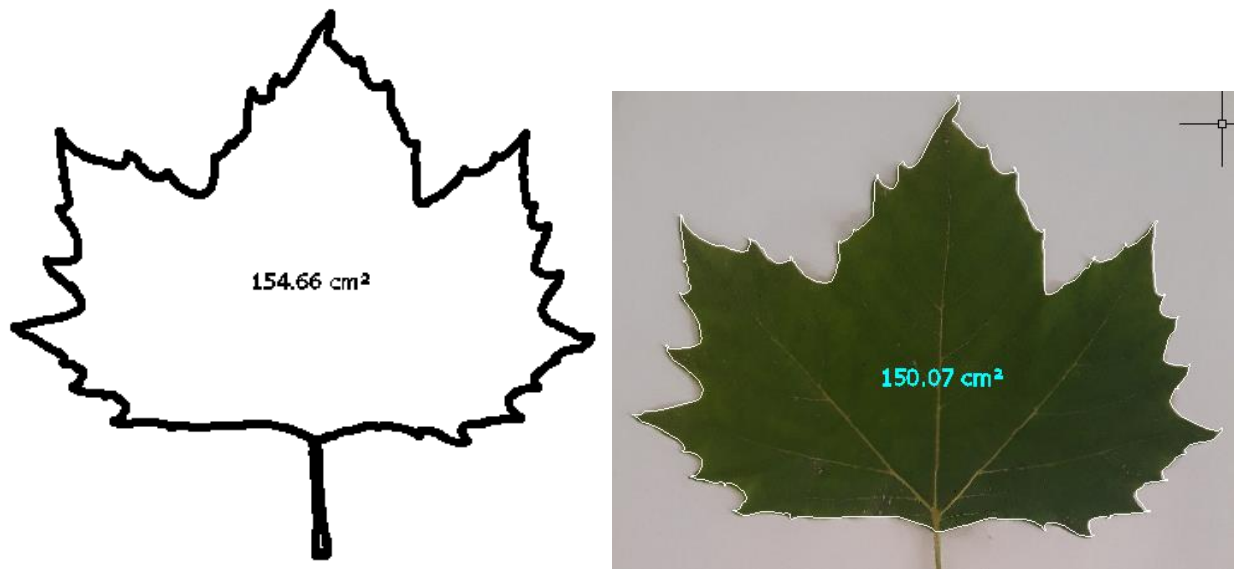


Figure 65 :Area of the same leaf by automatic vectorization in image on left, and manual vectorization on right.

The difference in areas of plant leaves is simply because in the manual vectorization, we are the ones in control of determining the part on which we want to perform the calculations.

As for the automatic vectorization, the software is responsible for the vectorization, so it vectorise the whole object, which means increasing the details and area.

3.3.2 :3D TREATMENT:

We do 3D treatment based on multiple images, on contrary 2D treatment that depends on a single image.

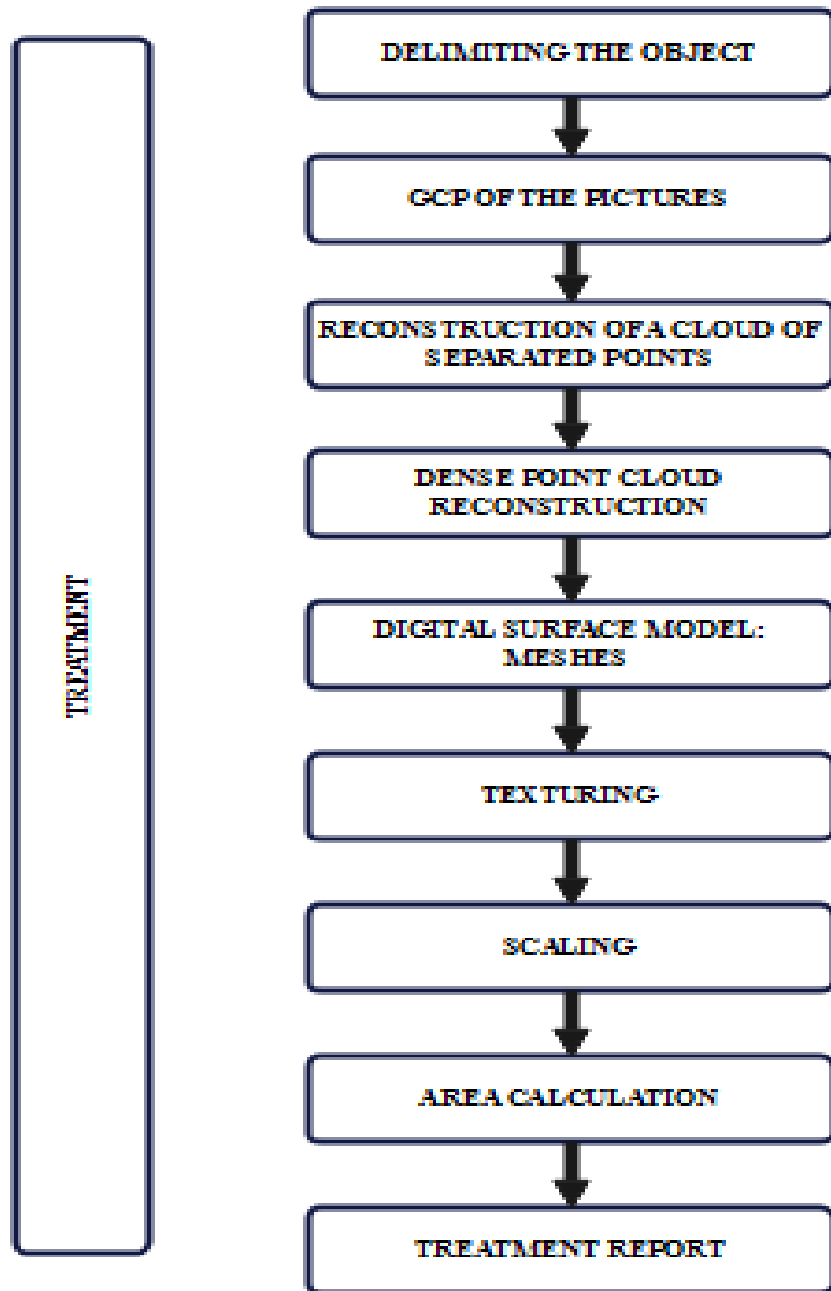


Figure 66 : 3D treatment tasks.

A. Delimitation of the object:

The backgrounds represent a major obstacle in the phase of processing of reconstruction. In fact, how can the software know or extract the object to be reconstructed?

To answer this question is to understand the algorithm used in this type of image processing.

We seek the correspondence of each pixel of the image N to its counterpart in the image $N+1$ then each pixel of the image $N+1$ to its counterpart of the image $N+2$. This type of processing is called per-image.

We can also search for all the homologs of the pixel of image N in all remaining images.

Recall that the pixel is defined by its position in the image and a value that corresponds to its color. But this is not enough to make the correspondence; it is necessary to introduce other algorithms based on set theory to treat the pixel with its environment (the pixels which surround it).

In order to speed up the process of this operation, which can take a few hours for a simple project, photomodeler offers the possibility of delimiting the object via vectorization tools.

Vectorization must be established in all shots, but it will be faster and faster with the semi-automatic tool that photomodeler offers.

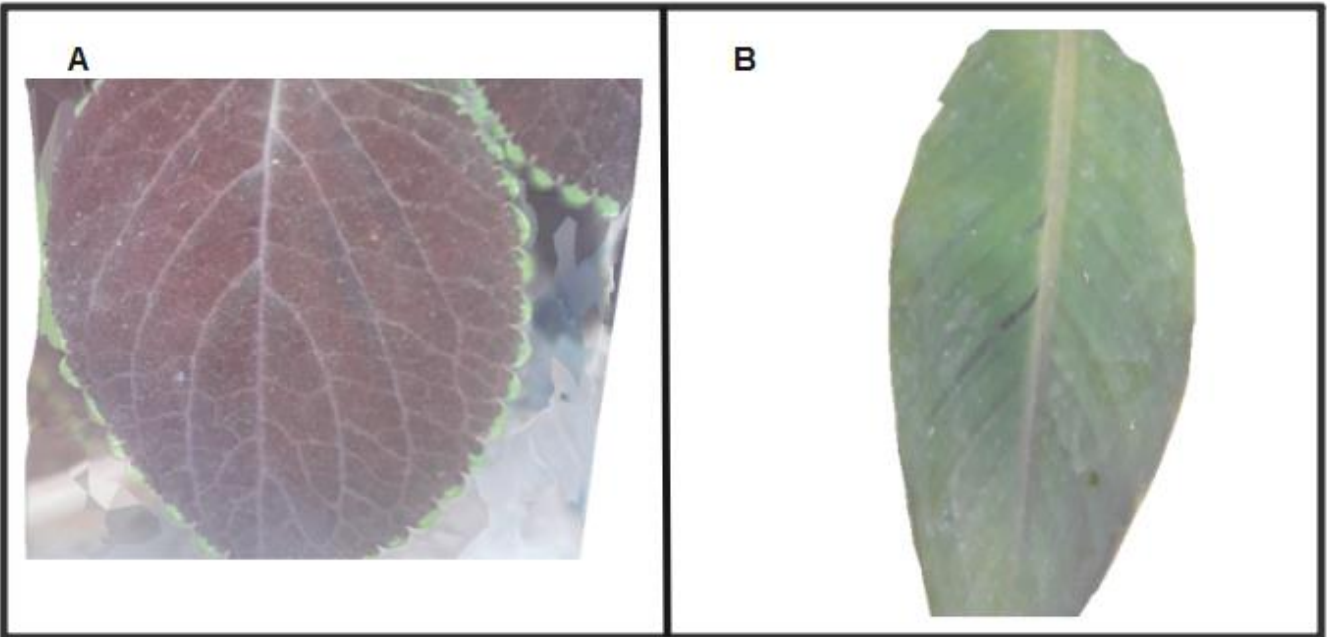


Figure 67 : Delimiting the leaves.

B. Ground control points (GCP) :

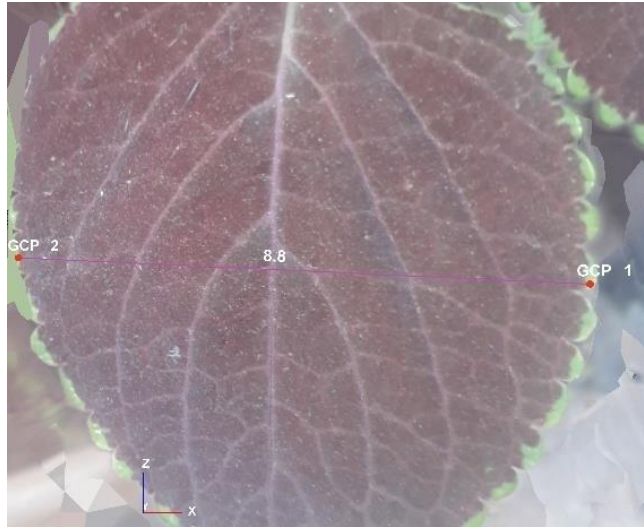


Figure68: Ground Control point (GCP) of the picture.

C. Spare point cloud:

The figure below represents separate point cloud for each of:

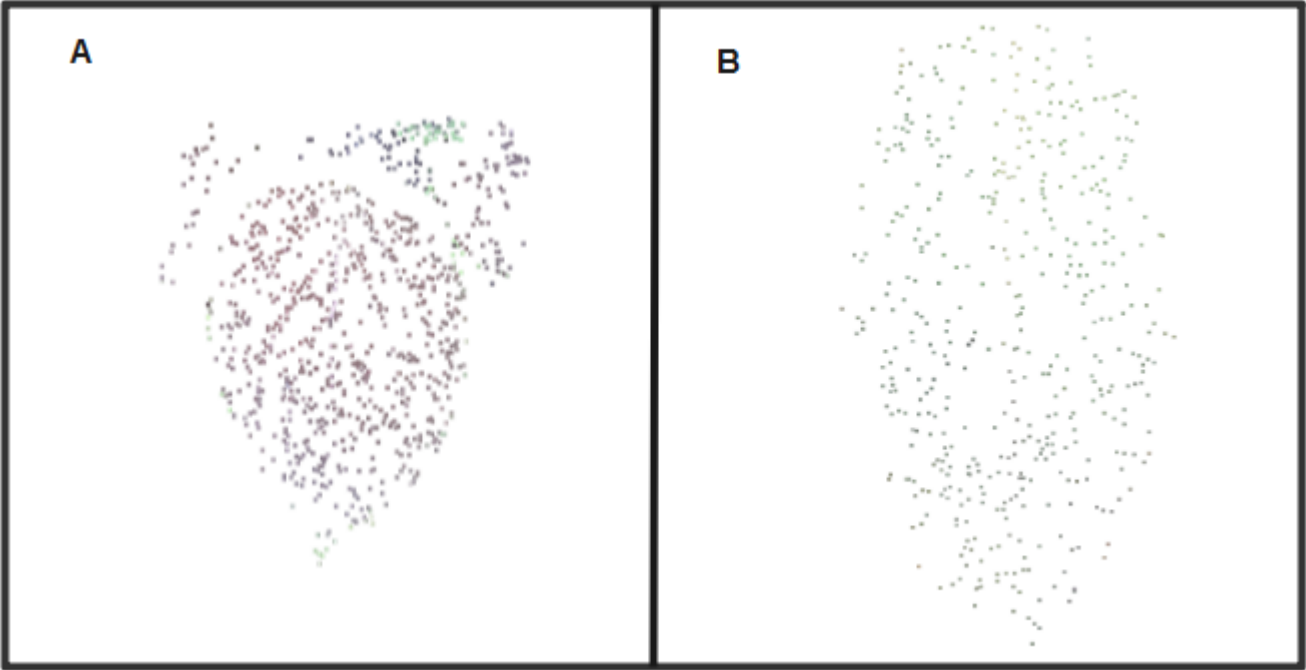


Figure 69:spare point cloud of each leaf A and B.

Indeed, we did not reference all points shown in the figure above, but the software was able to detect other significant points in the photos based on the referenced points.

D. Dense point cloud:

The fifth stage of treatment is necessarily based on the antecedent; photomodeler searches for the intermediate points between the separated points in order to densify the point cloud.

From this phase, the object becomes clearer although it is represented only by points.

The figure below represents a cloud of densified points for each of:

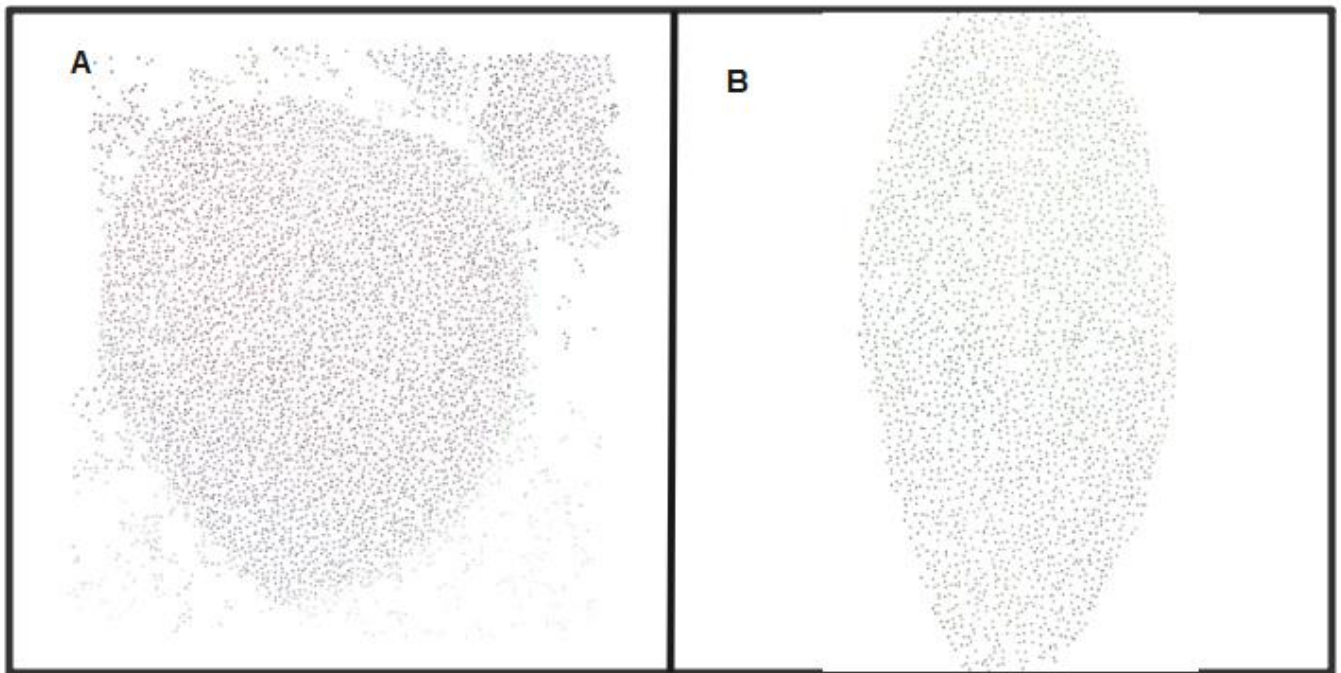


Figure 70 : Dense point cloud of leaves.

E. Mesh:

In order to convert the point cloud into a surface, a meshing method must be chosen.

Generally triangulation is what is currently used for this kind of treatment. All points will be connected to each other by triangles.

The figure below represents the mesh result for each of:

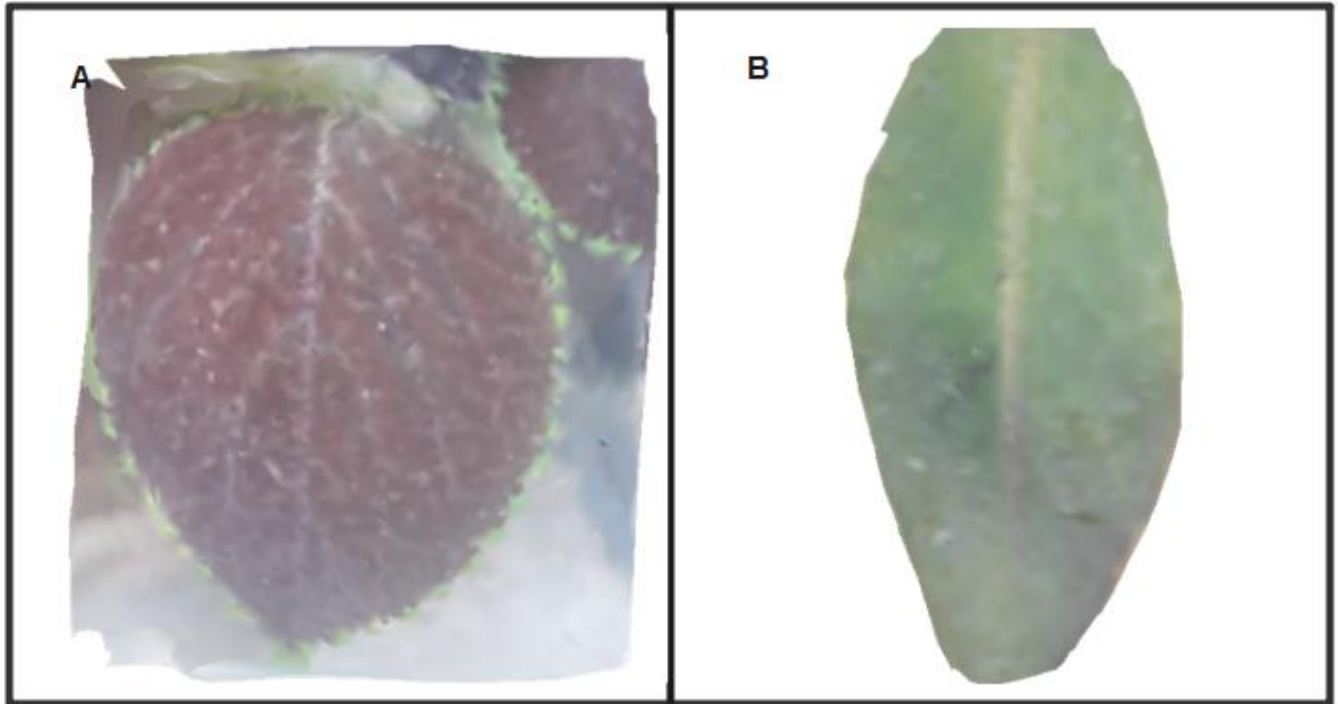


Figure 71 :meshes of reconstitution.

F.Texturing:

Finally, the triangles must be assigned a rendering with predefined lighting in order to give the 3D photo its aspect of realism. You can edit the textured photo to remove some pixel noise or unwanted objects.

The figure below shows the texturing result for each of:

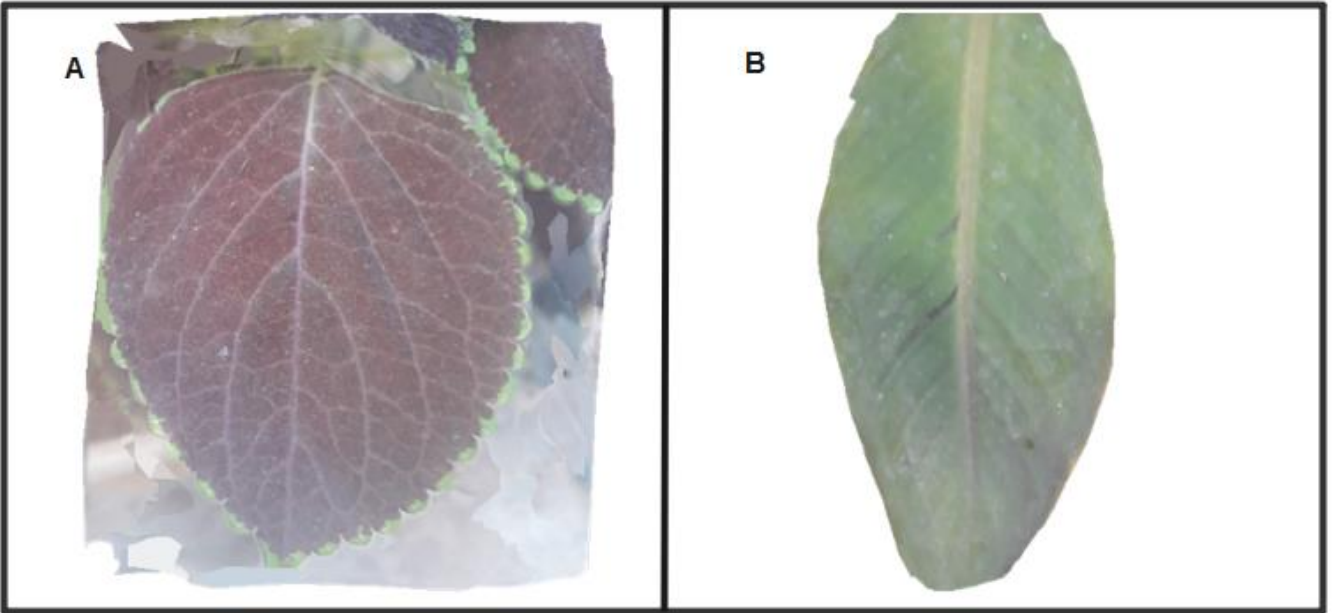


Figure 72 : Textured mesh of reconstitution A and B.

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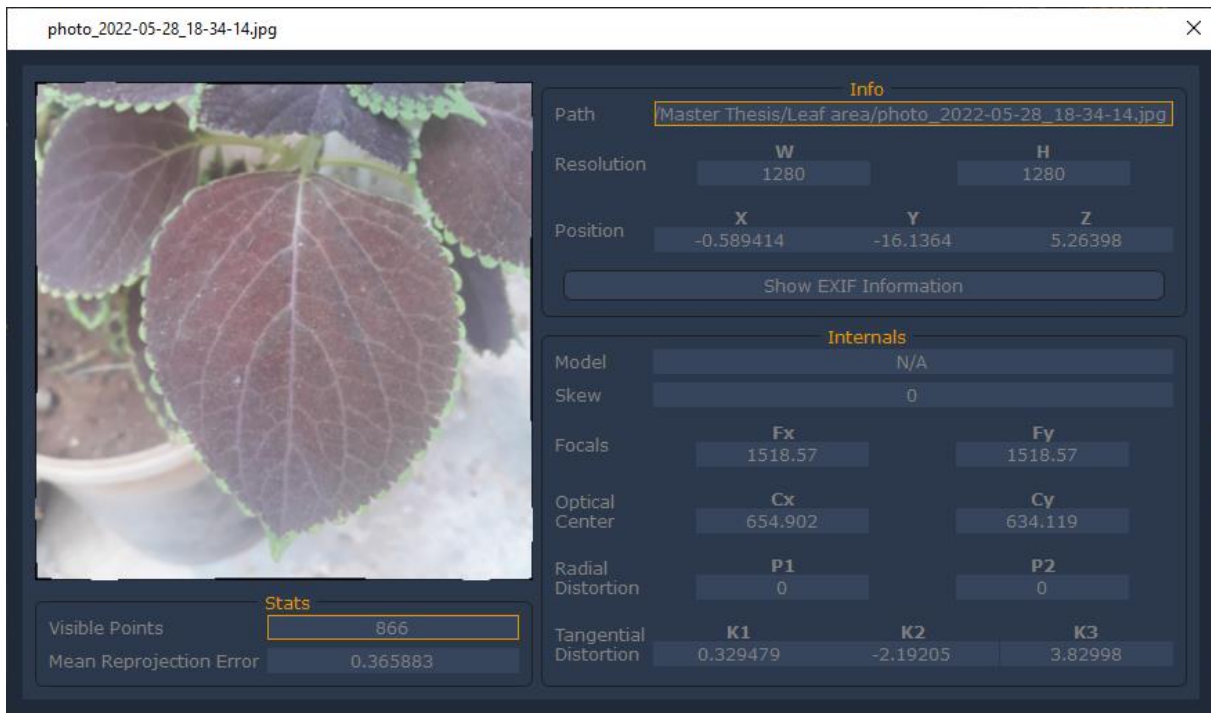


Figure 73 : calibration param

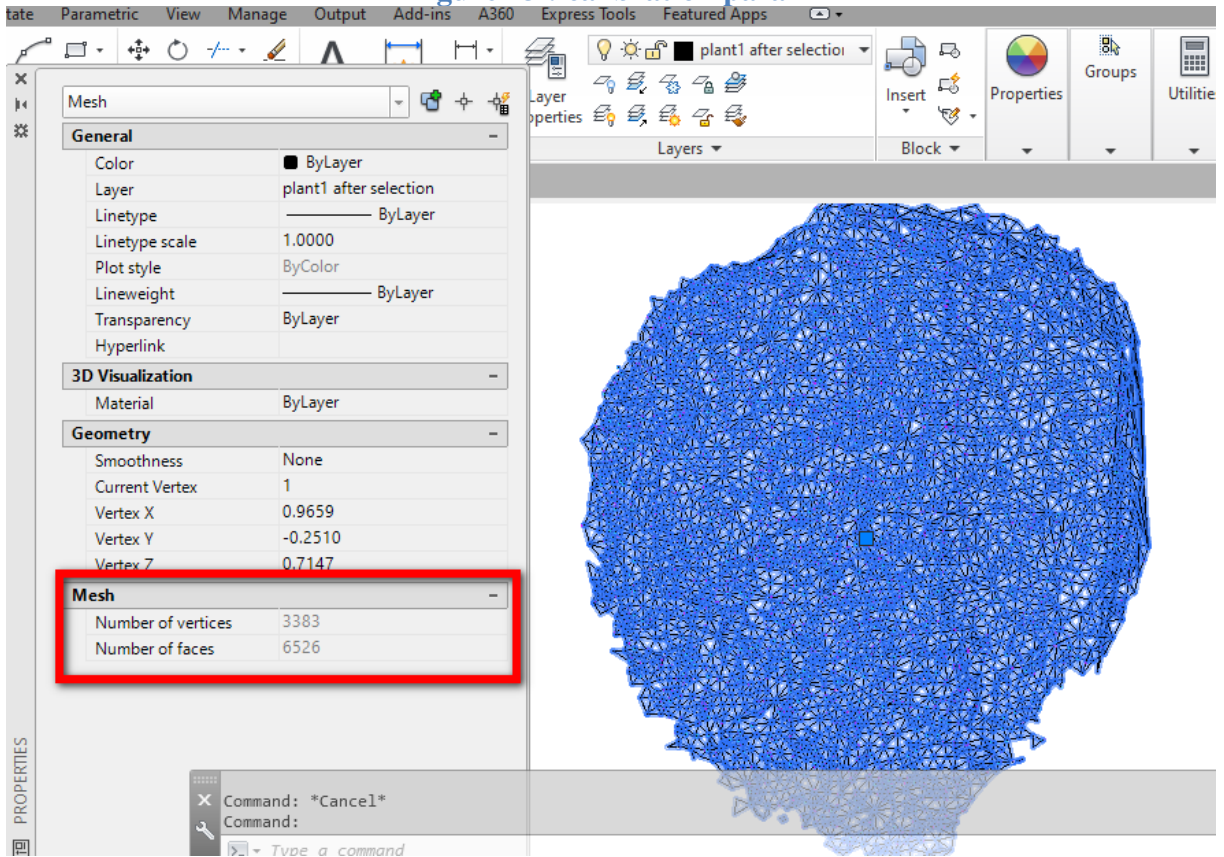


Figure 74 : TIN of Leaf automatic vectorization.

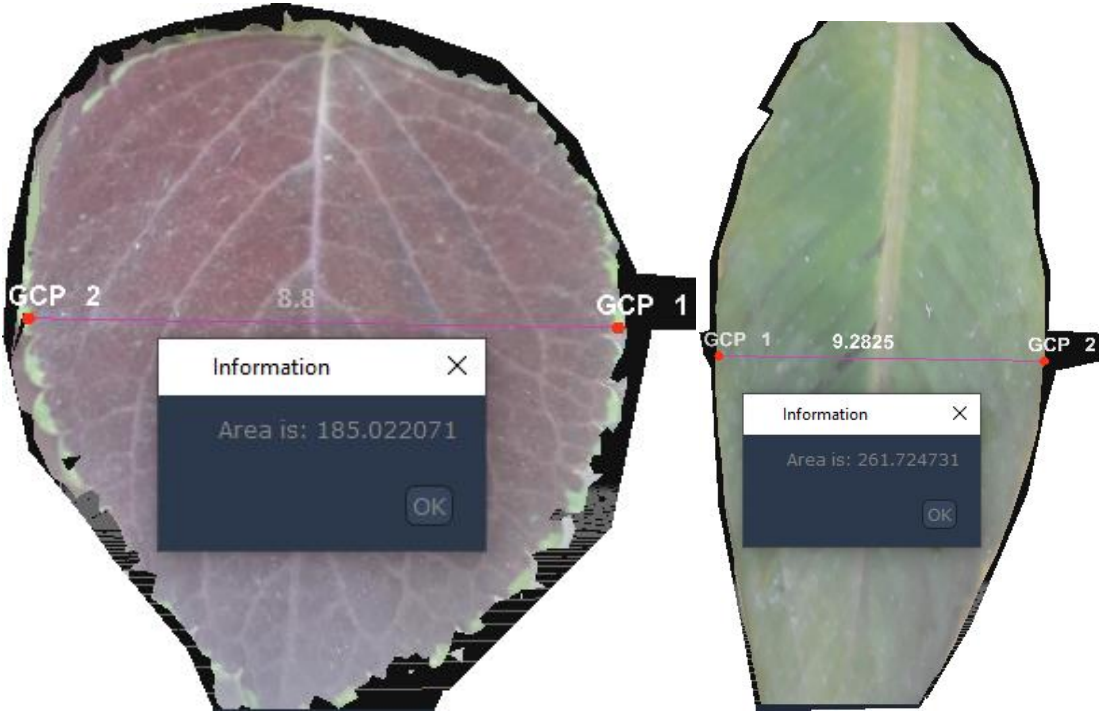


Figure 75 : leaves areas result.

4. RESULT AND DISCUSSION

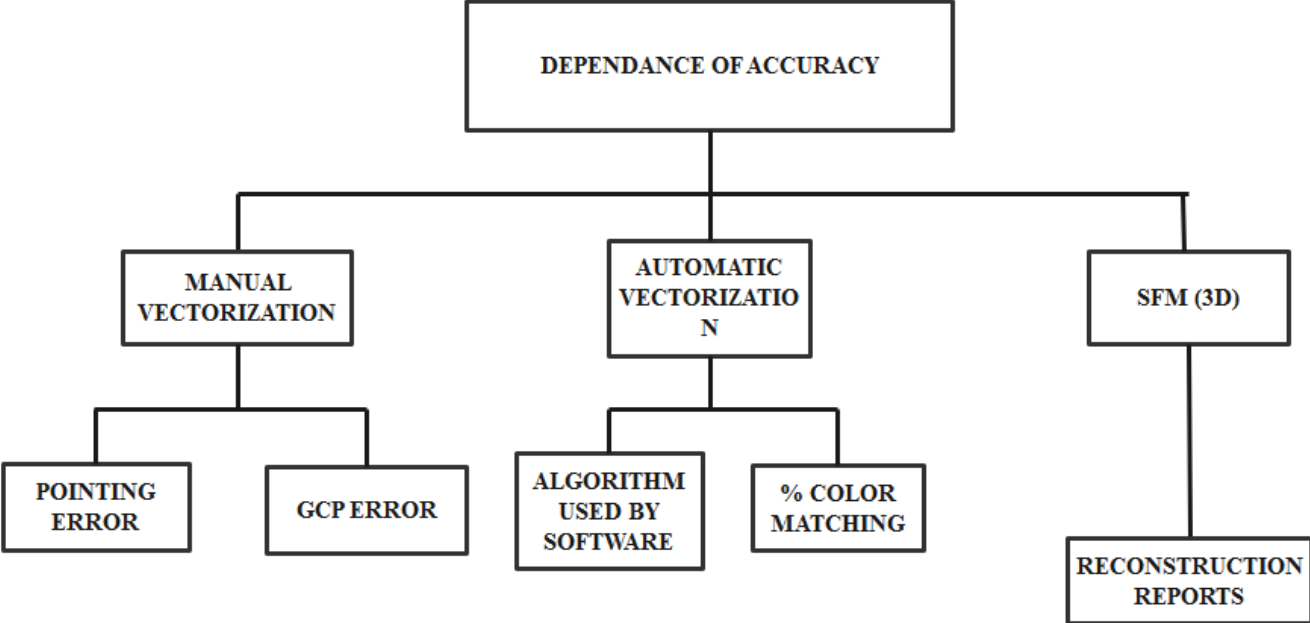


Figure 76 : The dependance of area calculation accuracy with the used method

4.1 AutomaticvectorizationunderGlobalMappr:

COLOR MATCHING(%)	NUMBER OF POLYGONS	TREATMENT TIME (min)	AREA
10	176,656	2,21	NOT DEFINED
30	24,517	1	NOT DEFINED
50	24,160	0,6	NOT DEFINED
70	73,799	1,53	NOT DEFIND

Table3: result for automaticvectorizationinGlobalMapper.

4.2Automaticvectorization in Vextractor:

From the settings, we choose the colors reduction method, and we choose number 12 in the number of colors field with the correct gradient.

As we mentioned earlier, vextractor is specific software to the vectorization and therefore we cannot calculate the area with it.

Manual vectorization under AutoCad:

CHAPTER5:APPLICATION




Treated leaf	Time (min)	Number of polygons	Area (cm ²)
	13,49	1	99,617
	2,21	1	2,81
	2,57	1	13,75

Table4: manual vectorization results in AutoCad.

After all these stages, we noticed that in the 2D treatment, the vectorization step is the primary step after taking pictures and converting them

In automatic vectorization: the processing time is relatively less than the processing time in manual vectorization, but the number of polygons is very high so it is too difficult to select the perimeter exactly in relation to the polygons that exist inside leaf .

On the other hand, in manual vectorization: the time is quite high but the precision is also high and we will have a single polygon so it was easy to calculate the surface automatically.

For automatic vectorization, the configuration parameters for color matching, or for the choice of vectorization

method varies from one plant to another view that each has its own texture and different colors it is for this reason that which is applicable to one plant cannot be obligatory applicable to another plant.

The manual vectorization is considered 100% exact and a reference for other vectorization in order to compare the results this is due to two parameters:

- The pointing error: here we minimize the pointing error we have a good polygon (a good vectorization).
- Image resolution.
 - But it's worth mentioning that, Our goal is not to make a comparison between automatic and manual vectorization, or show that this method is better than the other, but to show the diversity of this tool, that is to say we have the possibilities of use these methods according to the study case.

It turns out that in 3D treatment:

From the reports on plants, We notice that the mean square error is close for leaves A and B, the mean registered in order is 0,19 and 0,21 with a number of photos taken 3 for leaf A and 4 photos for the leaf B.

We also note that the time taken in the treatment to create the model is very few and close(45s for leaf A, 46s for leaf B),perhaps due to the lack of images for the two leaves.

It is not necessary to perform a 360° sfm on the plants in order to extract the surface for two reasons:

- The complexity of a 360° flight over living plants (integrated into their natural environment).
- Ansfm on the limb can be done by two photos only.
- ❖ As a general result we can say that we were able to obtain the different areas of different leaves on which the treatment was carried in any method.

CONCLUSION

CONCLUSION

To conclude this research, we would like to clarify definite points on the objective of our research result obtained to present the perspectives at the end.

Indeed, the objective of this work is to demonstrate various techniques on the area measurement by using a terrestrial photogrammetry on various leaves of plants using ordinary camera of a mobile phone after its calibration of course.

Following the results and discussion above, we can confirm the reliability of using this technique and instrument for all the leaves plants of different shapes and colors, because in this research the leaves were chosen arbitrarily.

Our goal is not to make a comparison between any method or technique, or show that this method is better than the other, but to show the diversity of this tool, that is to say we have the possibilities of use these methods according to the study case.

ANNEX

Processing Report

Plant A

Quick information

Project	
Date	28 May 2022
Program	PhotoModeler Premium
Version	2020
Cameras	3/3

Project Data

Cameras

Camera Name	Focal Length	Resolution
		1280 x 1280

Statistics

3D points per image	805
Oriented cameras	3
BA Mean Square Error	0.193844 px

Internal Camera Parameters

Camera calibrations

Camera Model	Skew	Focals	Optical Center	Radial Distortion	Tangential Distortion
	0.000000	X: 1518.573931 Y: 1518.573931	X: 654.902387 Y: 634.118759	K1: 0.329479 K2: -2.192053 K3: 3.829979	P1: 0.000000 P2: 0.000000

3D Points From Matches

Mean reprojection error

Image	Visible Points	Mean Reprojection Error
photo_2022-05-28_18-34-14.jpg	866	0.365883
photo_2022-05-28_18-34-15.jpg	845	0.36689
photo_2022-05-28_18-35-30.jpg	706	0.33827

Mean GSD	0.0106086
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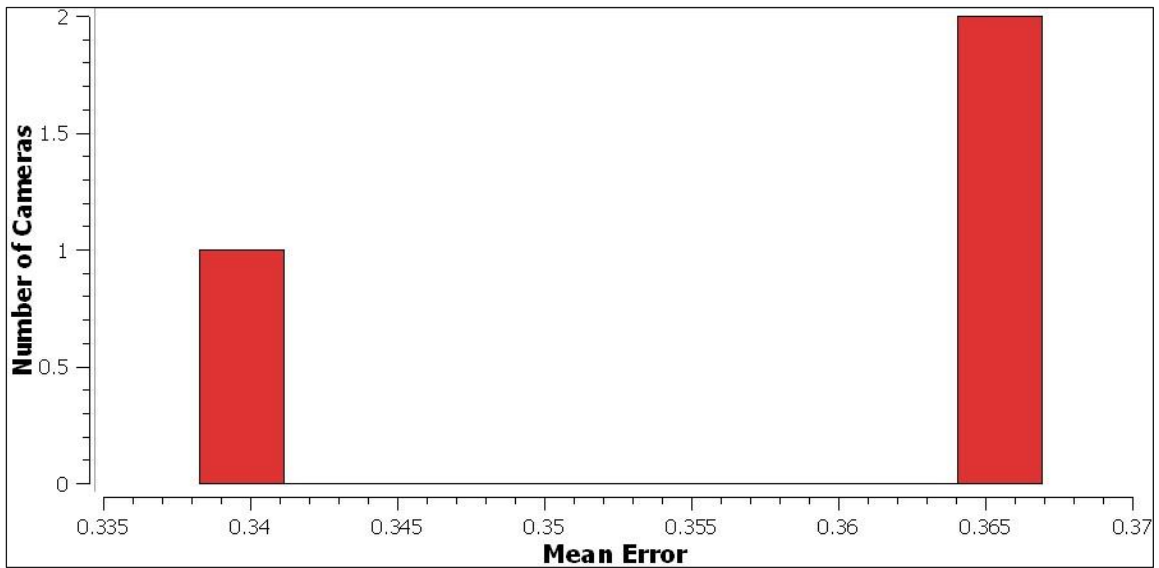


Figure 77 :Meanreprojection error histogram.

Sparse point cloud

Point cloud reconstruction information

Object Name	Sparse Point Cloud
Preset Type	General
Preset Name	Default
Computation Time	0d 0h 0m 16s
Point Count	876
BA Mean Square Error	0.193844
BA Reference Variance	0

Dense point Cloud 1

Point cloud reconstruction information

Object Name	Dense point cloud 1
Preset Type	General
Preset Name	Default
Computation Time	0d 0h 0m 8s
Seed Point Count	5839
Total Point Count	29375
Applied Filters	None

Mesh 1

Mesh reconstruction information

Object Name	Mesh 1
Preset Type	General
Preset Name	Default
Computation Time	0d 0h 0m 7s
Triangle Count	9980
Applied Filters	None

Textured mesh 1

Textured mesh reconstruction information

Object Name	Textured mesh 1
Preset Type	General
Preset Name	Default Single Texture
Computation Time	0d 0h 0m 14s
Triangle Count	9980
Texture Count	1
Applied Filters	None

Control Points

Name	X	Y	Z	Visible	Error
GCP 1	4.016681	-0.637984	5.466296	0	N/A
GCP 2	-4.644113	0.905488	5.686136	0	N/A

Alignment Information:

Final Mean residual: 0

Constraints residuals:

Constraint 0 Final residual: 0 (Before: 5.5002)

Processing Report

Plant B

Quick information

Project	Plant2
Date	28 May 2022
Program	PhotoModeler Premium
Version	2020
Cameras	4/4

Project Data

Cameras

Camera Name	Focal Length	Resolution
		1280 x 1280

Statistics

3D points per image	399
Oriented cameras	4
BA Mean Square Error	0.210661 px

BA Reference Variance

0.869424 px

Internal Camera Parameters

Camera calibrations

Camera Model	Skew	Focals	Optical Center	Radial Distortion	Tangential Distortion
	0.000000	X: 1134.494313 Y: 1134.494313	X: 553.216862 Y: 617.372265	K1: 0.177425 K2: -1.336016 K3: 2.271699	P1: 0.000000 P2: 0.000000

3D Points From Matches

Mean reprojection error

Image	Visible Points	Mean Reprojection Error
photo_2022-05-28_18-28-02.jpg	456	0.259252
photo_2022-05-28_18-28-03.jpg	458	0.260549
photo_2022-05-28_18-29-31.jpg	384	0.495803
photo_2022-05-28_18-29-32.jpg	299	0.484501

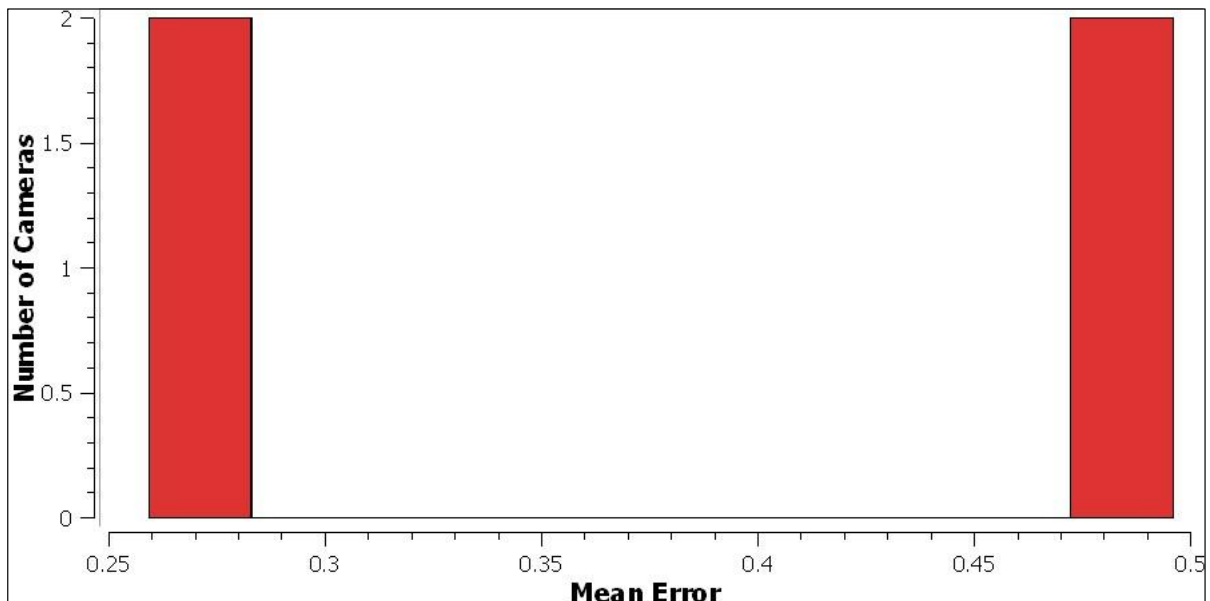


Figure 78 :Meanreprojection error histogram.

Sparse point cloud

Point cloud reconstruction information

Object Name	Sparse Point Cloud
Preset Type	General
Preset Name	Default
Computation Time	0d 0h 0m 17s
Point Count	487
BA Mean Square Error	0.210661
BA Reference Variance	0.869424

Dense point cloud 1

Point cloud reconstruction information

Object Name	Dense point cloud 1
Preset Type	General
Preset Name	Default
Computation Time	0d 0h 0m 10s
Seed Point Count	2682
Total Point Count	13434
Applied Filters	None

M e s h 1

Mesh reconstruction information

Object Name	Mesh 1
Preset Type	General
Preset Name	Default
Computation Time	0d 0h 0m 12s
Triangle Count	3533
Applied Filters	None

Textured mesh 1

Textured mesh reconstruction information

Object Name	Textured mesh 1
Preset Type	General
Preset Name	Default Single Texture
Computation Time	0d 0h 0m 7s
Triangle Count	3533
Texture Count	1
Applied Filters	None

Contr ol Points

Name	X	Y	Z	Visible	Error
GCP 1	-4.660111	0.291730	12.913033	0	N/A
GCP 2	4.352976	-1.905101	12.592160	0	N/A

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