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Trabajo Fin de Grado

Generation of photogrammetric products -digital elevation models and orthoimages- on the MTN 947

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List of abbreviations

MTN -	Mapa Topográfico Nacional (National Topographic Map)
GIS -	Geographic Information System
UAV -	Unmanned Aerial Vehicle (Drone)
GNSS -	Global Navigation Satellite System
GCP -	Ground Control Point
RMSE -	Root Mean Square Error
SfM -	Structure-from-Motion
MVS -	Multi-View Stereo
GIS -	Geographic Information System
GPS -	Global Positioning System
3D -	Three-Dimensional
2D -	Two-Dimensional
DEM -	Digital Elevation Model
IGN -	National Geographic Institute (Instituto Geográfico Nacional)
CNIG -	National Centre for Geographic Information (Centro Nacional de Información Geográfica)
PNOA -	National Plan of Aerial Orthophotography (Plan Nacional de Ortofotografía Aérea)
FOV -	Field of View
GSD -	Ground Sampling Distance
INS -	Inertial Navigation System
CMOS -	Complementary Metal-Oxide-Semiconductor
DSM -	Digital Surface Model

DTM -	Digital Terrain Model
RGB -	Red, Green, Blue (color channels)
GeoTIFF -	Geospatial Tagged Image File Format
KMZ -	Keyhole Markup Language (used for Google Earth files)
IDEE -	Infraestructura de Datos Espaciales de España (Spanish Spatial Data Infrastructure)
ETRS89 -	European Terrestrial Reference System 1989
UTM -	Universal Transverse Mercator (coordinate system)
COG -	Cloud Optimized GeoTIFF
IMU -	Inertial Measurement Unit
QGIS -	Quantum Geographic Information System
ASCII -	American Standard Code for Information Interchange
GPU -	Graphics Processing Unit
CPU -	Central Processing Unit
CPU -	Central Processing Unit
NDVI -	Normalized Difference Vegetation Index
RGB -	Red Green Blue
ExG -	Excess Green Index

General introduction

Photogrammetry is a powerful technique for precisely measuring objects and extracting 3D data from images. The geometric features of overlapping photographs can be used to determine the shape, size, and location of objects captured in the images. With numerous applications in fields such as surveying, mapping, architecture, engineering, and geology, photogrammetry facilitates the production of high-resolution digital elevation models, orthoimages, and 3D models of landscapes, buildings, and other elements. The accessibility and cost-effectiveness of photogrammetry have grown significantly with the introduction of drones and other aerial platforms, expanding its application across a wide range of domains [1].

The objective of this final year project report is to contribute to the field of geomatics and surveying by creating fundamental photogrammetric products.

This work has been developed in the Departament of Cartographic and Geodetical Engineering and Photogrammetry at the University of Jaén in Spain through a mobility grant. The University's renowned expertise in this field provides the guiding light, ensuring the precision and reliability of every step undertaken. With a commitment to cutting-edge methodologies and the application of advanced tools, this report unveils the intricate process from data acquisition to the generation of final outputs. The University's role as the hosting firm underscores the project's foundation in academic rigor and practical excellence.

Specifically, this project focuses on generating digital elevation models (DEMs) and orthomosaics using photogrammetric techniques applied to the MTN 947 sheet in Andalusia, Spain. These photogrammetric products are vital resources for mapping and analyzing terrain and land features. They offer precise spatial representation and insightful information about elevation variations.

The aim is to create an accurate and high-quality orthophotomap by using open data and contributing to the geospatial data and analysis capabilities of the region. The results will be valuable in various areas, supporting tasks such as infrastructure planning, environmental assessment, and land management. This project stands as a testament to the possibilities inherent in leveraging open source data. It serves as an illustrative example of the valuable outcomes achievable by users, namely, the creation of Digital Elevation Models (DEMs) and

Orthoimages of the terrain. Undoubtedly, these outputs hold immense significance and practical utility..

To achieve its objectives, this report is divided into three main chapters and a general conclusion.

Chapter 1 provides a foundational overview of the report, starting with a brief introduction to the project and its broader context. It outlines the key objectives to be achieved and concludes with a summary of the report's structure, setting the stage for the upcoming chapters.

Chapter 2 delves into the methodologies involved and discusses in detail the processes of aerial data acquisition, mission planning, orthophoto applications, orthomosaic generation, and quality control, including the software and equipment used.

Chapter 3 details the practical application, workflow, and results of the methodologies outlined in Chapter 2. It covers all aspects of the workflow, from data sources and pre-processing to the generation of final and secondary outputs, with a strong emphasis on quality control at each stage.

1.1. Introduction

This project aims to develop precise and high-quality photogrammetric products that are specifically designed for the MTN 947 sheet by utilizing contemporary hardware and software.

1.2. General context of the project

The MTN 947 sheet in Andalusia, Spain, is a topographic map that covers a specific area within the region. It is part of the MTN (Mapa Topográfico Nacional) series, which is a collection of topographic maps at a 1:50000 scale produced by the National Geographic Institute (IGN) of Spain. These maps provide detailed information about the terrain, including elevation contours, hydrographic features, vegetation, roads, and other relevant geographical elements [2].

The area of study is located in Andalusia, in the south of Spain, and covers an area of 1110.589 km². It spans across multiple cities, including Jaén, Torres, Los Villares, Cambil, Cárcheles, Pegalajar, Limena, and Mancha Real, as shown in the Figure below.

(Figure 1) is a map representing the geographical location of the study area:

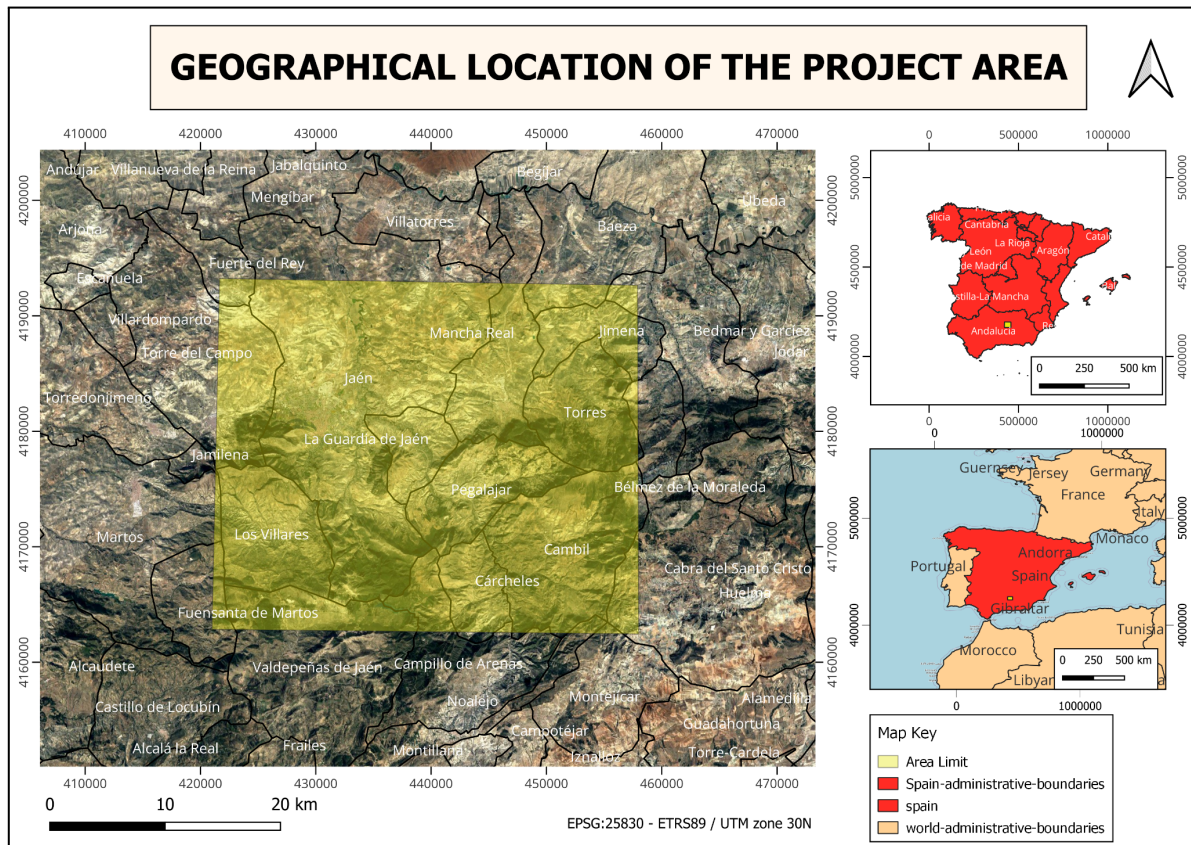


Figure 1. Geographic location of the study area

1.3. Objectives

The main objective of this project, which is to create high-quality and precise photogrammetric products for the MTN 947 sheet in Spain using modern technology and software, can be summarized as follows:

- Using photogrammetric techniques, acquire and analyze aerial images of the MTN 947 sheet.
- Create a high-quality and accurate DTM and DSM for the coverage region of the MTN 947 sheet.
- Generate an orthophotomosaic of the MTN 947 sheet utilizing the obtained DTM.
- Create an Orthophotomap that is professionally standardized and precisely in accordance with the rules and requirements stipulated by CNIG.
- Evaluate and ensure the precision and reliability of the photogrammetric products generated.

1.4. Report structure

This report is divided into the following sections:

- Introduction: This section provides an overview of the project, its objectives, and the significance of developing photogrammetric products for the MTN 947 sheet.
- Methodology: The methodology section details the software, equipment, and data acquisition procedures utilized in this project, as well as the step-by-step photogrammetric processing workflow.
- Application and results: This section presents the results of the project, including the generated photogrammetric products, quality control assessments, and any limitations encountered during the research.
- Conclusion: In the conclusion section, the main findings of the project are summarized and their implications are discussed.
- Bibliography: A comprehensive list of sources used in the project is provided for reference and further exploration.

1.5. Conclusion

By addressing the objectives outlined in this report, this project aims to contribute to the field of geomatics and surveying by providing accurate and valuable photogrammetric products specifically tailored to the MTN 947 sheet in Spain.

The first chapter provides a general introduction to the project, starting with a brief overview followed by the broader context in which the project is situated. It then outlines the primary objectives aimed at being achieved by the end of the project. Lastly, the structure of the report is presented, providing a roadmap for what to expect in the subsequent chapters.

In the next chapter, the discussion will detail the processes involved in aerial data acquisition, mission planning, orthophoto applications, orthomosaic generation, and quality control, including the software and equipment used.

2.1. Introduction to PNOA

The National Plan of Aerial Orthophotography (PNOA) is a Spanish government program that aims to create a national database of orthophotos of Spain. The National Geographic Institute (IGN) coordinates the project, which began in 2004.

The PNOA covers all of Spain, including the Balearic and Canary Islands. It produces high-resolution orthophotos that can be utilized for mapping, land-use planning, environmental monitoring, and disaster management.

It is a collaborative project involving the General State Administration and the Autonomous Communities. It involves photogrammetric flights and rigorous data processing, following technical specifications agreed upon by all participating Public Administrations. This collaborative production approach among different administrations is consistent with the spirit of the Inspire Directive, which calls for the establishment of a Geographic Data Infrastructure in Europe. The objective is to capture the maximum level of detail in geographic information only once and openly share it among different stakeholders with a need for such data [3].

2.2. Aerial data acquisition and mission planning

2.2.1. Image Acquisition

The initial phase of the project, centered on generating orthomosaics and digital elevation models (DEMs) from the MTN 947 sheet in Andalusia, involves the critical process of image acquisition. This process involves capturing aerial images of the target area using a specialized sensor mounted on an aerial platform, which, in this case, is a plane equipped with the Leica DMC III camera. The captured images serve as the foundation for subsequent photogrammetric processing.

2.2.1.1. Sensor Geometry

The sensor geometry of the Leica DMC III camera plays a pivotal role in determining the accuracy and quality of the captured images. Key parameters influencing sensor geometry include:

- **Focal Length:** The focal length of the camera lens, set at 92 mm, determines the camera's field of view and impacts the image scale, see (Figure 3).

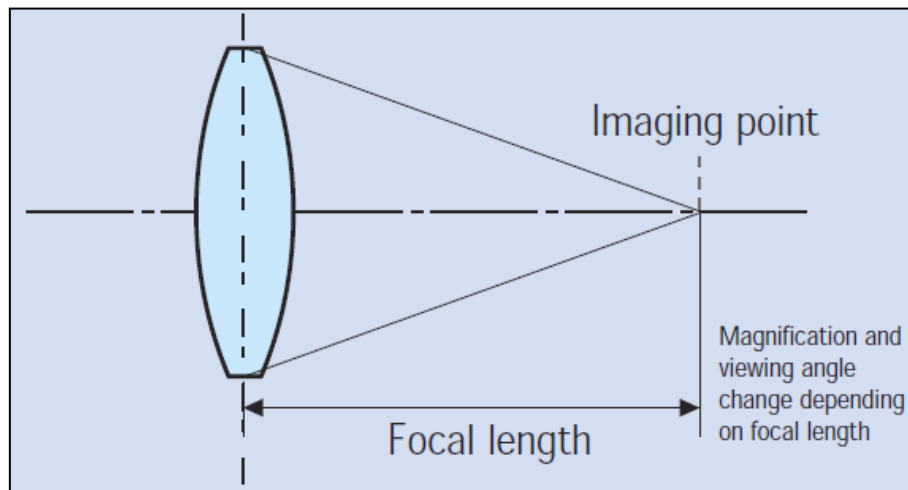


Figure 2. Representation of the focal length [4]

- **Pixel Size:** With a pixel size of $3.9\ \mu\text{m}$, the individual size of each pixel on the camera's sensor is established. This pixel size directly affects the level of detail captured in the images.
- **Sensor Position and Orientation:** The precise positioning (latitude, longitude, and altitude) of the camera within the aircraft and its orientation (roll, pitch, and yaw angles) relative to the scene are integral components for accurately projecting the scene onto the image plane.

2.2.1.2. Stenope Perspective and Mathematical Camera Model

At the heart of understanding how the sensor captures images lie the stenope perspective and the mathematical camera model. In the stenope perspective, light rays from various points in the scene pass through the camera's lens aperture, ultimately projecting onto the sensor.

The mathematical camera model combines intrinsic and extrinsic parameters to perform this projection.

For the MTN 947 sheet project, the mathematical camera model employs intrinsic parameters such as the camera's focal length, principal point, and distortion coefficients. Extrinsic parameters encompass the camera's spatial position and orientation during image acquisition. This model transforms the 3D coordinates of scene points to their corresponding 2D image coordinates, facilitating the faithful representation of the real-world scene in the images.

2.2.2. Desired outcome

The main goal of this research project is the meticulous creation of an orthophotomap that is professionally standardized and precisely in accordance with the rules and requirements stipulated by CNIG. This achievement is attained through a systematic process involving the development of a precise Digital Elevation Model (DEM) and the methodical assembly of an orthomosaic.

The resulting orthophotomap is not a mere visual depiction; rather, it embodies meticulous analysis and georeferenced precision. The harmonious amalgamation of the DEM and orthomosaic ensures each pixel carries significant geospatial value, thereby imparting a comprehensive understanding of the depicted terrain.

The desired outcome of this project is to produce an orthophotomap with the following distinct map features:

- **Georeferenced Accuracy:** The orthophotomap will exhibit precise georeferencing, ensuring that every pixel corresponds to an accurate geographic location on the Earth's surface. This foundational accuracy will support reliable spatial analysis and integration with other datasets.
- **True-to-Scale Representation:** The orthophotomap will maintain accurate scale proportions, preserving the true spatial relationships between features. This fidelity will allow for dependable measurements and assessments directly from the map.
- **High-Resolution Imagery:** The orthophotomap will showcase high-resolution imagery, capturing intricate details of landforms, vegetation, infrastructure, and built structures. This level of detail will facilitate in-depth analysis and informed decision-making.
- **Seamless Mosaicking:** The orthophotomap will seamlessly mosaic multiple aerial images, resulting in a continuous and coherent representation of the landscape. This cohesive presentation will eliminate visible image boundaries and provide a unified view.
- **Consistent Color Balance:** The color balance and tonal consistency across the orthophotomap will ensure that colors accurately reflect real-world conditions. This visual consistency will enhance interpretation and analysis.
- **Geospatial Reference Aids:** Orthophotomap will incorporate essential geographic reference aids, such as grids and scale bars, to assist in spatial orientation and accurate measurements.

- **Clear Feature Delineation:** Administrative, geographic, and thematic boundaries will be clearly delineated on the orthophotomap, ensuring a comprehensive understanding of territorial divisions and key features.
- **Contextual Information:** The orthophotomap will provide relevant contextual information, such as labels, place names, and notable landmarks, contributing to a richer interpretation of the area.
- **Metadata and Attribution:** The Orthophotomap will include thorough metadata detailing data sources, acquisition dates, image resolutions, and any pertinent copyright or attribution information.

2.2.3. Aerial photos characteristics

The PNOA conducts Aerial photography missions using a digital aerial camera. The resolution of the orthophotos has changed over time, Usually the resolution used for PNOA in the Andalusia region was 45 cm/pixel, with the objective of obtaining orthoimages with GSD of 50 cm/pixel, although as of 2017 the size was set to 22 cm/pixel with the objective of generating orthoimages with a higher level of detail (25 cm/pixel).

The scale of the map produced in this project is 1:25000, where one unit on the map corresponds to 25000 units on the ground, which characterizes a small-scale map intended to depict broader geographic regions, In this context, it's essential to note that the resolution achieved in this project permits the creation of cartographic products with a significantly higher level of detail, a fact well-documented in the ASPRS Guidelines []. Remarkably, the resolution of the images used here surpasses the requirements for a 1:25000 scale map. However, this scale, widely recognized as a global standard due to its myriad of applications, aligns with the product catalog of the NGI and hence has been adhered to.

This decision underlines the versatility and utility of the 1:25000 scale in various geographic and cartographic contexts. This section delves into the expectations and considerations regarding the level of detail attainable at this scale.

- **Landforms and Terrain:** A scale of 1:25000 allows for the depiction of major landforms with clarity. Prominent mountain ranges, expansive valleys, and significant hills will be distinctly represented, offering an overview of the terrain's larger features. However, finer undulations and subtle changes in topography might not be as pronounced.

- **Water Features:** Notable water bodies, such as major rivers, expansive lakes, and extensive oceans, will be visibly showcased on the map. Larger bodies of water contribute to the map's overall context. Smaller streams, ponds, and minor water features may not receive the same level of prominence.
- **Human Settlements:** Urban centers, towns, and villages of significant size will be identifiable, often accompanied by their primary road networks. While the layout and extent of larger settlements are depicted with clarity, smaller hamlets, villages, and intricate street patterns might appear less detailed.
- **Transportation Networks:** The map will effectively display major transportation routes, including highways and principal roads, contributing to the map's functional utility. However, local roads, narrower streets, and lesser-used transportation arteries may be depicted in a more generalized manner.
- **Vegetation and Land Cover:** Distinctive vegetation types and sizable forested areas will be discernible, providing insights into the region's natural landscape. Yet, the intricate details of smaller groves and individual trees may not be as explicitly represented.
- **Built Environment:** Prominent infrastructure and notable features, such as airports, major buildings, and significant landmarks, will find representation on the map. However, smaller structures and localized features might receive less emphasis due to the scale's broader focus.
- **Administrative Divisions:** Larger administrative boundaries, such as regional and district demarcations, will be clearly indicated, contributing to the map's informational context. Smaller administrative divisions may be portrayed with a reduced level of distinction.
- **Topographic Aspects:** Significant topographic elements, such as valleys, ridges, and primary contour lines, will be perceptible, offering insights into the region's broader topographical characteristics. More intricate topographic nuances might be less pronounced.

To achieve the desired outcome of this project and taking into account the level of detail to be reached, here are the characteristics of PNOA aerial photos [5]:

- **Ground Sampling Distance (GSD):**

The GSD for PNOA aerial photos is typically 0.22 meters, which means that each pixel represents an area of 0.22 square meters on the ground.

- Contrast and Luminosity:

PNOA aerial photos aim to capture high contrast and well-balanced luminosity. This ensures that objects and features on the ground are clearly distinguishable and accurately represented in the images.

- Shadow Levels:

The aerial photos strive to minimize shadows to ensure that features are visible and identifiable. This is particularly important for accurate photogrammetric processing and the subsequent generation of orthophotos and DEMs.

- Avoiding Hotspots:

PNOA aerial photos are captured in a way that minimizes the presence of overexposed areas (hotspots) and underexposed areas. This helps to maintain uniform lighting conditions across the images and ensures accurate data extraction.

- Weather Conditions:

Flights for PNOA aerial photos are scheduled in clear weather conditions. Cloud cover, fog, mist, and adverse weather conditions are avoided to ensure optimal image quality and reliable data capture.

- Color Consistency:

PNOA aerial photos aim to maintain color consistency throughout the coverage area. This ensures that color variations caused by changes in lighting conditions are minimized, resulting in accurate and reliable data for processing.

- Technical Specifications:

The images are captured using a digital aerial camera with a specific resolution, lens, and sensor characteristics that are calibrated to meet rigorous technical standards.

2.2.4. Flight plan calculation

In order to cover a specific area of the territory to obtain orthophotos, the flight path of an aircraft must be such that the photographs have overlap or a common photographed area, both in the direction of flight progression and between adjacent passes, Refer to (Figure 4) below, which represents the Longitudinal Overlap and the Transverse Overlap:

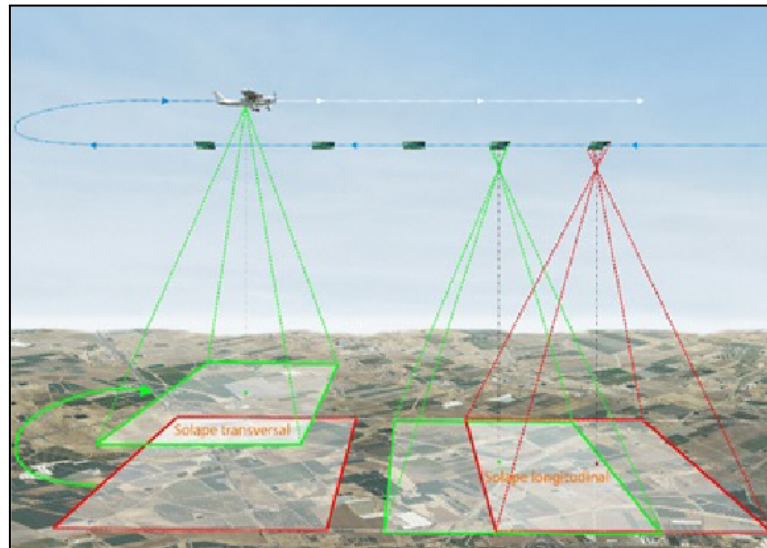


Figure 3. Representation of the photographs overlap [6]

In PNOA, the configuration of the flight passes, except in exceptional cases, is East-West, and the trajectory would have a geometry similar to that of (Figure 5):

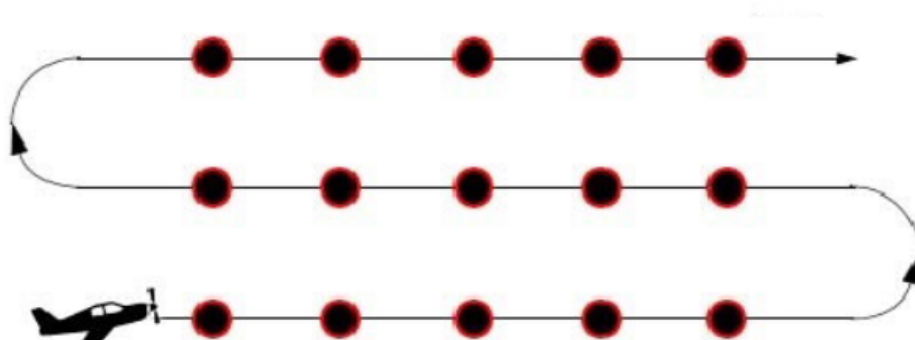


Figure 4. Flight trajectory [7]

The flights are usually conducted in strips of one kilometer by fifteen kilometers, but the strip length may vary from mission to mission depending on the characteristics of the region of interest. The strips are then patched together to form a complete orthophoto of the area.

Prior to flight, the camera must be calibrated, which is a crucial step in photogrammetry that aims to correct various distortions and inaccuracies inherent in remote sensing systems and cameras. It ensures that the acquired imagery accurately represents the real world. In the context of the Leica DMC sensor, calibration involves addressing lens distortion and radiometric inconsistencies.

- **Lens Distortion Correction:** Lens distortion, a common optical aberration, causes straight lines to appear curved in images. Calibration corrects this distortion using

mathematical models that rectify the image to remove these distortions, ensuring that objects are represented accurately. Common lens distortions are the barrel and pincushion distortions [8], See (Figure 6) below:

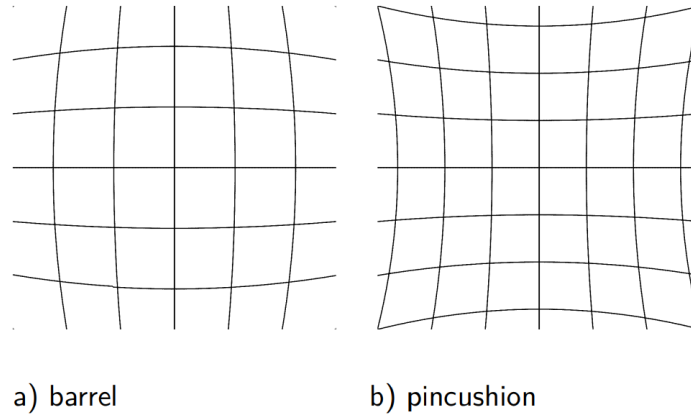


Figure 5. Common lens distortions [9]

- **Radiometric Calibration:** Radiometric calibration addresses variations in sensor sensitivity and illumination conditions, ensuring consistent brightness and color across the image. This step is crucial for accurate interpretation and analysis.

Ground Sampling Distance (GSD): GSD refers to the physical distance on the ground that is represented by a single pixel in an image. It essentially quantifies the level of detail that can be captured in an image. Smaller GSD values indicate higher image resolution, as each pixel covers a smaller area on the ground, allowing for finer details to be captured.

Pixel Size: Pixel size, on the other hand, is a measure of the dimensions of each individual pixel in the image, typically expressed in units like micrometers (μm) or millimeters (mm) for aerial or satellite imagery. It represents the size of the area that each pixel covers on the ground.

The relationship between GSD and pixel size can be expressed mathematically as:

$$\text{GSD} = (\text{Pixel Size} \times \text{Flying Height}) / \text{Focal Length}$$

Pixel Size: The dimensions of the pixel in the image sensor, usually provided by the sensor specifications.

Flying Height: The altitude at which the camera or sensor is mounted above the ground.

Focal Length: The focal length of the camera lens.

This relationship is crucial for flight planning in aerial photography or remote sensing. It allows for the calculation of the GSD needed to achieve a certain level of detail in the captured images. By adjusting the flying height, pixel size, or focal length, one can control the GSD, ensuring that it meets the requirements of the specific project, whether it's mapping, surveying, or any other application.

Based on the aforementioned considerations, the project's desired outcome, and the characteristics of the aerial photographs, the flight must comply with the following requirements, represented in the tables below.

The Table below represents the requirements for the Longitudinal Overlap and the Transverse Overlap:

Table 1. The Longitudinal Overlap and the Transverse Overlap [10]

Longitudinal Overlap:	60% In mountainous and coastal areas, and based on the flight planning analysis, the decision may be made to increase the longitudinal coverage to avoid areas without stereoscopy.
Transverse Overlap:	$\geq 30\%$ calculated individually for each frame, with a Field of View (FOV) equal to or less than 65° . If it is greater, a FOV of 65° will be considered for transverse coverage purposes. In mountainous areas, the number of passes will be increased, or interspersed passes will be made in such a way that at no point in the frame is the coverage less than 25%.

The reason for this overlap is to generate three-dimensional models in order to apply corrections to the images for relief effects.

Increased overlap in photogrammetry offers several key benefits. Firstly, it enhances the reliability of photogrammetric data by providing more observations, making the results more robust. Secondly, it helps prevent the loss of information in areas with low overlap, ensuring more comprehensive 3D terrain data. Lastly, higher overlap reduces the potential for displacement due to terrain relief in orthoimage generation, resulting in more accurate orthoimages.

The conditions for the execution of the flight specified in the technical specifications are represented in the table below:

Table 2. The conditions for the execution of the flight [11]

Date	Flights will be scheduled to ensure that the Sun's altitude is $\geq 40^\circ$.
Schedule:	The schedule will be such that the Sun's altitude above the horizon is $\geq 40^\circ$ sexagesimal degrees.
Weather conditions:	Clear weather, without clouds, fog, mist, snow, flooded areas, or generally any adverse weather conditions. Avoid flights at noon in July and August on calm days because Overexposed image risk is very high, specifically in bright terrains. The flight for this project was conducted on 19/07/2022.
Pixel Size and Flight Altitude:	For a flight with a GSD of 0.25 m: The average pixel size for the entire pass will be 0.25 m $\pm$ 10%. There will be no more than 10% of frames in each pass with an average pixel size greater than 0.25 m.
Pass Direction:	East - West (following parallels). Other flight configurations may be proposed that differ from the Technical Direction, and the Technical Direction will decide whether the proposed configurations are feasible.

Summary

Overall, the PNOA is a valuable resource not only for Spanish geomatics and surveying communities, these products are used as basic geographical information products for all the people who work in terrain information (agronomy, geology, infrastructures, ecology, forestry, archaeology, etc.). providing high-quality orthophotos that could be utilized for a variety of purposes. The photogrammetric flights technical specifications ensure that the produced photographs are accurate, dependable, and of high quality.

2.3. Applications of orthophotos

Orthophotos are widely used for cartography and land usage. Further, they can be used to update and construct high-accuracy and detailed maps, which can be useful in a range of industries such as urban planning, agriculture, forestry, and environmental monitoring. They can also be used to identify occupancy changes and patterns over time, which can help inform land use management and planning decisions.

Orthophotos have a wide range of real-world applications across various fields, including:

- **Urban Planning and Development:** In major cities like Singapore, orthophotos assist urban planners in analyzing existing infrastructure, identifying potential areas for expansion, and optimizing transportation networks to accommodate the growing population [12].
- **Agriculture and Crop Management:** In fertile agricultural landscapes, orthophotos are used by farmers to monitor the health of olive groves, vineyards, and citrus orchards. They help in assessing irrigation needs, detecting disease outbreaks, and optimizing harvest schedules.
- **Environmental Monitoring:** In the Sierra Nevada mountains and Doñana National Park, orthophotos aid environmentalists in monitoring biodiversity and habitat changes. They assist in tracking vegetation dynamics, animal migrations, and the effects of climate change in many research projects all around the world [13].
- **Tourism and Recreation:** Orthophotos can play a crucial role in promoting tourism across the region's historical cities like Granada and Cordoba. Interactive maps and trail guides based on orthophotos enable tourists to explore historical sites and natural attractions.
- **Cultural Heritage Documentation:** Andalusia is rich in cultural heritage, with landmarks like the Alhambra and Mezquita. Orthophotos provide accurate documentation for preservation and restoration efforts, assisting conservationists in maintaining these iconic structures [14].
- **Coastal Management:** Along the Costa del Sol and Costa de la Luz, orthophotos assist coastal authorities in monitoring erosion, coastal development, and managing beachfront infrastructure to maintain the region's appeal [15].

- Emergency Management and Disaster Response: In regions prone to wildfires or flash floods, orthophotos are helpful for disaster response. Authorities can use them to assess affected areas and plan evacuation routes.
- Infrastructure Management: In industrial zones like the Bay of Algeciras, orthophotos can help manage port facilities, road networks, and utility infrastructure. They support maintenance, expansion, and safety assessments.
- Natural Resource Management: In rural areas, orthophotos can assist in managing grazing lands and protecting sensitive ecosystems. They provide data for land use policies that balance agriculture with environmental conservation.
- Transportation Planning: In the region's transportation hubs like Malaga, orthophotos can be used for analyzing traffic patterns, optimizing public transportation routes, and managing road maintenance.
- Renewable Energy Site Planning: With increasing interest in renewable energy, orthophotos can aid in site selection for solar and wind energy projects. They provide accurate terrain data for assessing feasibility and optimizing energy generation.
- Archaeological Surveys: Orthophotos help archaeologists uncover buried archaeological sites across the region, such as Roman ruins in Italica or Phoenician settlements near Cadiz.
- In Andalusia, as in many regions, orthophotos offer essential geospatial information that supports a variety of sectors. They contribute to sustainable development, informed decision-making, and effective resource management while preserving the region's natural and cultural heritage.

Additionally, Orthophotos outperform typical aerial photogrammetry in various ways; here are some of the main advantages [16]:

- Orthophotos are accurate and distortion-free representations of the earth's surface made by correcting aerial images for distortions induced by camera angle, terrain topography, and other variables. As a result, the earth's surface is represented true-to-scale and without distortion.
- Orthophotos provide a consistent representation of the earth's surface since they are created from aerial photographs taken at the same scale and with the same camera.
- Orthophotos are simple to interpret and can be used to identify objects such as roads, buildings, and changes in land use.

- GIS-compliant: Orthophotos can be utilized as a starting layer in GIS applications, enabling spatial analysis and mapping.
- Advantages in both expense and time: Orthophotos can be utilized for a variety of purposes, including mapping, land use planning, and environmental monitoring. They provide a quick and inexpensive approach to gathering current and accurate information on the Earth's surface.

Overall, the use of orthophotos can improve the accuracy and efficiency of geomatics and surveying applications significantly.

2.4. The methodology to obtain orthomosaics

The following steps are typically used to obtain orthomosaics:

Acquisition of Aerial Photos: The first stage is to gather aerial photos of the target area using an unmanned aerial vehicle (UAV), an airplane, or a satellite. The photos must be of high quality and have enough overlap to be photogrammetrically processed.

Photogrammetric Processing: The obtained images are then processed with photogrammetric software to generate a digital elevation model (DEM), which is then used to generate a terrain-corrected orthophoto, this is done using the differential rectification method which is a process that rectifies small portions of a photograph individually. It contrasts conventional optical methods with digital ones. In digital differential rectification, each pixel is transferred from the original image to the resulting one. A digital elevation model (DEM) is used to correct for terrain variations. The DEM is assumed to have the same format as the digital image. The objective is to assign gray values from the photograph to each DEM pixel. This is achieved by transforming 3D DEM coordinates (X, Y, Z) into image coordinates (x, y) using collinearity equations:

$$x = x_p - c \frac{r_{11}(X - X_0) + r_{21}(Y - Y_0) + r_{31}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} = f_x(x', y')$$

$$y = y_p - c \frac{r_{12}(X - X_0) + r_{22}(Y - Y_0) + r_{32}(Z - Z_0)}{r_{13}(X - X_0) + r_{23}(Y - Y_0) + r_{33}(Z - Z_0)} = f_y(x', y')$$

where:

- The interior orientation of the camera: x_p' , y_p' , c
- The exterior orientation of the camera: X_o' , Y_o' , Z_o'
- perspective center, R
- a rotation matrix composed of w , ϕ , κ rotation angles
- The pixel-spacing of the digital image in camera units: p_x , p_y (mm)
- The cell-size of the DEM pixels in ground units: g_x , g_y (m)

Gray values are then interpolated using resampling methods, and the density is stored in the digital orthophoto at the corresponding X , Y location.

Orthomosaic production:

1. Feature Detection and Matching:

- **Identification:** For each orthophoto, software pinpoints unique keypoints or features. These represent distinct patterns or points within an image that can be consistently recognized across multiple photos.
- **Matching:** Upon identifying these features in each orthophoto, the software seeks matches within overlapping sectors of neighboring images.
- **Orientation and Position:** Through the recognized matched features, the software calculates the relative orientation and placement of each image in relation to its adjacent counterparts.

2. Bundle Adjustment:

- **Optimization:** Central to photogrammetry, bundle adjustment is an essential optimization process. Its purpose is to enhance the accuracy of camera orientations and positions by reducing the re-projection error of matched points.
- **Alignment:** Simplified, the process ensures that the features identified in the previous stage seamlessly align in the resultant stitched imagery.

3. Seam Line Generation:

- **Imperfections:** Due to variables like lighting variances, exposure differences, or diverse ground conditions when each shot was captured, not all overlapping orthophotos will match flawlessly.

- **Determination of Seam:** To counteract these discrepancies, the software discerns the most effective "seam" to join two overlapping images. Selection criteria typically involve routes that traverse areas with minimal differences or that bypass significant features, facilitating a more seamless connection.

4. Radiometric Adjustment:

- **Need:** Subsequent to the seam identification, there may still exist radiometric (color and brightness) disparities among the stitched orthophotos.
- **Adjustment:** To address this, radiometric adjustments, sometimes termed color balancing or feathering, are applied. This process modulates image brightness, contrast, and color to ensure a uniform look across the entire mosaic.

5. Mosaicking and Blending:

- **Blending Process:** Once optimal seam lines are ascertained and radiometric modifications are made, the software initiates the image blending procedure.
- **Transition Management:** To guarantee smooth transitions, the borders of each image along its seam undergo feathering or blending, obviating any discernible shifts from one orthophoto to its neighboring image.

2.5. Quality Control

The orthomosaic is checked for any flaws, such as misregistration or color anomalies. Any errors were identified and corrected. It encompasses critical aspects such as color consistency, seamline optimization, and pixel shift assessment, all aimed at ensuring the highest standards of accuracy and reliability for the final orthomosaic product.

the methodology and standards established by ASPRS (American Society for Photogrammetry and Remote Sensing) for accuracy assessment of digital geospatial data:

- **Horizontal and Vertical Accuracy Testing:** ASPRS accuracy standards require the testing of both horizontal and vertical accuracy of geospatial datasets. Horizontal accuracy is assessed by comparing planimetric coordinates, while vertical accuracy is assessed by comparing elevations.
- **Well-Defined Points:** Accuracy testing is based on comparing dataset coordinates with those from an independent source of higher accuracy. These points should be

well-defined, easily visible or recoverable on the ground, in the independent source, and in the dataset being tested.

- **Accuracy Requirement:** The independent source of higher accuracy used for QA/QC (Quality Assurance/Quality Control) checks should be at least three times more accurate than the required accuracy of the geospatial dataset being tested.
- **Elevation Datasets:** Elevation datasets often lack clearly-defined point features. To assess vertical accuracy, Triangulated Irregular Networks (TINs) are interpolated at the horizontal coordinates of vertical check points to determine elevations for the dataset being tested.
- **Terrain and Slope:** Vertical check points should be surveyed on flat or uniformly-sloped terrain with slopes of 10 percent or less to reduce interpolation errors.
- **Accuracy Classes:** ASPRS defines accuracy classes for both horizontal and vertical accuracy based on root-mean-square-error (RMSE) statistics. Class I represents the highest accuracy suitable for demanding engineering applications, Class II is standard high-accuracy mapping-grade data, while Class III and larger classes are for lower-accuracy visualization-grade data.

2.5.1. Color Consistency

- **Camera Calibration:** Precise camera calibration minimizes color variations and lens distortions for consistent image data.
- **Color Correction:** Advanced techniques normalize color tones and brightness levels across the image dataset.
- **Color Balancing:** Rigorous color balancing ensures an accurate representation of true scene colors.
- **Visual Inspection:** A thorough visual examination identifies and rectifies color consistency deviations.

2.5.2. Seamline Optimization

- **Image Alignment Quality:** Accurate image alignment minimizes visible seamlines between overlapping images.
- **Seamline Analysis:** Assessing seamlines between images to identify abrupt changes or inconsistencies.

- **Overlap and Coverage:** Effective overlap management promotes precise alignment and minimizes seamline artifacts.

2.5.3. Pixel Shift

- **Georeferencing Accuracy:** Georeferencing with ground control points (GCPs) achieves precise spatial alignment.
- **Accuracy Assessment:** Rigorous assessment, involving control points, quantifies pixel shift errors through root mean square error (RMSE) calculations.
- **Comparison with Reference Data:** A thorough comparison with reference data detects pixel shifts or misalignments.
- **Visual Inspection:** A detailed visual examination ensures accurate pixel alignment.

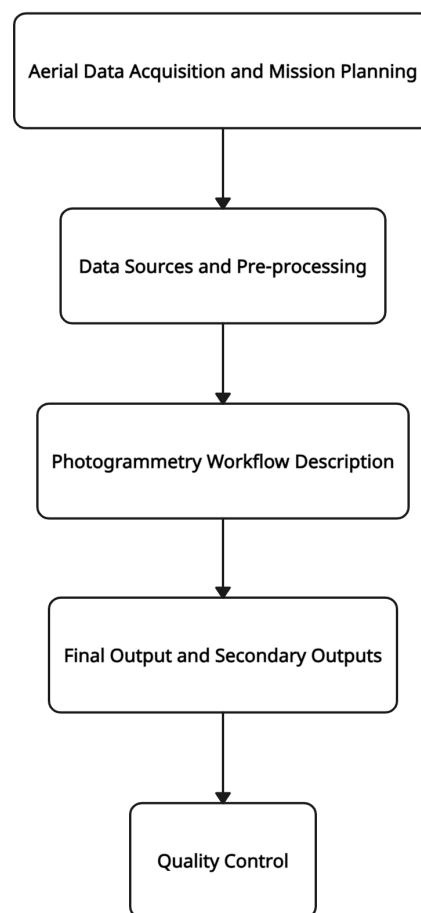


Figure 6. Activity Diagram

Overall, the methodology for creating orthomosaics referred to in (Figure 7), necessitates careful planning, the collection of aerial photographs, and precise photogrammetric processing in order to provide a trustworthy output that can be utilized for a range of applications.

2.6. Camera and Software used

This part resumes the software choice for this project and the equipment used to acquire the data set, which in this case is the sensor used .

2.6.1. Software

Depending on the project requirements and available resources, the specific software and equipment used to generate orthophotos may vary. Photogrammetry softwares such as Pix4D and Agisoft Metashape are commonly used. The selection of software is influenced by factors such as processing capabilities, features, ease of use, limitations, and compatibility with other tools in the workflow.

The selection of the appropriate photogrammetry software for the specific needs of this project, which involves high-altitude plane flights, large surface area coverage, and high-resolution photos with substantial size, required a meticulous comparison of available software options. The primary contenders for this project were Agisoft Metashape, Pix4Dmapper and MicMac.

The comparison encompassed various aspects to ascertain the optimal choice for the project's unique requirements, which are summarized in the Table below:

Table 3. Photogrammetry softwares comparison

Software/ Aspect	Agisoft Metashape	Pix4Dmapper	MicMac
Capabilities	Robust 3D reconstruction, dense point clouds, DEMs, orthomosaics	Aerial image processing, mapping, point clouds, and orthomosaics	Flexible photogrammetry, dense matching, point clouds, and customization
Ease of Use	User-friendly, suitable for both novices and experts	User-friendly, particularly for drone-based applications	Requires experience due to customization and command-line interface
Processing Time	Efficient processing speed	Processing time varies based on dataset size	Processing time varies, impacted by flexibility and hardware
Large Image Handling	Efficient with adequate hardware	Efficient handling of large datasets	Requires careful hardware considerations for large images
Output Quality	Excellent output quality with accurate inputs	Excellent output quality with accurate inputs	Output quality depends on input accuracy and parameters

After a thorough comparison of the available photogrammetry software options, the decision was made to opt for Agisoft Metashape. This choice was based on its suitability for meeting the specific requirements of the project. Metashape is User-friendly, suitable for both novices and experts, and can handle large data sets with adequate hardware, which in this case was sufficient for generating the required outcomes.

Agisoft Metashape, formerly known as Agisoft PhotoScan, is a powerful photogrammetry software used for generating georeferenced 3D models, orthophotos, and digital elevation models (DEMs) from a collection of 2D images.

Metashape employs two fundamental processes: Structure-from-Motion (SfM) and Multi-View Stereo (MVS). These processes work in tandem to reconstruct the geometry and appearance of objects and scenes captured in the input images [17].

Structure-from-Motion (SfM):

SfM is a technique used to create 3D models from a collection of 2D images by estimating the camera positions and orientations relative to the scene (Figure 7).

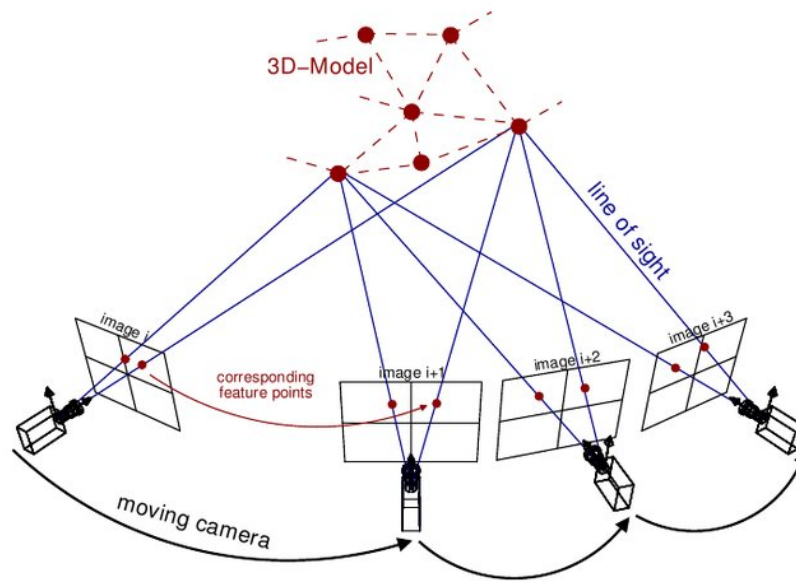


Figure 7. Structure-from-Motion (SfM)

It involves the following steps:

Structure from Motion from Two Views

For the simple case of structure from two stationary cameras or one moving camera, one view must be considered camera 1 and the other one camera 2. In this scenario, the algorithm assumes that camera 1 is at the origin and its optical axis lies along the z-axis.

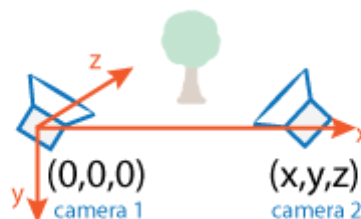


Figure 88. Structure from Motion from Two Views

Structure from Motion from Two Views

SfM requires point correspondences between images. Find corresponding points either by matching features or tracking points from image 1 to image 2. Feature tracking techniques as cameras move further apart falls apart, feature matching can be used instead.

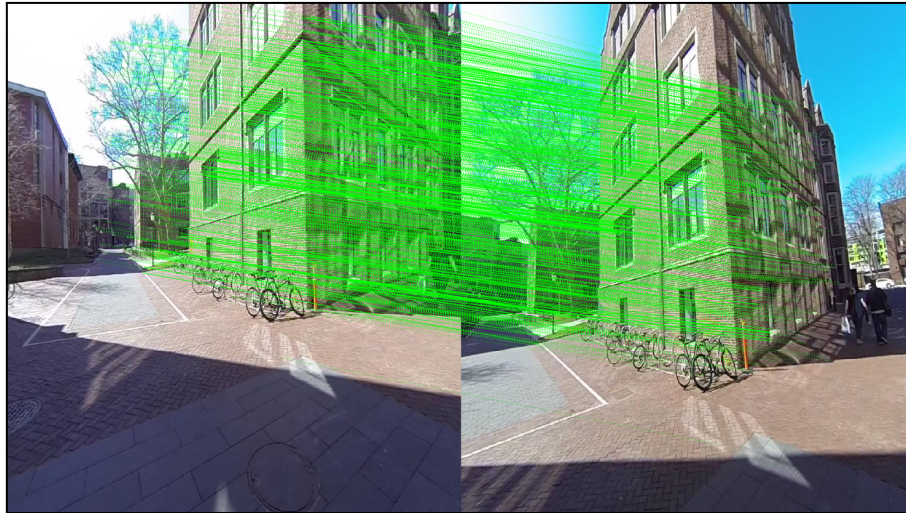


Figure 9. Feature tracking

Figure 9. Feature tracking

Here's how the process of matching features works:

Feature Detection:

The first step is to detect distinctive features in each of the images you want to match. These features are points or regions in the image that have unique characteristics and are likely to be recognizable across different views.

- Common feature detection algorithms include SIFT (Scale-Invariant Feature Transform), SURF (Speeded-Up Robust Features), ORB (Oriented FAST and Rotated BRIEF), and Harris corners, among others.
- The choice of feature detection algorithm depends on factors like the nature of the images and the computational requirements.

Feature Description:

After detecting features, the next step is to describe them. Each feature is represented by a descriptor, which is a compact representation of the feature's local neighborhood.

- The descriptor captures information about the feature's appearance, including its gradient orientation, color, texture, or other relevant characteristics.
- Feature descriptors are designed to be robust to changes in scale, rotation, and illumination, making them suitable for matching across images.

Feature Matching:

Once features are detected and described in both images, the matching process begins. The goal is to find pairs of features that correspond to the same 3D point in the scene.

- Feature matching is typically done by comparing the feature descriptors between the two images. Common distance metrics like Euclidean distance or Hamming distance (for binary descriptors like ORB) are used to measure the similarity between feature descriptors.
- For each feature in the first image, a potential match is sought in the second image by comparing its descriptor to the descriptors of all features in the second image. The closest match or matches are considered potential correspondences.

Matching Criteria and Thresholding:

To determine valid correspondences, a matching criteria or threshold is applied. This helps filter out incorrect or ambiguous matches.

- One common approach is to set a distance threshold, and only matches with descriptor distances below this threshold are considered valid correspondences.
- Additionally, geometric constraints and consistency checks, such as the ratio test or RANSAC, can be applied to further refine the matches.

Establishing Correspondences:

After filtering and validating matches, you establish correspondences between the features in the two images. Each correspondence pair links a feature in the first image to its corresponding feature in the second image.

Repeat for Multiple Images:

- In SfM, this process is repeated for multiple pairs of images, creating a network of correspondences that span the entire image sequence.
- As more images are added to the reconstruction, the number of correspondences grows, allowing for the estimation of camera poses and 3D point positions.

To find the pose of the second camera relative to the first camera, the software computes the fundamental matrix. Uses the corresponding points found in the previous step for the computation. The fundamental matrix describes the epipolar geometry of the two cameras. It relates a point in one camera to an epipolar line in the other camera. It relates a point in one camera to an epipolar line in the other camera.

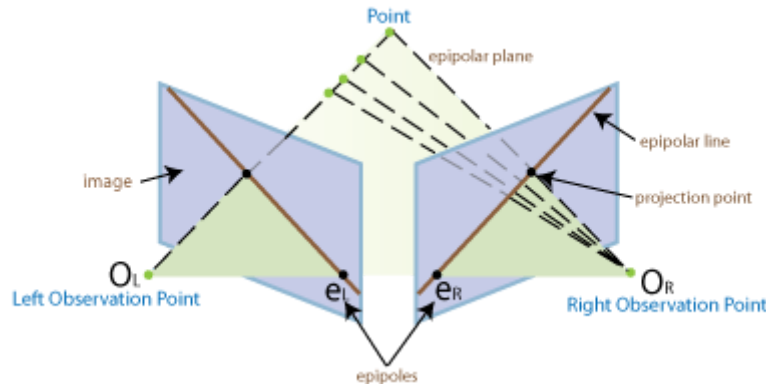


Figure 10. epipolar geometry of the two cameras

Figure 10. epipolar geometry of the two cameras

The fundamental matrix is a fundamental concept in computer vision and photogrammetry, particularly in the context of stereo vision and multiple view geometry. It is a mathematical representation that describes the geometric relationship between two cameras or views in a multi-camera system. Here's the methodological basis of the fundamental matrix:

The fundamental matrix, denoted as F , is a 3×3 matrix that represents the epipolar geometry between two cameras or views in a stereo vision setup. It relates the coordinates of corresponding points in two images, satisfying the epipolar constraint. Here's a simplified form of the fundamental matrix equation:

For a point in the first image (x_1, y_1) and its corresponding point in the second image (x_2, y_2) , the fundamental matrix F satisfies the following equation:

$$[x_2, y_2, 1] * F * [x_1$$

$$[y_1]$$

$$[1]$$

In matrix form, this equation can be represented as:

$$\begin{bmatrix} x_2 & y_2 & 1 \end{bmatrix} * F * \begin{bmatrix} x_1 \\ y_1 \\ 1 \end{bmatrix} = 0$$

Here, F is the 3×3 fundamental matrix, and $[x_1, y_1, 1]$ and $[x_2, y_2, 1]$ are homogeneous coordinates of the corresponding points in the two images.

The fundamental matrix F is determined using a set of corresponding point pairs and estimation methods, such as the 8-point algorithm or the normalized 8-point algorithm. The resulting F matrix encapsulates the epipolar geometry and can be used for various tasks in stereo vision and multi-view geometry, including rectification, stereo matching, and 3D reconstruction.

The fundamental matrix F has the following form:

$$F = \begin{bmatrix} F_{11} & F_{12} & F_{13} \\ F_{21} & F_{22} & F_{23} \\ F_{31} & F_{32} & F_{33} \end{bmatrix}$$

Each element of the matrix (F_{ij}) represents a coefficient that relates the coordinates of corresponding points in two images and satisfies the epipolar constraint as described earlier.

- To calculate the relative rotation and translation between camera poses:

It is important to calculate the essential matrix (E) which serves as the bridge connecting the fundamental matrix to the camera calibration matrices (K_1 and K_2) of the two cameras. The essential matrix is calculated through the formula:

$$E = K_2^T * F * K_1$$

Here, K_1 and K_2 represents the camera matrices for the first and second cameras, respectively.

Next, we decompose the essential matrix (E) into its constituent parts: the relative rotation matrix (R) and the relative translation vector (t), using Singular Value Decomposition (SVD):

$$E = U * S * V^T$$

Where:

- U and V are orthogonal matrices.
- S is a diagonal matrix with singular values.

From the SVD decomposition, we extract R and t as follows:

Rotation Matrix (R)

$$R = U * W * V^T$$

Here, W is a 3x3 rotation matrix that accounts for a 90-degree rotation around the z-axis.

Translation Vector (t)

$$t = U(:, 3)$$

The translation vector t can be obtained directly from the last column of U.

The approach used for SfM from two views can be extended for multiple views. The set of multiple views used for SfM can be ordered or unordered. The approach taken here assumes an ordered sequence of views.

Triangulation is a fundamental technique in computer vision and 3D reconstruction that plays a crucial role in estimating the 3D coordinates of points in a scene from their corresponding 2D image coordinates in stereo images. This process enables the reconstruction of the 3D structure of a scene from multiple viewpoints. Here's an overview of how triangulation works:

- Mapping 2D to 3D: Triangulation calculates the 3D coordinates (X, Y, Z) of a point in the 3D scene using the corresponding 2D image coordinates (x1, y1) in the left image and (x2, y2) in the right image.
- System of Equations: The triangulation process typically involves solving a system of equations that relates the 3D point (X, Y, Z) to the image coordinates (x1, y1) and (x2, y2), as well as the camera projection matrices.
- Camera Projection Matrices: The camera projection matrices are obtained from the camera calibration parameters and describe how 3D points are projected into 2D image coordinates and vice versa. These matrices are essential for mapping between the 3D and 2D worlds.

- Solving Equations: By solving these equations, triangulation finds the 3D position of the point that best fits the observed 2D positions in both images. It calculates the X, Y, and Z coordinates in the scene.

The triangulation process is not limited to a single point but is repeated for multiple corresponding points in the stereo images. Each point pair results in a set of 3D coordinates.

Multi-View Stereo (MVS):

MVS is a technique used to create dense 3D representations of a scene by reconstructing the 3D positions of pixels in each image. This process is more detailed and accurate compared to SfM. The key steps are as follows:

- Dense Point Cloud Generation: The software refines the sparse point cloud created by SfM by considering more image pixels and their corresponding 3D positions. This results in a denser point cloud that better captures the surface geometry.
- Surface Reconstruction: The dense point cloud is used to generate a 3D mesh, which is a surface representation consisting of interconnected triangles. This mesh closely resembles the actual shape of the objects in the scene.
- Texture Mapping: The original images are projected onto the 3D mesh, creating a texture-mapped model that replicates the appearance of the scene.

Summary

In conclusion, the selection of Agisoft Metashape as the preferred photogrammetry software for this project, even though other softwares are more capable of handling large data sets, was a strategic decision because of its user-friendly interface combined with advanced features and efficient processing speed..

2.6.2. Camera

Regarding equipment, In this project, a plane equipped with a Leica DMC III camera is used to capture aerial images from high altitude. The sensor is compact and is the first large format camera using CMOS sensor technology, reaching beyond the limitations of traditional CCD technology. The sensor captures more information with a 100% increase in dynamic range and unsurpassed image quality thanks to less image noise and almost zero blooming [18], (Figure 8) below is a real picture of the sensor.



Figure 11. The Leica DMC III sensor [18]

The Leica DMC III is a high-quality digital camera specifically designed for aerial photogrammetry applications. It is known for its advanced imaging capabilities, capturing high-resolution images with exceptional detail and accuracy. The camera is mounted on the plane, which serves as the platform for conducting the aerial survey.

The Leica DMC III combines advanced imaging technology with precise navigation systems, allowing for efficient and reliable data acquisition. It offers features such as GPS/INS (Global Positioning System/Inertial Navigation System) integration, which ensures accurate georeferencing of the captured images.

The Leica DMC III is a valuable tool for capturing aerial imagery with a spatial resolution of 25,728 across track and 14,592 along track for panchromatic images. Its use in this project ensures the acquisition of aerial images with the necessary level of detail and precision to reach the desired outcome.

This sensor has a Focal length of 92 mm and a Pixel size of $3.9\ \mu\text{m}$, according to the Leica DMC III product specifications. the Flying height is around 5897 m, which, according to the specification sheet of the sensor, allows for a ground sampling distance GSD of 25 cm.

Analyzing the impact of spherical correction and atmospheric refraction becomes highly significant at this specific flight altitude.

Earth Curvature Correction:

Earth Curvature Correction is the adjustment made to account for the curvature of the Earth's surface when making observations or measurements over long distances. It ensures that measurements and observations accurately reflect the true geometric relationships on a spherical Earth.

- The correction depends on the height above the Earth's surface. As one goes higher, objects on the Earth's surface will appear visually corrected to be farther away due to the Earth's curvature.

For a flight height of 5897 meters:

$$D = \sqrt{(2 \cdot R \cdot h + h^2)}$$

Where:

- R is the radius of the Earth (approximately 6,371 kilometers or 6,371,000 meters).
- h is the flight height (5897 meters).

$$D = \sqrt{(2 \cdot 6371000 \cdot 5897 + 5897^2)}$$

$$D \approx 6544.11 \text{ meters}$$

So, the Earth Curvature Correction is approximately 6,544.11 meters, which means that objects on the Earth's surface would be visually corrected to appear around 6.54 kilometers farther away due to the Earth's curvature.

Atmospheric Refraction:

Atmospheric Refraction is the bending of light as it passes through the Earth's atmosphere, affecting the apparent position of objects, especially near the horizon.

- Atmospheric refraction causes objects, particularly those near the horizon, to appear slightly higher in the sky than their actual positions.
- This effect varies with atmospheric conditions but can lead to deviations of several hundred meters or more for objects near the horizon when observing from typical altitudes.

Calculate the apparent height of an object (H_{apparent}) above its true height (H_{actual}):

$$H_{\text{apparent}} = H_{\text{actual}} + \delta H$$

Where:

- δH is the correction due to atmospheric refraction.

$$\delta H = R * (1 - \cos(r))$$

Where:

- R is the radius of the Earth (6,371,000 meters).
- r is the refraction angle, The actual value for the refraction angle can vary significantly depending on atmospheric conditions and is typically not constant. It can range from near zero to several degrees.

As indicated in this chart, which summarizes the Ground sampling distance GSD in relation to the flight height, see (Figure 9):

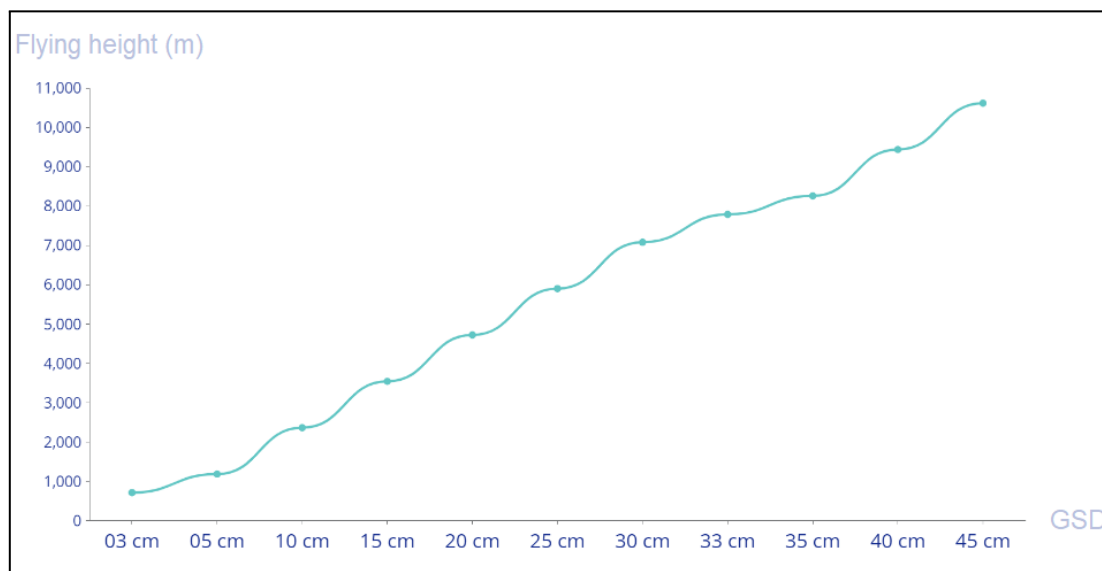


Figure 1212. Ground sampling distance in relation to the flight height

The use of a plane in this project offers several advantages, including the ability to cover larger areas efficiently and access more remote or challenging locations.

The combination of the plane as a platform and the Leica DMC III camera provides a reliable and effective solution for capturing the aerial imagery required for this project's photogrammetric data acquisition.

Summary

To summarize, the choice of appropriate software and equipment plays a pivotal role in achieving the project's goals. After a comprehensive evaluation of various options, the Leica DMC III aerial camera and Agisoft Metashape photogrammetry software have been selected as the optimal combination for this endeavor.

2.7. Conclusion

The chapter starts with an introduction to PNOA, followed by a detailed discussion on aerial data acquisition and mission planning, which includes sensor geometry, stenope perspective, mathematical camera models, and the desired outcomes. It further elaborates on the characteristics of aerial photos, and the calculations involved in a flight plan. The chapter also discusses the applications of orthophotos, and the methodology to obtain orthomosaics. Quality control is a significant aspect, and the chapter discusses the processes involved in ensuring color consistency, seamline optimization, and pixel shift. Finally, it concludes by listing the software and equipment used for the processes. This comprehensive overview not only serves as a guideline in the creation of orthomosaics, but also helps in understanding the quality control processes necessary to ensure the accuracy and reliability of the final output.

The next chapter will elaborate on the practical application of the methodologies detailed in Chapter 2. It will cover the data sources, pre-processing, and workflow from data preparation to final output, including important steps like adding GCPs, image alignment, point clouds, DTM and DSM generation, and orthomosaic generation. Each step will be accompanied by a discussion on quality control measures.

3.1. Introduction

In this section, the comprehensive methodology for generating digital elevation models (DEMs) and orthomosaics from aerial imagery is detailed. The methodology encompasses data acquisition, pre-processing, software utilization, parameter tuning, and quality control, ensuring the accuracy and reliability of the final orthophoto output.

3.2. Data Sources and Pre-processing

The foundation of the project lies in acquiring essential data components. Aerial images were sourced from the Organismo Autónomo Centro Nacional de Información Geográfica (CNIG), following specific criteria of the MTN 947 sheet in Andalusia, Spain. The images, obtained in GeoTIFF format, were optimized for storage and efficient handling. Ground Control Points (GCPs) were meticulously acquired and filtered from a KMZ file, enhancing the georeferencing accuracy of the project.

3.2.1. Data Source

The National Center for Geographic Information (CNIG) is an Autonomous Agency created as a commercial entity by Article 122 of Law 37/1988, of December 28, on the General State Budget for 1989. It is attached to the Ministry of Transport, Mobility, and Urban Agenda, through the Directorate General of the National Geographic Institute (IGN) [19].

The CNIG has a Strategic Plan that outlines the strategic lines for the organization's activities. The plan is reviewed every three years and is complemented by annual plans that further develop the objectives for the following year, the Strategic Plan encompasses six general objectives, which are developed through 24 activities and evaluated through 41 indicators. The plan takes into account the functions entrusted to the CNIG in its Statute.

Specifically, the objectives are:

- Distribution, promotion, dissemination, and commercialization of geographic products.
- Exploitation of CNIG's geographic products.
- Management of the Spanish Spatial Data Infrastructure (IDEE) and the IGN's IDE node.
- Web publication of the IGN and CNIG portals and services.

- Development of projects, either independently or in collaboration with other organizations.
- Representation of the IGN and the State in national and international forums.

3.2.2. Image acquisition

3.2.2.1. Data Availability

The aerial images utilized in this project were sourced from the Organismo Autónomo Centro Nacional de Información Geográfica (CNIG). The CNIG is known for its commitment to providing open source and freely accessible geospatial data. The availability of these aerial images without any usage restrictions or licensing fees greatly facilitates research.

This figure showcases the different products available at the Centro Nacional de Información Geográfica (CNIG):



Figure 13. Available products at the Centro Nacional de Información Geográfica (CNIG)

The CNIG's data portal offers a user-friendly interface that enables easy access to a wide range of geospatial datasets, including aerial imagery. The open source nature of the data allows researchers, professionals, and the general public to leverage this valuable resource for various applications without any financial constraints.

3.2.2.2. Image Selection Criteria

For this project, all 255 aerial images within the MTN 0947 sheet covering the region of Andalusia were downloaded. The selection of these images was based on specific criterias

to ensure their relevance and suitability for the study. The following criterias were considered during the selection process:

(Figure 12) showcases the search tool used to look for aerial images within the MTN 0947 sheet:



Figure 14. The search tool used to look for aerial images

- **Coverage Area:** The MTN 0947 sheet encompasses the desired study area in Andalusia. By downloading all the available images within this sheet, the dataset provides comprehensive coverage of the region of interest.
- **Flight Year:** The focus of this project is on the most recent flight carried out in 2022. By selecting images from this specific flight, the dataset captures the most up-to-date information, reflecting the current state of the area.
- **Spatial Resolution:** The chosen images have a resolution of 0.25 meters. This resolution ensures the availability of fine-grained details, enabling accurate and precise analysis of the captured features and terrain within the study area.

All 255 images available in the MTN 0947 sheet that meet the selection criteria are depicted in (Figure 13) below:



Figure 15. Images adhering to the selection criteria

By adhering to these selection criteria, the dataset obtained from the CNIG provides a comprehensive and current representation of the MTN 0947 sheet in Andalusia. The inclusion of the most recent flight's imagery and the high resolution of the images further enhance the quality and relevance of the dataset for the intended results.

3.2.2.3. Metadata and Documentation

The downloaded aerial images from the CNIG are accompanied by comprehensive metadata and documentation, providing essential information for processing and analysis. The following details were extracted from the metadata:

Sensor: Leica DMC III Product Specifications:

The aerial images in this project were captured using the Leica DMC III sensor. Here are the product specifications for the sensor:

- Serial Number: 00128300 (PAN Head)
- Date of Calibration: 29. April 2019
- Pixel Across Track: 25,728 pixels
- Pixel Along Track: 14,592 pixels
- Focal Length: 92 mm
- Pixel Size: 3.9 μm

Coordinate System: The images are georeferenced to the European Terrestrial Reference System 1989 (ETRS89) using the Universal Transverse Mercator (UTM) projection with Zone 30 North (ETRS/89 UTM Zone 30N). This coordinate system ensures compatibility with other geospatial datasets and facilitates accurate spatial analysis and integration.

Image Specifications: The image specifications are represented below in (Table 4) as follows:

Table 4. Image Specifications

Image Specifications	Characteristics
Spatial Resolution	14,592 pixels (width) x 25,728 pixels (height)
Compression	Compressed for storage and transmission
Format	Cloud Optimized GeoTIFF (COG)
Benefits of COG format	Efficient access, distribution, and retrieval
Ground Sample Distance (GSD)	25 cm per pixel
Spectral Resolution	RGB images
Radiometric Resolution	14-bit radiometric resolution, (16,384) different levels of brightness.

3.2.2.4. Image Download Process

The image download process was quick and straightforward. The following steps were taken:

- **Filtering by Format:** The images were filtered based on the desired format, in this case, COG GeoTIFF. This filtering ensured that only images in the GEOTIFF format were included in the download selection.
- **Filtering by Date:** Another filtering criterion involved selecting images captured specifically in the year 2022. By applying this date filter, only images from the desired time period were included in the selection.
- **Selection of Images:** With the filters in place, a total of 255 images were identified that met the format and date criteria. These images represented the dataset required for the project.
- **Downloading Process:** The final step involved initiating the download of the selected images; see (Figure 16):

Producto	Fichero	Formato	Tamaño (MB)	Eliminar
Fotogramas PNOA	H50-0926-FOT-020-0048-COG.TIF	Cloud Optimized GeoTIFF	98.26	
Fotogramas PNOA	H50-0926-FOT-020-0049-COG.TIF	Cloud Optimized GeoTIFF	96.44	
Fotogramas PNOA	H50-0926-FOT-020-0050-COG.TIF	Cloud Optimized GeoTIFF	100.15	
Fotogramas PNOA	H50-0926-FOT-020-0051-COG.TIF	Cloud Optimized GeoTIFF	100.25	
Fotogramas PNOA	H50-0926-FOT-020-0052-COG.TIF	Cloud Optimized GeoTIFF	98.74	
Fotogramas PNOA	H50-0926-FOT-020-0053-COG.TIF	Cloud Optimized GeoTIFF	96.64	
Fotogramas PNOA	H50-0926-FOT-020-0054-COG.TIF	Cloud Optimized GeoTIFF	95.40	
Fotogramas PNOA	H50-0926-FOT-020-0056-COG.TIF	Cloud Optimized GeoTIFF	98.22	
Fotogramas PNOA	H50-0926-FOT-020-0057-COG.TIF	Cloud Optimized GeoTIFF	104.29	
Fotogramas PNOA	H50-0926-FOT-020-0058-COG.TIF	Cloud Optimized GeoTIFF	107.83	
Fotogramas PNOA	H50-0926-FOT-020-0059-COG.TIF	Cloud Optimized GeoTIFF	105.07	
Fotogramas PNOA	H50-0926-FOT-020-0060-COG.TIF	Cloud Optimized GeoTIFF	104.65	
Fotogramas PNOA	H50-0926-FOT-020-0061-COG.TIF	Cloud Optimized GeoTIFF	106.54	
Fotogramas PNOA	H50-0926-FOT-020-0062-COG.TIF	Cloud Optimized GeoTIFF	109.72	
Fotogramas PNOA	H50-0926-FOT-020-0064-COG.TIF	Cloud Optimized GeoTIFF	112.71	
Fotogramas PNOA	H50-0926-FOT-020-0065-COG.TIF	Cloud Optimized GeoTIFF	112.67	
Fotogramas PNOA	H50-0926-FOT-020-0066-COG.TIF	Cloud Optimized GeoTIFF	112.20	

Figure 16. Image Download Process

Summary

In conclusion, the image acquisition process for this project involved downloading a set of aerial images from a reliable source. The acquired images were filtered based on specific criteria and stored for further analysis and processing.

3.2.3. GCP acquisition

The GCP acquisition process plays a crucial role in enhancing the accuracy and precision of photogrammetric products.

The CNIG (Centro Nacional de Información Geográfica) in Spain typically acquires Ground Control Points (GCPs) through a systematic process that involves field surveys, geodetic measurements, and satellite-based positioning techniques. GCPs serve as reference points on the ground that are accurately surveyed and whose coordinates are known with high precision. These points are crucial for the georeferencing and accurate alignment of aerial and satellite imagery during photogrammetric processes.

The acquisition process for GCPs by CNIG might involve the following steps:

- **Field Surveys:** CNIG teams may conduct field surveys to physically locate and mark GCPs on the ground. These surveys often use high-precision GPS equipment to determine the exact coordinates of the GCPs.

- **Geodetic Measurements:** Geodetic techniques, such as triangulation and trilateration, can be used to establish accurate distances and angles between GCPs, forming a geodetic network. This network helps ensure the accuracy of the GCP coordinates.
- **Satellite Positioning:** Modern Global Navigation Satellite System (GNSS) technologies, such as GPS and GNSS augmentation systems (e.g., Spain's EGNOS), are employed to determine the precise coordinates of GCPs. GNSS receivers can provide centimeter-level accuracy.
- **Data Integration:** The collected field survey data and GNSS measurements are integrated into a geodatabase or Geographic Information System (GIS), creating a reliable dataset of GCP coordinates.
- **Validation and Quality Control:** The accuracy of GCPs is verified through redundancy checks, statistical analysis, and comparisons with known benchmarks. Any discrepancies are corrected, and the GCP dataset is refined.
- **Cataloging:** The GCP dataset, along with detailed metadata about the points' characteristics and positions, is cataloged and made available for various applications, including photogrammetric projects like orthophoto and DEM generation.

The following (Figure 17) depicts the process of obtaining GCPs and an accompanying sketch design (croquis):

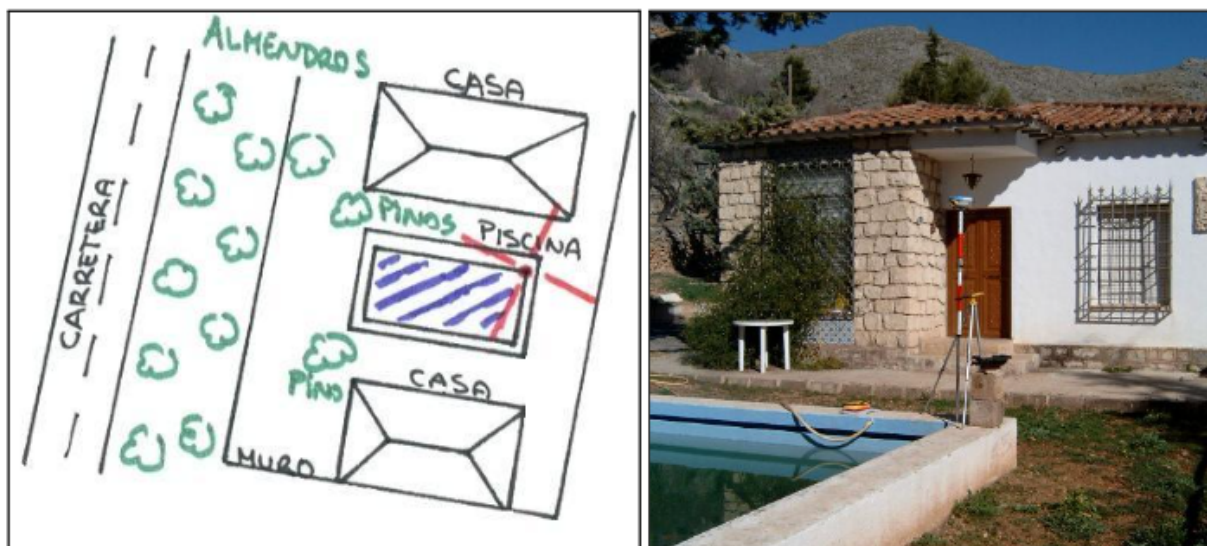


Figure 17. The acquisition process for GCPs by CNIG with a sketch design

The GCP acquisition process for this project involved these steps:

- **GCP File Download:** The first step involved downloading the GCP file, which contains the coordinates of ground control points for the study area. This process consisted of downloading a KMZ (Keyhole Markup Language) file that contains all the GCPs in the region of Andalusia, see (Figure 18):

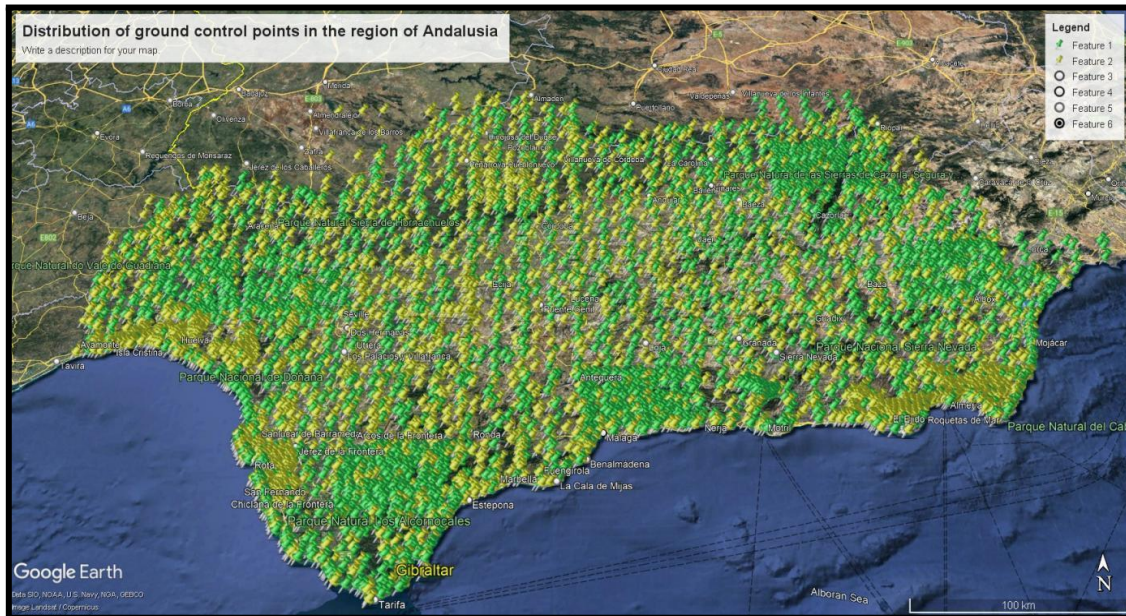


Figure 18. Distribution of GCPs in the region of Andalusia

The following (Figure 19) showcases the available information about ground control points this database is from the regional government (Junta de Andalucía) and this base is administrated by REDIAM:

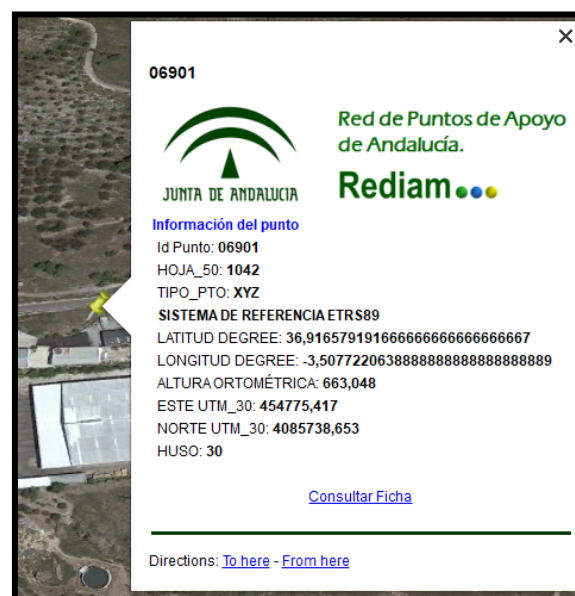


Figure 19. available information about ground control points

- GCP Limitation and Identification: Using QGIS, the GCPs specific to Sheet 0947 were limited and identified. This process involved visually inspecting the imagery and correlating the ground features with the GCP locations.

This is shown in the map below, where the black points represent the ground control points in the study area, (Figure 20).

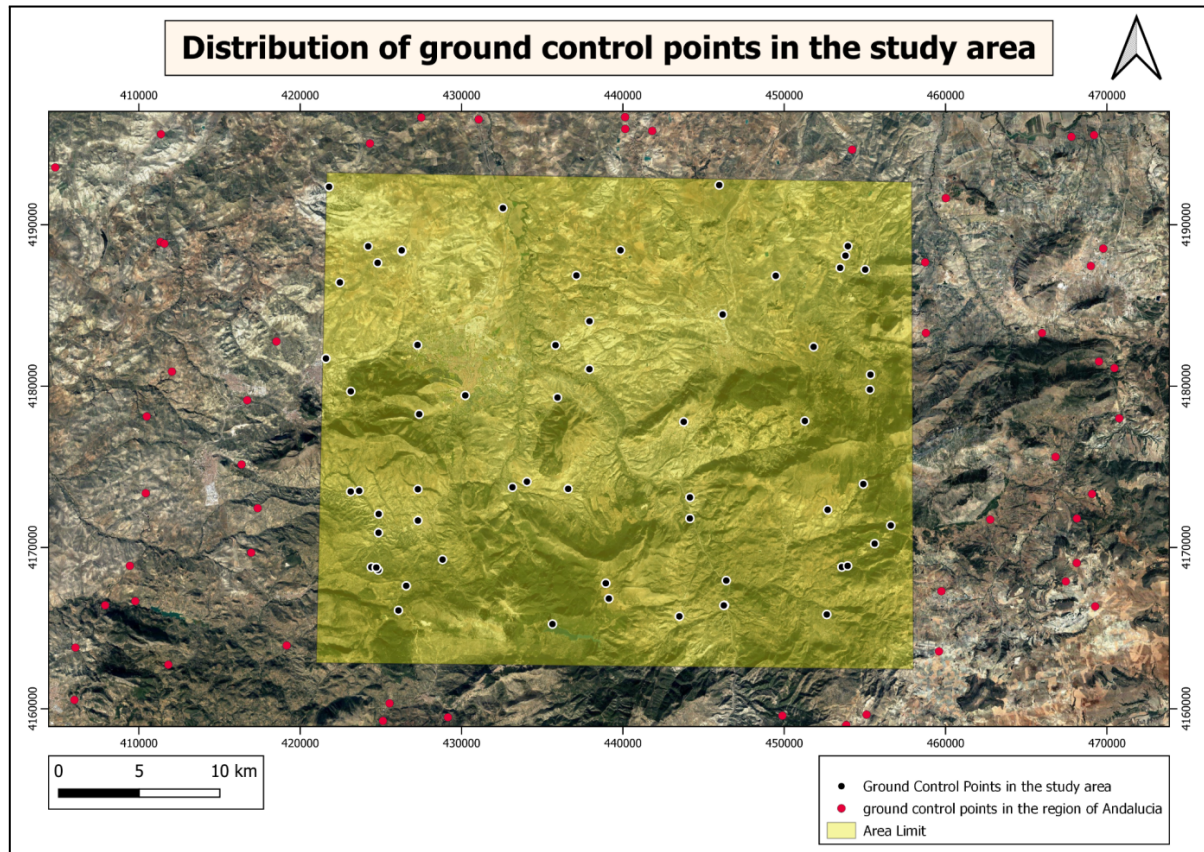


Figure 20. Distribution of ground control points in the study area

- GCP Extraction: Once the GCPs were identified, they were exported into a separate file dedicated to the sheet. This isolated file contains the relevant GCPs which are in orthometric heights for further processing, as indicated in (Figure 21).

Name	X	Y	zcoord
23819	426311.4577	4188352.611	408.92
23846	424841.797	4168597.942	942.318
238PNOA079454	424859.1582	4170911.513	251.915
23907	437124.1488	4186858.997	469.515
23911	453472.0026	4187331.516	666.938
23912	455317.3761	4179784.345	1039.058
23929	430235.5971	4179422.616	582.709
23930	446189.8538	4184440.27	701.35
23931	434056.3477	4174076.126	529.464
23932	444155.5523	4171799.499	562.741
23940	427300.1841	4171667.651	609.731
23945	437934.8625	4184022.67	475.443
23946	443775.8323	4177788.276	845.415

Figure 21. A Table containing the relevant GCPs

Summary

By utilizing QGIS, the GCPs were effectively managed and refined, ensuring a selection of GCPs specifically tailored to the Sheet 0947 area. This focused approach facilitates accurate georeferencing and the subsequent improvement of the photogrammetric products.

3.2.4. Flight trajectory estimation

Flight trajectory determination is a fundamental component of the project's methodology and critical for understanding the spatial context of the acquired aerial imagery. This phase establishes the planned route that the aerial platform will follow during data acquisition. Due to the unavailability of IMU (Inertial Measurement Unit) data, an estimation process was adopted for the photos positions in order to provide a initial estimation to the software, the he approximation in omega, phi and kappa angles happens later when intriducing the images to Metashape for an initial alignment.

The flight trajectory determination process involved organizing the images in QGIS and utilizing the tile index to transform raster images into polygons. Here's an exploration of the modified flight trajectory determination process:

- Organizing the Images: The initial step involved organizing the acquired images in QGIS. This ensures that the images are properly managed and ready for further analysis and processing.

Represented in (Figure 22) below the study area limit in yellow and the organized images.

- Tile Index Conversion: Utilizing the tile index functionality in QGIS, the raster images were transformed into polygons. This conversion provides a structured and organized representation of the images within the project area.

Below in (Figure 23) are the tile index tool parameters, which produce image extents that are later represented in a map in (Figure 24).

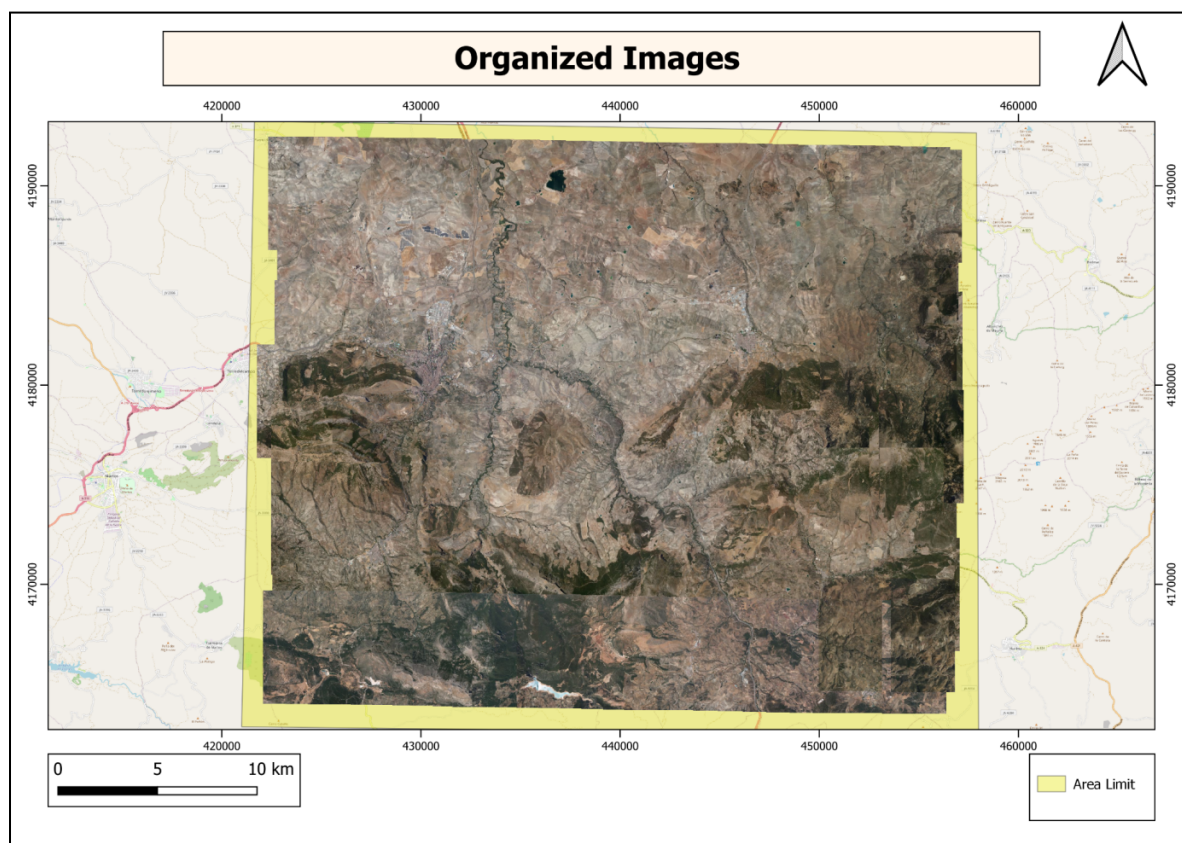


Figure 22. Study area limit and the organized images

Figure 23. Tile index tool parameters

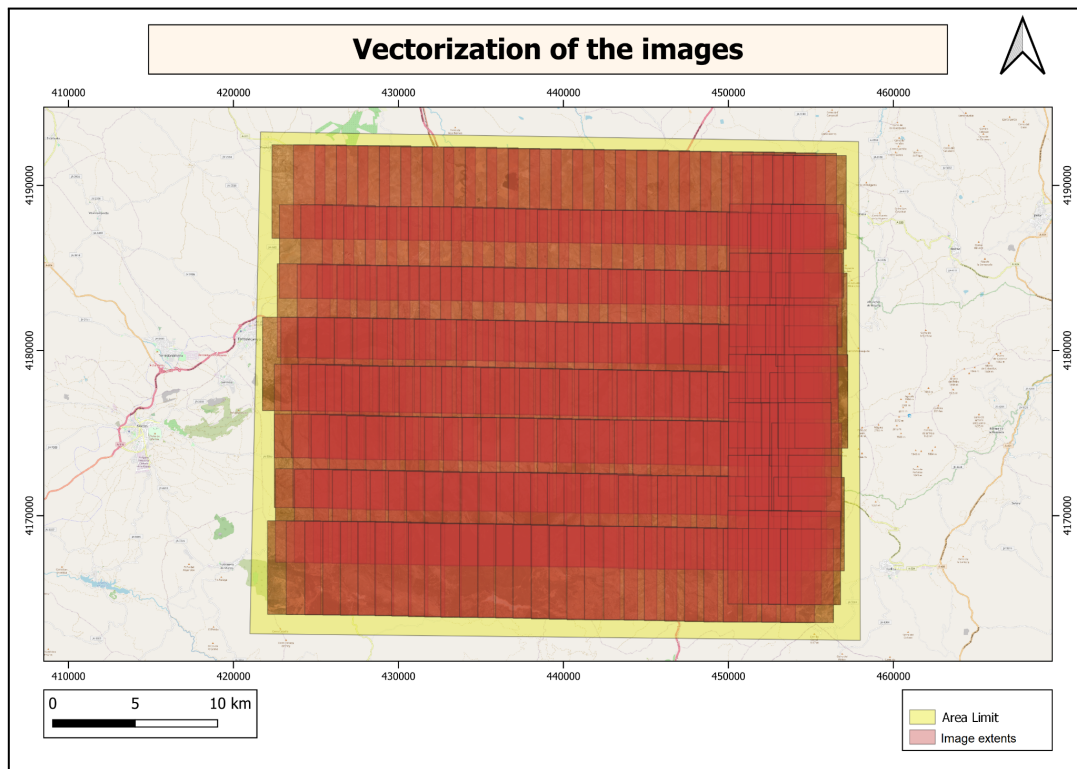


Figure 24. Produced image extents

- **Centroids Determination:** The centroids tool in QGIS was employed to determine the center points of the polygons representing the images, which was possible because the imagery is in GeoTIFF format. These centroid points serve as reference points for flight trajectory estimation but it is only an initial approximation to the real camera position that was obtained after the orientation process.

As follows (Figure 25) shows the centroids tool parameters, which produces center points of the polygons representing the images that are later represented in a map in (Figure 26).

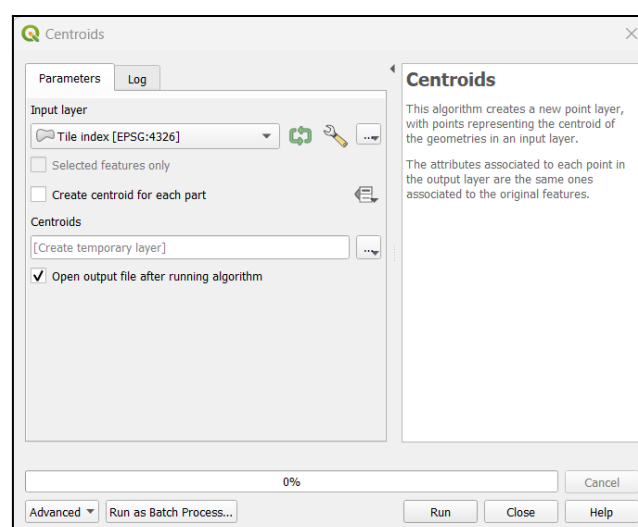


Figure 25. Centroids tool parameters

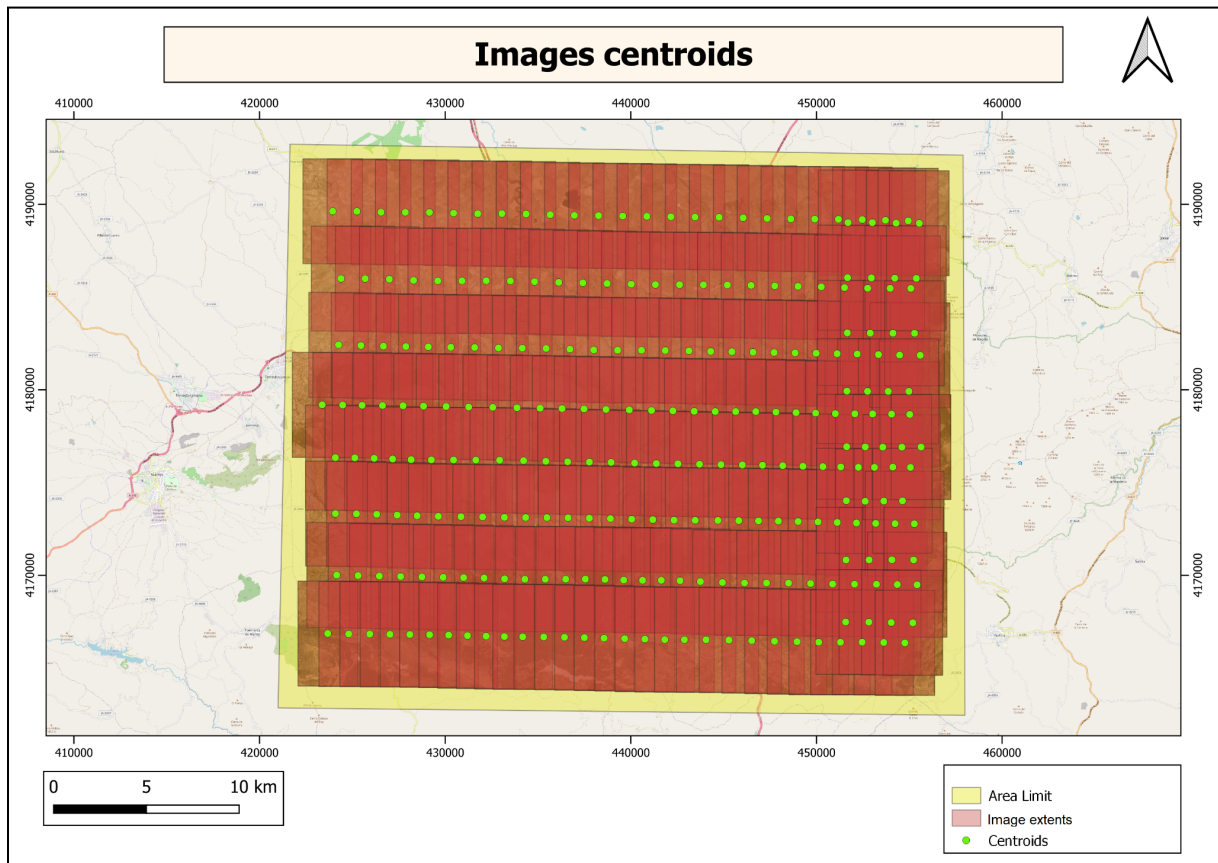


Figure 26. Images centroids

- By linking the centroid points of the images, a flight trajectory or path was established. This trajectory defines the planned route that the aerial platform would follow during data acquisition; refer to (Figure 27) below.

The primary source of information for the flight trajectory determination is the GPS (Global Positioning System) data associated with each image. These GPS positions serve as reference points, offering insight into the geographical locations where each image was captured. Unfortunately, in this particular project, IMU data, which provides precise orientation and movement information, was not available.

→ To address this absence, an alternative approach was employed. Instead of relying solely on IMU data, a process of linking the centroid points of the acquired images was done. These centroids represent the central points of each image frame. By connecting these centroids sequentially, a flight trajectory was established. This trajectory simulates the planned path of the aerial platform during the data acquisition process.

While this approach provides a reasonable estimation of the flight trajectory, it's important to acknowledge that it may not capture intricate aerial maneuvers or deviations that could occur during data acquisition. Nonetheless, for the purposes of this project and in the absence of IMU data, this estimation method provides a practical solution to establish a trajectory that guides subsequent processing steps within Agisoft Metashape.

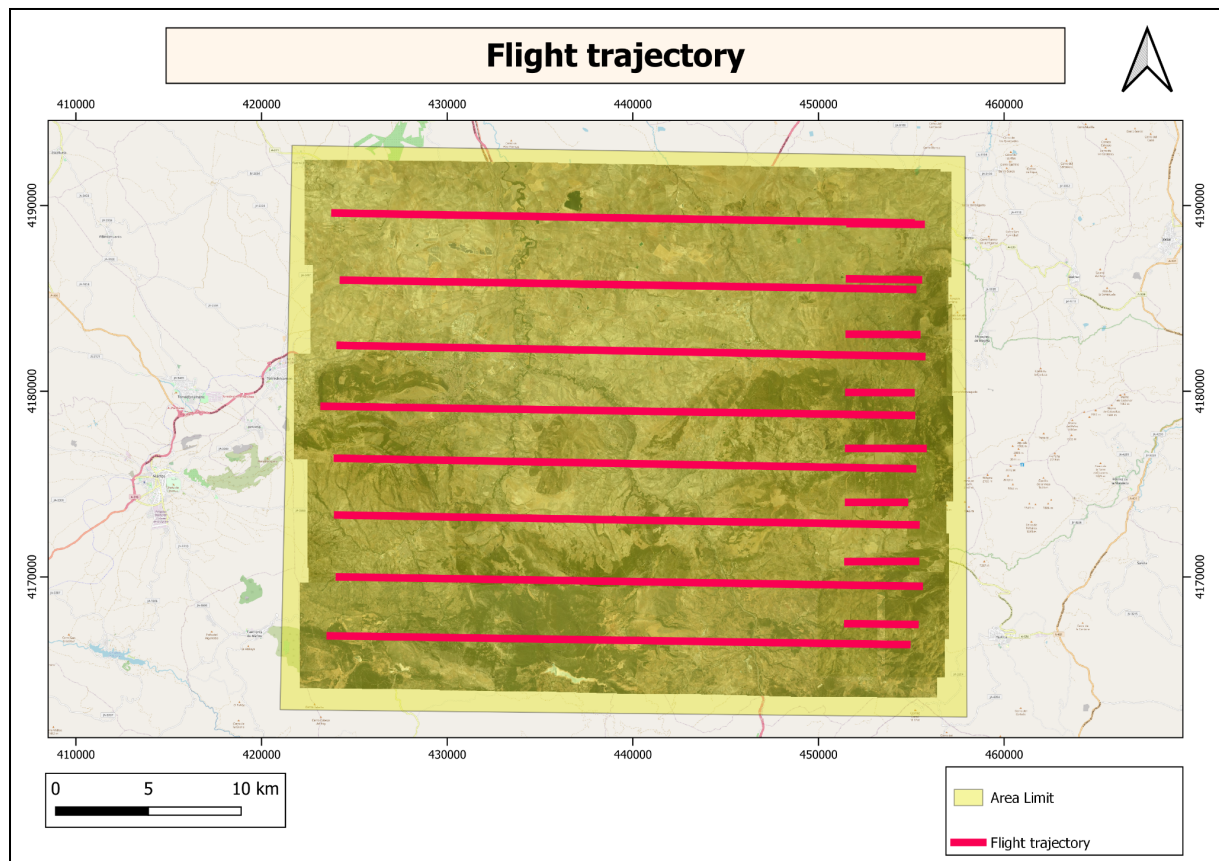


Figure 27. Estimated flight trajectory

Summary

The flight trajectory determination process, albeit an estimation in this instance, is a critical step that contributes to the project's overall success. While the absence of IMU data presents challenges, this approach ensures that subsequent steps, such as image alignment and orthophoto generation, are performed with a reasonable spatial context.

3.3. Workflow Description

The workflow unfolds within Agisoft Metashape, an advanced photogrammetric software renowned for its capabilities in creating precise orthophotos and DEMs. Each step is meticulously executed, staying in alignment with the scientific methodology.

- **Image Import and Camera Calibration:** The downloaded images are imported into the software, adhering to specific camera parameters for the Leica DMC III. The intrinsic and extrinsic camera parameters are calibrated, ensuring accurate geometric reconstruction.
- **GCP Integration:** GCPs are seamlessly incorporated into the project, aligning images spatially and minimizing distortions.
- **Tie Points and Dense Cloud Generation:** Tie points are generated, linking corresponding points across images. A dense cloud is then constructed, representing the 3D geometry of the area.
- **DEM Generation:** A digital elevation model (DEM) is computed from the dense cloud, capturing ground surface elevation variations with high precision.
- **Orthomosaic Generation:** The DEM is fused with the original images, rectifying any perspective distortions. The result is a seamless orthomosaic with uniform scale and correct georeferencing.

3.3.1. Pre-processing and Data Preparation

These are crucial steps in any geospatial project, including photogrammetry. These steps help ensure that the input data is accurate, consistent, and appropriately formatted for later processing.

Adjusting Software Preferences:

Before starting to process the images, it is important to make sure that Metashape is set up correctly. It is crucial to make sure the right graphics card (GPU) is turned on.

by clicking Tools and Preferences in the GPU tab, if multiple GPUs are listed, it is important to uncheck the integrated (Intel) GPU and place checkmarks next to only the powerful dedicated GPU. Also, in this case, leave the (Use CPU when performing GPU accelerated processing) box unchecked (as indicated in the following figure, for example), (Figure 28).

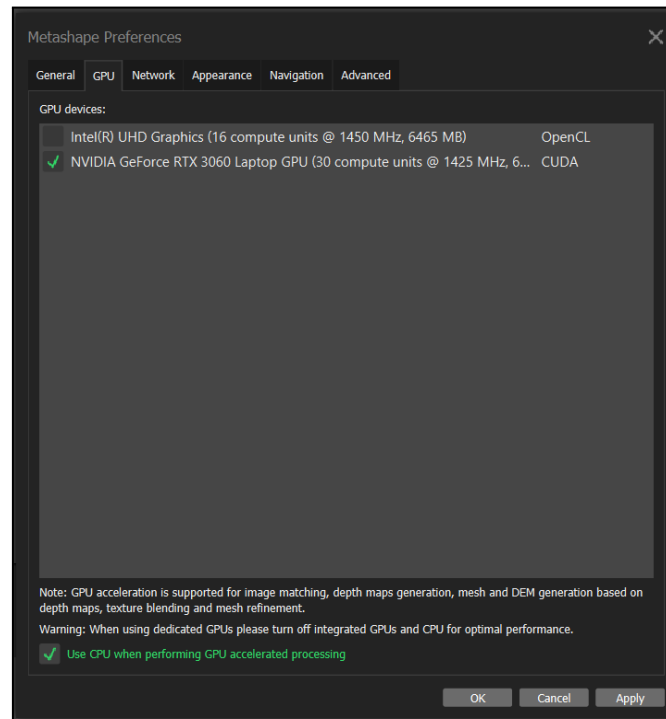


Figure 28. Adjusting Software Preferences

Project Initialization and Image Import:

The first step is to create a new project in Metashape to initiate the photogrammetric workflow. It is important to set up the project parameters, including coordinate systems, scale, and other relevant settings.

The selected aerial images from Sheet 0947 were imported into the project either individually or by specifying a folder where the images are located, as indicated in (Figure 29).

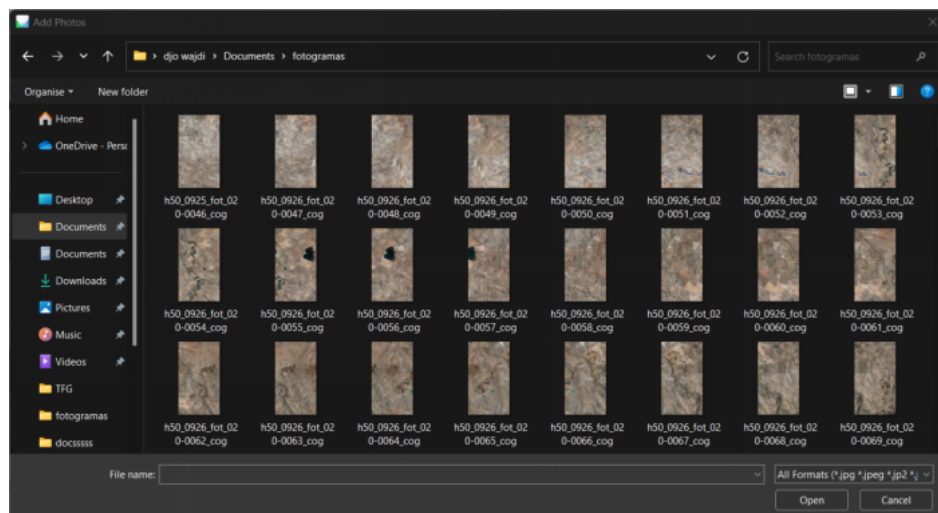


Figure 29. Specifying a folder for Image Import

Coordinate System Setup:

The next step is to define the correct coordinate system, ETRS89 UTM Zone 30N, for precise georeferencing Both the marker reference and the camera reference must be assigned the same Coordinate System.

(Figure 30) below shows the coordinate system defined for camera reference and marker reference:

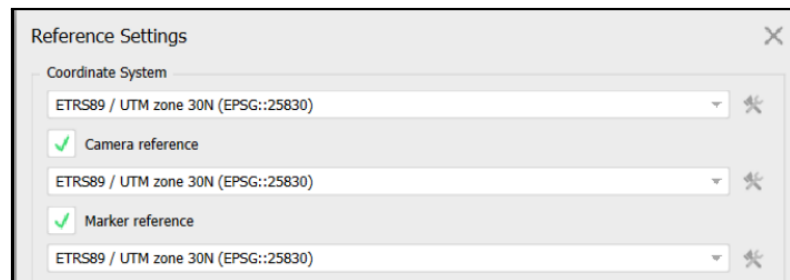


Figure 30. Coordinate System Setup

Camera Calibration:

The camera parameters were calibrated using available reference data for the Leica DMC III sensor. Camera calibration is crucial for determining the precise camera parameters, including the focal length and principal point. This process improves the accuracy of later photogrammetric processing. (Figure 31) shows the camera calibration menu and the introduced parameters:

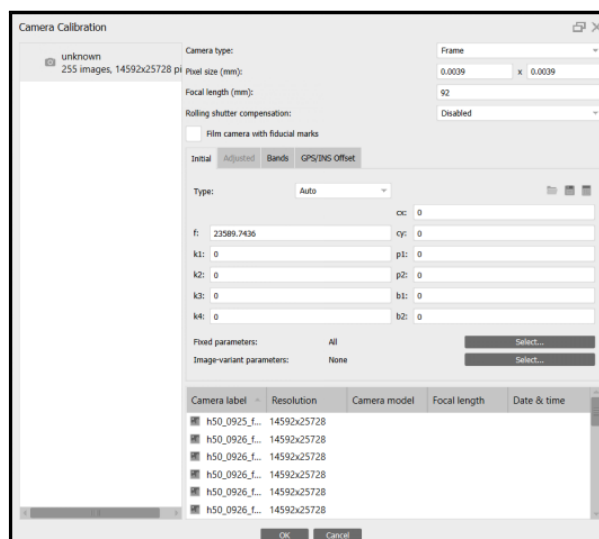


Figure 31. Camera Calibration process

- Metashape can automatically estimate image quality. Images with a quality value of less than 0.5 units are recommended to be disabled and thus excluded from the photogrammetric processing.

Quality is estimated by right-clicking on a photo in the Reference-window, selecting “Estimate Image Quality”, and selecting “All cameras” as indicated in (Figure 32) below:

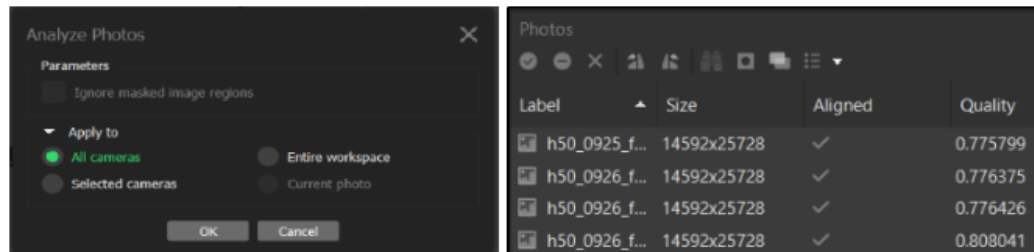


Figure 32. Image quality check

- after sorting the photos by the “Quality”-column.photos with lower quality than 0.5 were disabled (0 photos in this case).

3.3.2. Initial Alignment

Once the images are imported into Metashape, the next step is to import the camera reference data in ASCII format see (Figure 33). This data contains important camera parameters for each image, such as the principal point coordinate. which are an initial calculation reference, the camera alignment accuracy is later optimized when introducing GCPs and calibration during the photogrammetric processing.

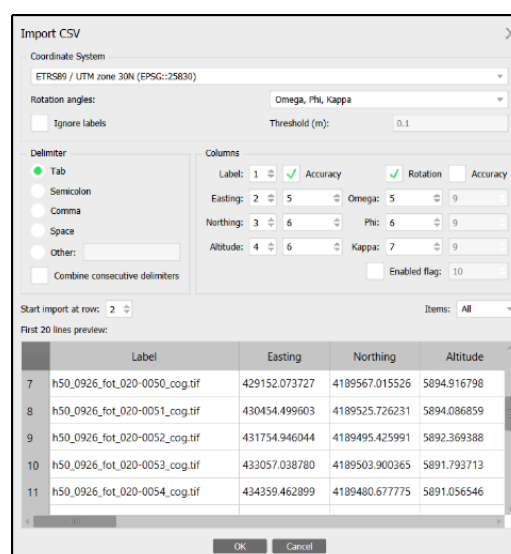


Figure 33. Import the ASCII file

Initial Alignment:

Based on common features in the images, the initial alignment process estimates the approximate camera positions and orientations. Metashape uses algorithms to match corresponding points and estimate the camera parameters. This step provides a rough alignment of the images.

Metashape performs feature matching, which is the process of finding and matching shared details or features in various images. In order to accurately align the images, these points serve as reference points.

The settings for this project are represented in (Figure 34) below:

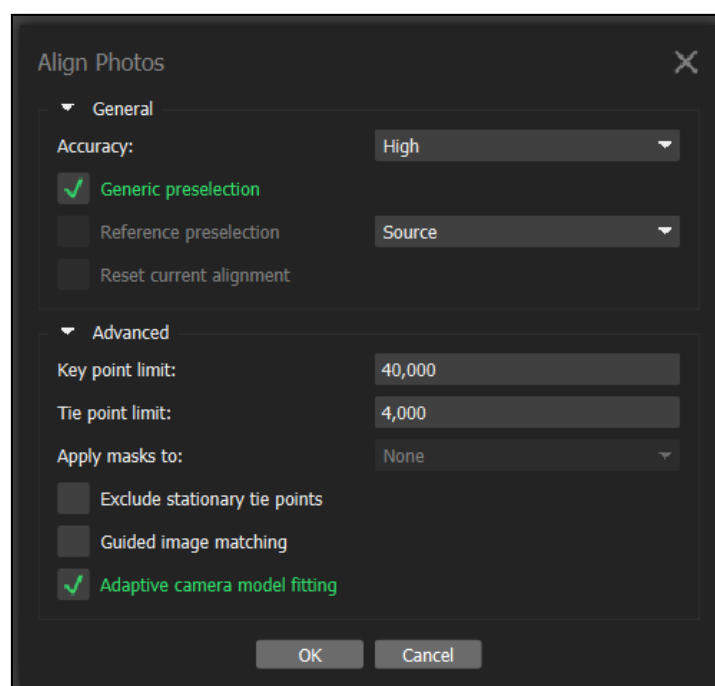


Figure 34. Initial Image Alignment settings

- Higher accuracy settings help to obtain more accurate camera position estimates, At High accuracy, Metashape uses the full resolution of the photos.
- Lower accuracy settings can be used to get a rough estimation of camera positions in a shorter period of time.

Pair Pre-Selection:

With Pair pre-selection set to Generic, Metashape will make a quick pre-scan to see which photos share the same view. If the photos do not share the same view, then it makes no sense to compare the points in the photos. This makes the alignment much faster.

Key Point Limit:

The number indicates the upper limit of feature points on every image to be taken into account during the current processing stage. Using zero values allows Metashape to find as many key points as possible, but it may result in a large number of less reliable points [17].

The maximum number of points Metashape will extract from each photo, In this case, it was set to 40,000, which makes the alignment much faster and easier for the hardware.

Tie Point Limit:

When this setting is active, Metashape makes a pre-selection based on the (visual) quality of the extracted points (so it only compares the highest quality points).

For example, if the Key Point limit is set to 40000 and the Tie Point Limit is set to 4000, then Photoscan will first extract 40000 points for each photo and only keep the best 4000 points. These 4000 points per photo are then used for the alignment calculations.

This would speed up the alignment a lot because there are only a fraction of the points to compare [17].

Adaptive camera model fitting:

This option enables the automatic selection of camera parameters to be included in the adjustment based on their reliability estimates. When checked, Metashape will calculate all the factors it can take into account (focal length, principal point position, and distortion coefficients) [17].

(Figure 35) shows the Partial output, which is a Rough Alignment of the Images:

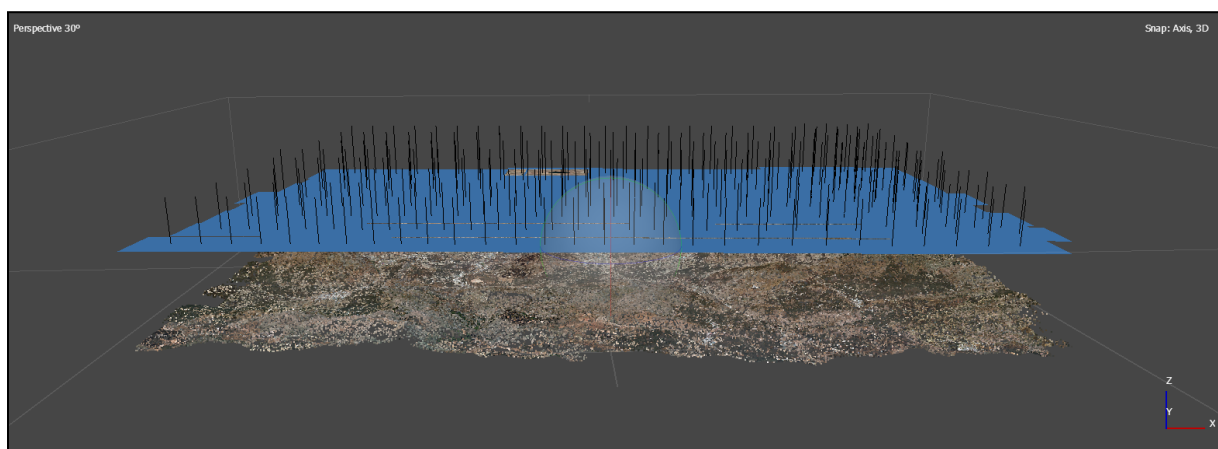


Figure 35. Rough Alignment of the Images

By creating a Metashape project, importing the images, setting up the coordinate system, calibrating the cameras, controlling the Image quality, and executing an initial alignment, the groundwork for further processing is laid.

3.3.3. Adding Ground Control Points (GCPs) and Check Points

Adding Ground Control Points (GCP) is a crucial step in the photogrammetry workflow to enhance the accuracy and georeferencing of the generated products. GCPs are reference points with known coordinates that serve as control points for aligning and georeferencing the photogrammetric data.

Adding Ground Control Points (GCP) to the project involves these steps:

GCP Data Import:

It consists of using the GCP import functionality in Metashape to import the GCP data file. Similar to importing camera reference data, by browsing and selecting the file containing GCP information, which typically includes unique identifiers and their corresponding surveyed coordinates as indicated below in (Figure 36):

Import CSV

Coordinate System: ETRS89 / UTM zone 30N (EPSG::25830)

Rotation angles: Omega, Phi, Kappa

☐ Ignore labels

Threshold (m): 0.1

Delimiter: ☒ Comma

Columns:

Label	1	2	3	4	5	6	7	10
Accuracy								
Rotation								
Omega								
Phi								
Kappa								
Enabled flag								

Start import at row: 2

Items: All

First 20 lines preview:

	Label	Easting	Northing	Altitude	Easting Accuracy
1	Name	X	Y	zcoord	
2	23819	426311.4577	4188352.611	408.92	
3	23846	424841.797	4168597.942	942.318	
4	238PNOA079454	424859.1582	4170911.513	251.915	
5	23907	437124.1488	4186858.997	469.515	

OK Cancel

Figure 36. The GCP data file import

Filtering GCPs:

Once the GCP data is imported, the next step is to filter the GCPs by images to identify which GCPs are visible in each image. This step helps in locating the GCPs accurately in the alignment and georeferencing processes.

It is important to control the locations of GCPs to ensure their accuracy and eliminate any GCPs with unknown exact locations or tolerance errors. This step contributes to the reliability and precision of photogrammetric products, the GCPs accuracy and error are both indicated in (Figure 37):

Markers		Easting (m)	Northing (m)	Altitude (m)	Accuracy (m)	Error (m)
✓	23912	455317.376000	4179784.346000	1039.058000	0.005000	0.010934
✓	25006	438945.072000	4167780.514000	1134.338000	0.005000	0.010457
✓	GCP05	422517.430000	4181702.540000	646.462000	0.005000	0.000845
✓	GCP12	446766.230000	4185340.580000	662.220000	0.005000	0.001859
✓	GCP11	442394.860000	4176105.200000	692.230000	0.005000	0.002279
✓	23946	443775.832300	4177788.276000	845.415000	0.005000	0.002395
✓	GCP01	430859.770000	4181654.160000	485.059000	0.005000	0.001429
✓	GCP09	436901.690000	4180876.870000	419.677000	0.005000	0.002210
✓	GCP10	438346.160000	4178748.510000	528.639000	0.005000	0.001618
✓	23930	446189.853800	4184440.270000	701.350000	0.005000	0.001361
✓	GCP03	431617.340000	4185012.400000	414.905000	0.005000	0.001549
✓	2495E...	424709.456000	4168758.600000	909.017000	0.005000	0.000606
✓	23929	430235.597000	4179422.616000	582.709000	0.005000	0.001595

Figure 37. GCPs accuracy and error

Locating GCPs in Images:

Metashape includes tools for locating each GCP in all images where it is visible. This involves manually or automatically identifying the GCP in each image by marking its position as indicated in the next figure (Figure 38):

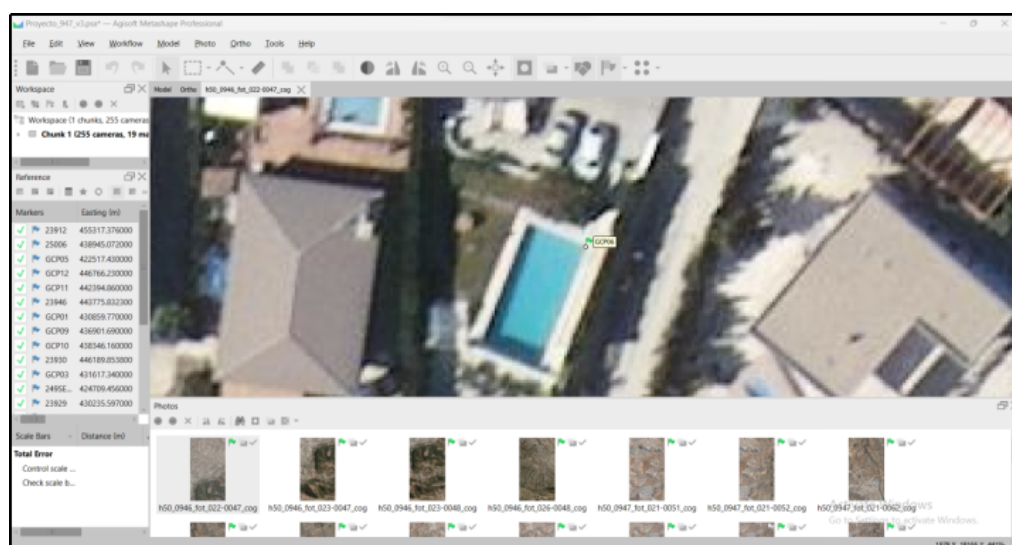


Figure 38. Locating GCPs in Images

Check Points:

In addition to adding and locating Ground Control Points (GCPs), it is important to designate some checkpoints from the GCPs that have known exact locations and minimal errors see (Figure 39). Checkpoints serve as independent validation points to assess the accuracy and reliability of the photogrammetric results.

Markers	Error (m)	Error (pix)
✓ 23930	0.001361	0.923
✓ GCP10	0.001618	0.935
✓ GCP09	0.002210	1.048
✓ GCP01	0.001429	1.151
✓ 23946	0.002395	1.295
✓ GCP11	0.002279	1.403
✓ GCP12	0.001859	1.500
✓ GCP05	0.000845	1.689
✓ 25006	0.010457	4.372
✓ 23912	0.010934	4.872
Total Error		
Control points	0.003824	1.956
Check points	0.072421	0.386

Figure 39. Checkpoints designation

Check Points are excluded from Optimization during the photogrammetric processing to assess their accuracy independently. This ensures that the checkpoints are not used in the adjustment of camera positions and alignment.

By adding GCPs and locating them accurately in the images, the georeferencing and alignment of the photogrammetric data are enhanced. The quality control step ensures the GCPs used in the process meet the required standards for accuracy and tolerance, and By designating check points from the GCPs with known exact locations and minimal errors, it is possible to validate the accuracy of the photogrammetric outputs and assess the overall quality of the generated DEMs and orthophotos.

3.3.4. Image Re-Alignment and Point Cloud Generation

3.3.4.1. Image Re-Alignment

One of the most important steps in the photogrammetric workflow is image alignment, which entails precisely aligning the images to produce a reliable and accurate photogrammetric model. Here's an exploration of the image alignment process:

After performing an initial alignment and adding Ground Control Points (GCPs) in Metashape, the next step is to re-align the photos. This step is crucial to improving the accuracy of the products.

GCP-based Refinement:

With GCPs, the software can now perform a more precise bundle adjustment. It adjusts the camera positions, orientations, and other parameters to minimize the difference between the projected positions of the GCPs in the images and their actual coordinates. This process greatly improves the alignment's accuracy.

→ This georeferencing data is incorporated by Metashape during the alignment procedure to guarantee alignment with the coordinate system used in the real world.

Checkpoint Validation:

Check points were designated from the GCPs, and the accuracy of the alignment can be assessed by comparing the photogrammetrically derived coordinates of the check points with their known surveyed coordinates. This validation step helps verify the accuracy of the alignment results.

Re-alignment:

After the GCP-based refinement, it is important to re-align the photos. This means that the software will adjust the positions and orientations of the images again, but this time taking into account the accurate GCP information. The goal is to minimize the errors in both the GCPs and the tie points (points automatically matched between images).

3.3.4.2. Quality control

Photos alignment:

Photo alignment is a crucial part of the quality control process in photogrammetry. Properly aligned photos serve as the foundation for generating accurate and reliable results (Figure 40).

- **Accuracy of Reconstruction:** Photo alignment directly affects the accuracy of the reconstructed 3D model. If the photos are not aligned properly, the resulting model may have distortions, inaccuracies, and misalignments.
- **Visual Realism:** Well-aligned photos lead to a more visually realistic 3D model. Proper alignment ensures that textures and features are correctly positioned, making the model visually convincing.
- **Consistency:** Proper alignment ensures that the scale, rotation, and position of each photo are consistent with the others. This consistency is essential for a coherent and accurate 3D reconstruction.
- **Avoiding Errors:** Misaligned photos can introduce errors that propagate through the entire reconstruction process. These errors can be difficult to correct downstream, making it essential to catch alignment issues early.
- **Effective Use of Tie Points:** Tie points are used to match features across photos and aid in alignment. Quality alignment ensures that tie points are accurate and evenly distributed, leading to a better reconstruction.

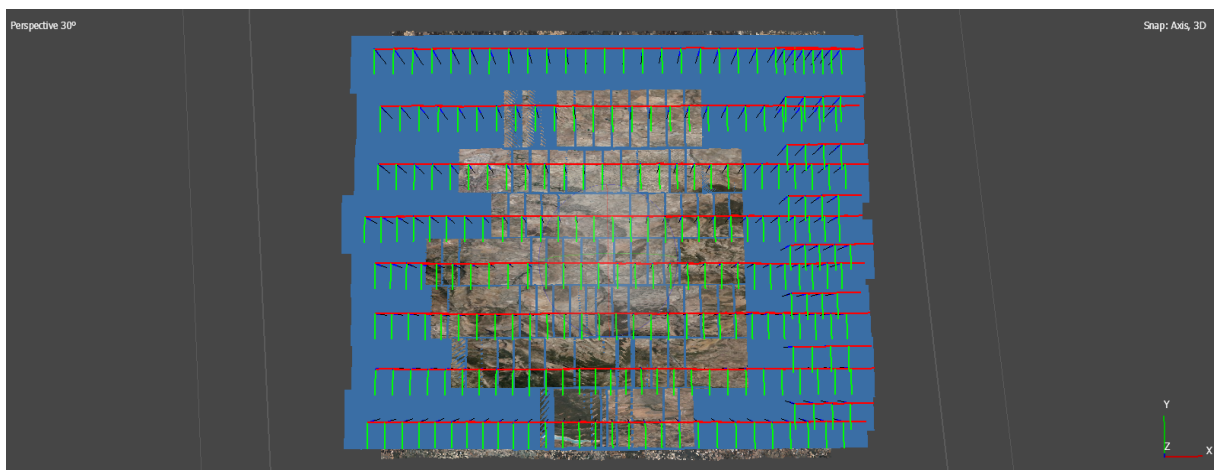


Figure 40. Alignment results after quality control

→ In this project, no alignment errors were detected, so the next step is to start filtering the tie points generated after the alignment.

Tie points filtering:

Filtering tie points is an important step in photogrammetry because it helps to clean up the project and improve processing efficiency. In overlapping images, tie points are automatically identified as matching points, and filtering them can remove any erroneous or unnecessary points.

In Agisoft Metashape, the "Gradual Selection" tool is used to select and filter tie points based on their quality or other criteria. This tool allows for gradual refinement of the selection of tie points by applying different criteria and thresholds. The tool provides four options, each of which helps define the gradual selection process, which are represented in (Figure 41):

- After each step, the erroneous points were deleted, and the optimization tool was used before passing to the next criteria.
- The recommended values used were gathered from the Metashape support group and other projects and by visually inspecting the results of this project.

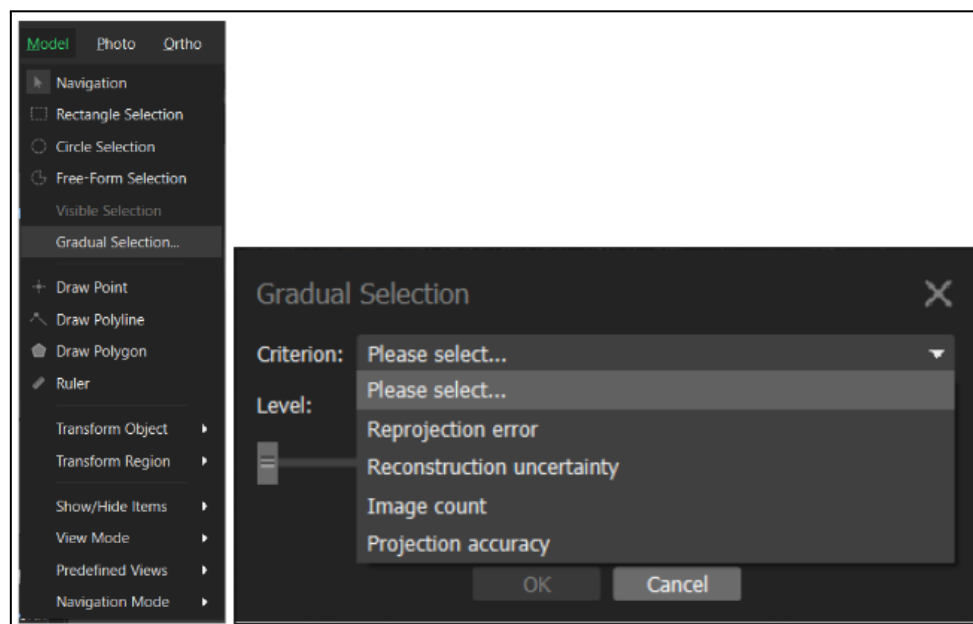


Figure 41. Gradual Selection Tool

Reprojection Error:

- Description: Reprojection error, or Statistical error in point placement, is a measure of how accurately a tie point's 3D coordinates match its 2D image projections. A lower reprojection error indicates a more accurate tie point.

- Option: This option allows for gradually selecting tie points based on a specified reprojection error threshold. Tie points with reprojection errors exceeding the threshold will be progressively deselected.
- Recommended Value: 0.5, which is half a pixel and below, see (Figure 42).

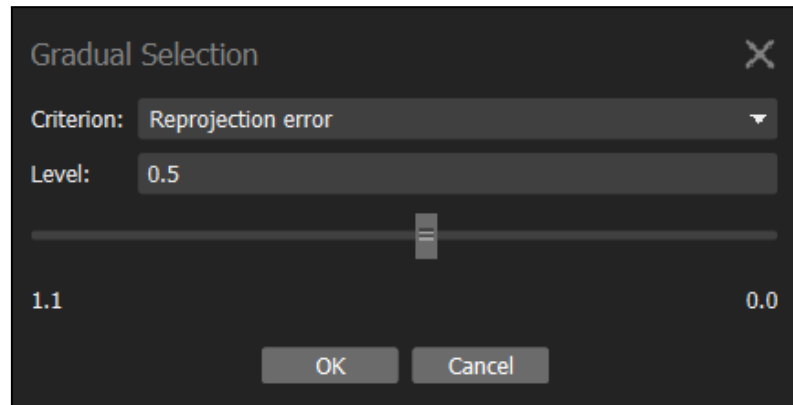


Figure 42. Reprojection Error Selection criteria

Reconstruction Uncertainty:

- Description: Reconstruction uncertainty is a measure of the 3D reconstruction's accuracy in a specific area. It considers the uncertainty in tie points' positions, camera parameters, and more.
- Option: This option allows for gradually selecting tie points based on a specified maximum reconstruction uncertainty value. Tie points associated with higher uncertainty values will be gradually removed.
- Recommended Value: 10 and below as long as it does not exceed 25% of the total number of tie points, see (Figure 43).

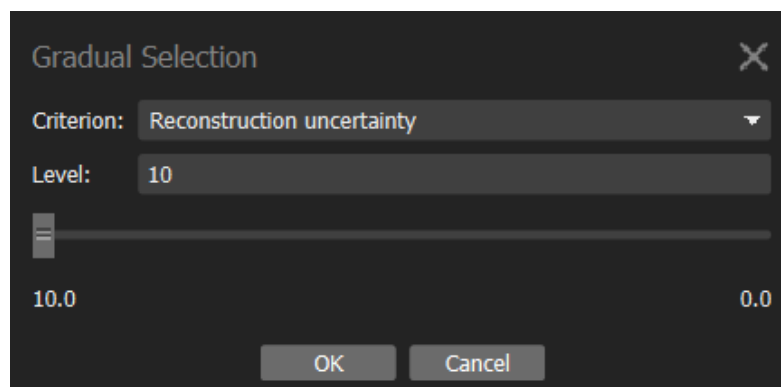


Figure 43. Reconstruction Uncertainty Selection criteria

Projection Accuracy:

- Description: Projection accuracy refers to how accurately the tie point's image projections match the actual image locations or the Accuracy of point placement from local neighbor points.
- Option: The "Projection Accuracy" option gradually selects tie points based on a specified projection accuracy threshold. Tie points with projection accuracy values exceeding the threshold will be progressively filtered out.
- Recommended Value: 3 and below as long as it does not exceed 50% of the total number of tie points, see (Figure 44).

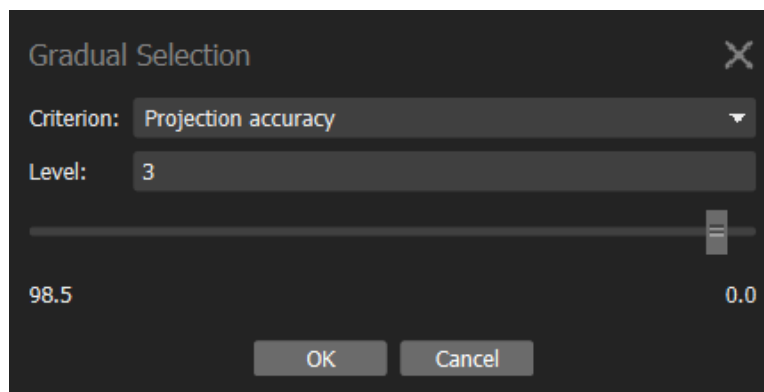


Figure 44. Projection Accuracy Selection criteria

Tie Points Distribution:

It is important to check if tie points are evenly distributed throughout the project area. Sparsely populated areas might result in incomplete reconstructions; in this case, after the filtering, the tie points are distributed evenly across the images, indicating that we have a well-aligned dataset, which is indicated in (Figure 45):



Figure 45. Tie Points Distribution

3.3.4.3. Point Cloud Generation

Building a dense point cloud is a crucial step in the photogrammetric process, as it generates a detailed 3D representation of the scene by densely reconstructing points in space.

- **Point Cloud Generation:** Once the images are aligned, the next step is to begin the process of generating a dense point cloud. Metashape does this by analyzing the overlapping images and matching the corresponding pixels to identify common features in multiple images.
- **Depth Map Calculation:** The software calculates depth maps for each image by estimating the distance of each pixel from the camera viewpoint. This process involves analyzing the parallax between corresponding pixels in different images to determine the pixel's depth or distance from the camera.
- **Point Cloud Reconstruction:** Using the depth maps, the software reconstructs a point cloud by triangulating the corresponding points in 3D space. This process involves calculating the 3D coordinates of each point based on the pixel's depth information and camera parameters.

Build Point Cloud parameters:

The settings for this project are as indicated below in (Figure 46):

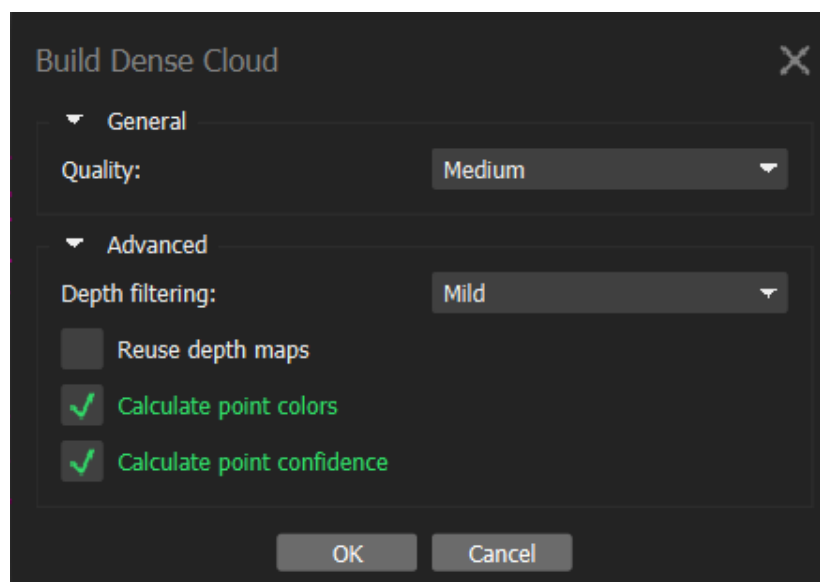


Figure 46. Build Point Cloud parameters

Quality:

It Specifies the desired quality of the depth maps generation. Higher quality settings can be used to obtain more detailed and accurate geometry, but they require longer time for processing [17].

- Due to hardware limitations, the Medium option was chosen for the quality of the depth maps generation.

Depth filtering modes:

At the stage of point cloud generation reconstruction Metashape calculates depth maps for every image. Due to some factors, like noisy or badly focused images, there can be some outliers among the points. To sort out the outliers Metashape has several built-in filtering algorithms that answer the challenges of different projects.

In the case there are important small details which are spatially distinguished in the scene to be reconstructed, then it is recommended to set Mild depth filtering mode, for important features not to be sorted out as outliers [17].

- To keep as much detail as possible the **Mild** depth filtering mode was selected for this project.

Calculate point colors:

This option can be unchecked in case the points color is not of interest. This will allow to save preprocessing time [17].

- in this case it was checked because the points color is needed in this project.

Calculate point confidence:

If the option is enabled, the Metashape will count how many depth maps have been used to generate each point cloud point. This parameter can be used for point cloud filtering [17].

Dense Point Cloud Filtering:

The generated dense point cloud may contain noise or outliers. To ensure a clean and accurate representation, the point cloud is typically filtered to remove erroneous points or areas with poor matching quality.

Manual filtering:

Manually filtering and deleting points from the dense point cloud is useful to refine the quality of the project. This process consists of manually selecting and removing points that might be outliers, noise, or artifacts.

- using the selection tool, (Figure 47), to manually click on or draw a selection box around the points that need to be deleted. It is possible to select individual points, clusters of points, or areas with noise or artifacts.

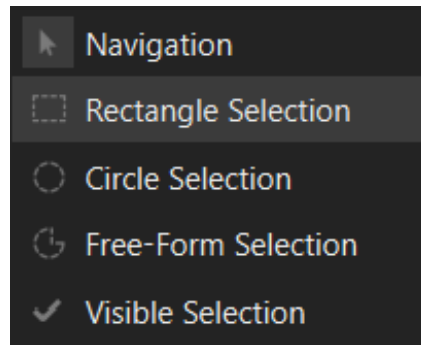


Figure 47. The selection tool

The selected points are then deleted from the dense cloud as shown in (Figure 48):



Figure 48. Manual filtering

Filtering by Density Threshold:

Filtering based on density can help remove points in areas with an excessive number of points. This can help simplify the point cloud while retaining important details, because of the size of the data, a point spacing of 2 meters was selected for the filtering, see (Figure 49):

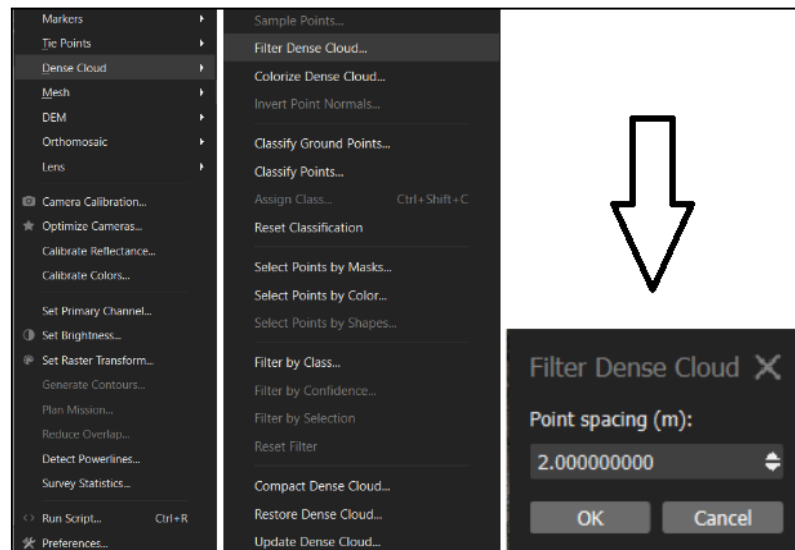


Figure 49. Filtering by Density Threshold

Filtering by class:

before attempting to filter the dense cloud, it is important to start by classifying it. Dense cloud classification in Agisoft Metashape involves categorizing points in the dense point cloud into different classes based on their characteristics. This process helps differentiate between various types of surfaces and objects, which is valuable for further analysis, visualization, and manipulation.

Through the classification process, it is possible to filter the dense cloud by extracting unwanted classes such as Overlap points and Low points (noise).

- The first step in dense cloud classification is to classify ground points, which can be done automatically using a tool in Metashape.

The automatic classification procedure consists of two steps. In the first step, the point cloud is divided into cells of a certain size. In each cell, the lowest point is detected. The triangulation of these points gives the first approximation of the terrain model.

- ➔ Additionally, at this step, Metashape filters out some noise points to be handled as Low points.
- At the second step, a new point is added to the ground class, providing that it satisfies two conditions: that it lies within a certain distance from the terrain model and that the angle between the terrain model and the line to connect this new point with a point from the ground class is less than a certain angle. The second step is repeated while there are still points to be checked [17].

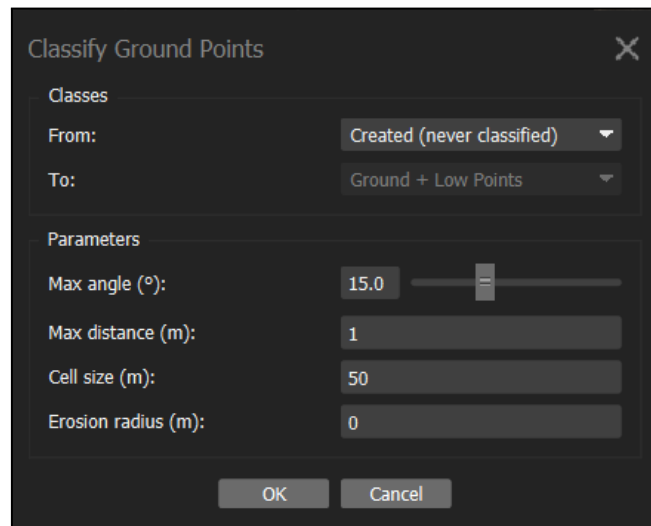


Figure 50. Automatic ground points classification

The following parameters control the automatic ground points classification procedure, which are indicated in (Figure 50) above:

Max angle (deg)

Determines one of the conditions to be checked while testing a point as a ground one, i.e., sets a limitation for an angle between the terrain model and the line to connect the point in question with a point from a ground class. For nearly flat terrain, it is recommended to use the default value of 15 degrees for the parameter. It is reasonable to set a higher value if the terrain contains steep slopes [17].

Max distance (m)

Determines one of the conditions to be checked while testing a point as a ground one, i.e., sets a limitation for a distance between the point in question and the terrain model. In fact, this parameter determines the assumption for the maximum variation of the ground elevation at a given time [17].

Cell size (m)

Determines the size of the cells for the point cloud to be divided into as a preparatory step in the ground points classification procedure. Cell size should be indicated with respect to the size of the largest area within the scene that does not contain any ground points, e. g., a building or point forest [17].

Erosion radius (m)

Determines the indentation (in meters) from unclassified points to create an additional area around the object; it is useful when classifying houses and trees to exclude the remaining "stumps" when building DTM [17].

- It is possible to visualize only the classified ground points by filtering the dense cloud by class and choosing ground.

As shown in (Figure 51) below:

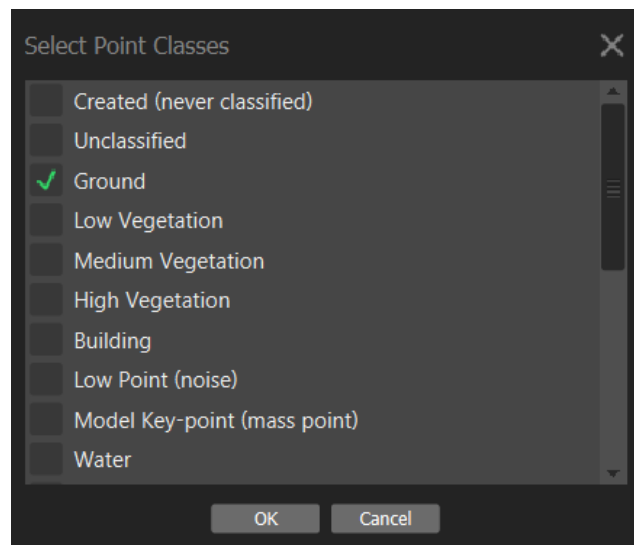


Figure 51. Filtering the Dense cloud by class (ground points)

The next figure, (Figure 52) represents the Ground points classified by the software:

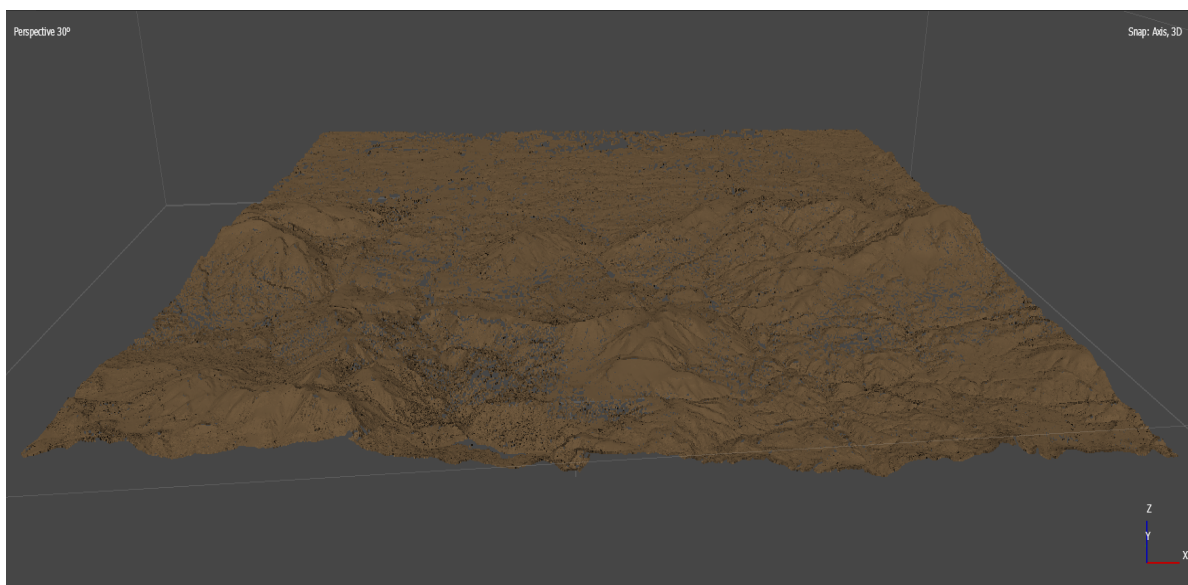


Figure 52. Ground points classified by the software

- The software is also able to classify the low points (noise), which makes it possible to delete them or exclude them from the dense cloud, see (Figure 53).

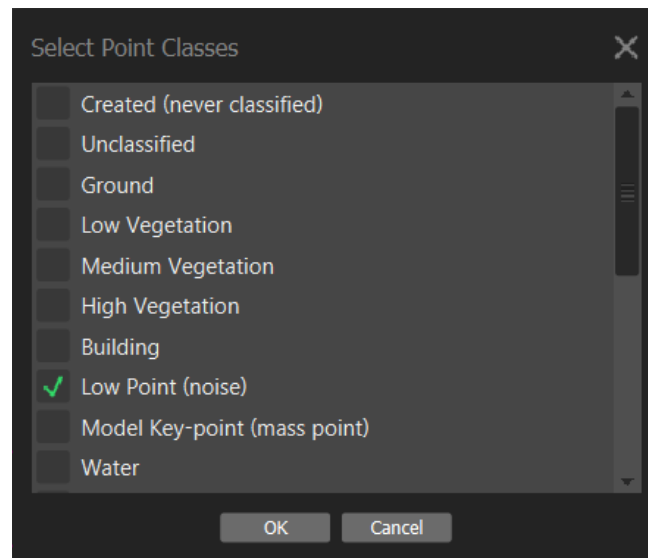


Figure 53. Filtering the Dense cloud by class (low points)

And as follows, the next figure represents the Low points (noise) classified by the software, (Figure 54):

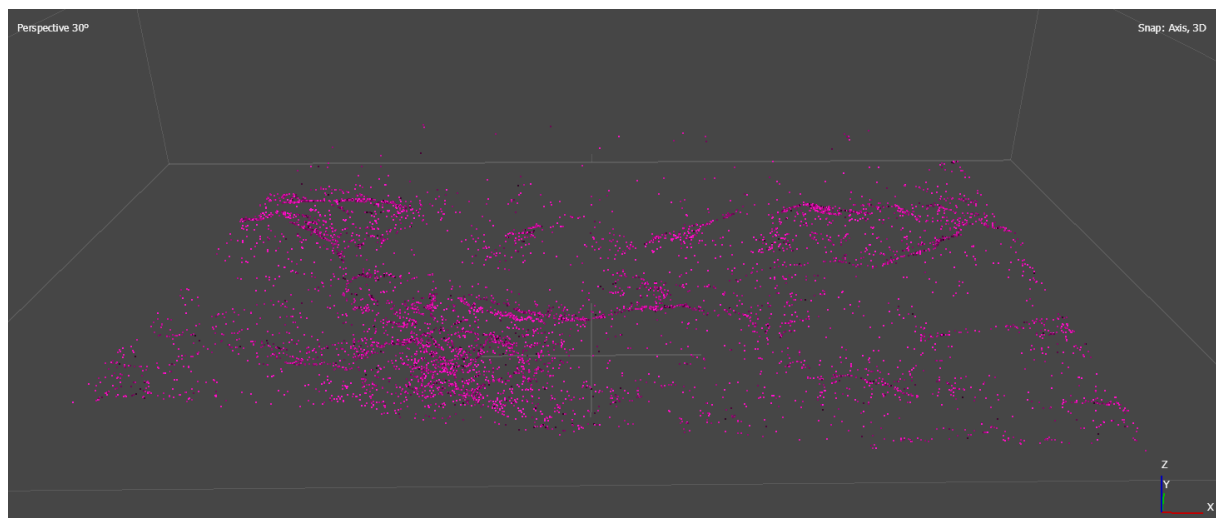


Figure 54. Low points classified by the software

- After that, the next step is to automatically classify the rest of the points (Created (never classified)), see (Figure 55).

Automatic classification of point clouds in Agisoft Metashape involves using algorithms to classify points into different categories, such as ground, vegetation, buildings, etc. This process helps organize and segment the point cloud data, making it more useful for various applications.

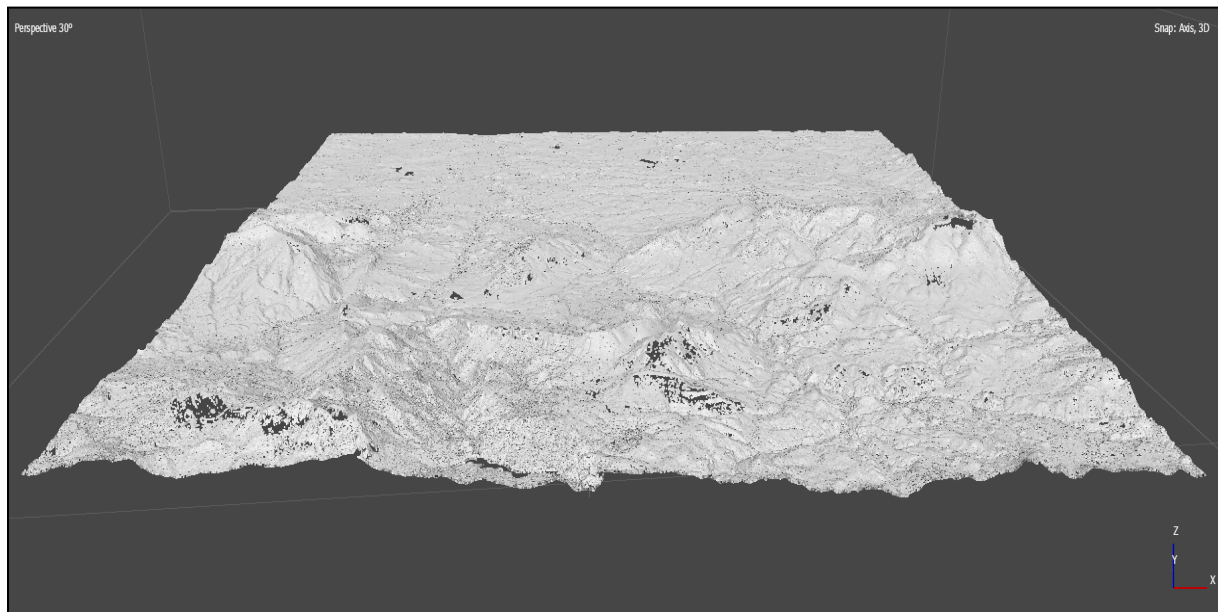


Figure 55. Created points (never classified)

The next figure represents the automatic classification Tool that is used to classify Vegetation and buildings (Figure 56):

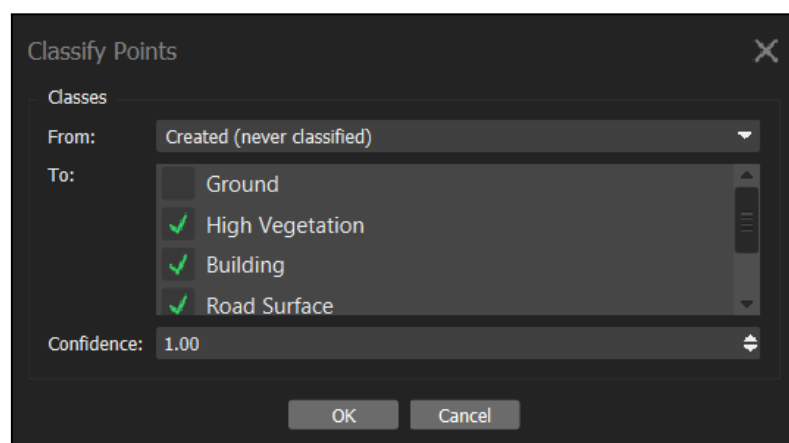


Figure 56. Automatic Classification Tool

Manual Editing:

- After the initial classification, it is important to manually check and edit the classification if necessary.

This can be done by manually selecting objects that are not classified properly, as indicated in (Figure 57) below, using the selection tools in Metashape mentioned in (Figure 47) above, and then assigning them to their specific classes.



Figure 57. Selecting misclassified objects.

- Using the assign class tool indicated in the next figure, any misclassified points can be assigned to the correct class. In most cases, the software confuses high vegetation with buildings, which is why this step is important, see (Figures 58 and 59).

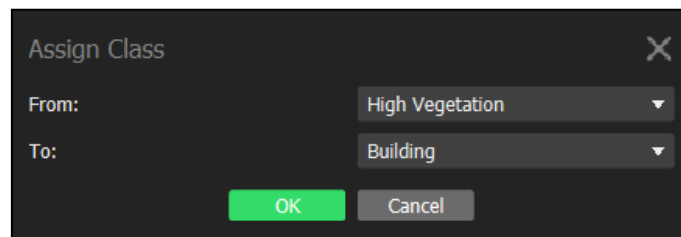


Figure 58. Assign class tool

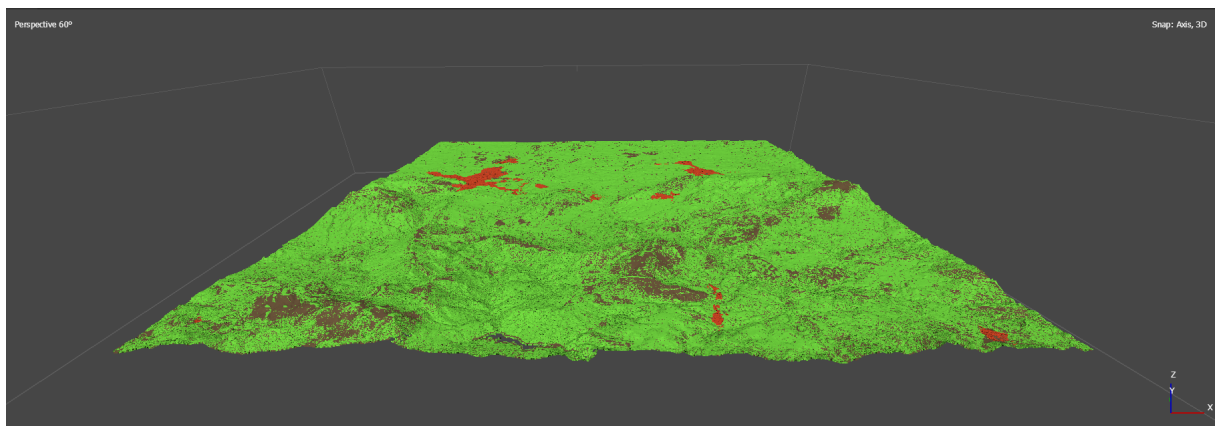


Figure 59. Classification results

- while automatic classification can significantly speed up the process, it might not always achieve perfect results, especially in complex environments. Manual refinement and quality control are essential steps to ensure the accuracy of the classification results.

3.3.4.4. Quality control

Quality control for dense cloud classification in photogrammetry software like Agisoft Metashape is essential to ensuring that the resulting classified point cloud accurately represents the real-world scene.

which consists of multiple steps and considerations:

- **Visual Inspection:** The first step is to visually inspect the classified point cloud. Using the 3D visualization tools in the software to explore the classified points and look for any obvious errors or misclassifications, this step helps identify and address major issues.
- **Density and Completeness:** Assessing the density and completeness of the classified point cloud to ensure that there are no significant gaps or areas with too few points
- **Ground Points:** It is important to focus on the ground points and verify that they are correctly classified, see (Figure 60). Ground points provide a reference surface for subsequent processing steps like digital terrain model (DTM) generation. Misclassified ground points can lead to elevation errors.

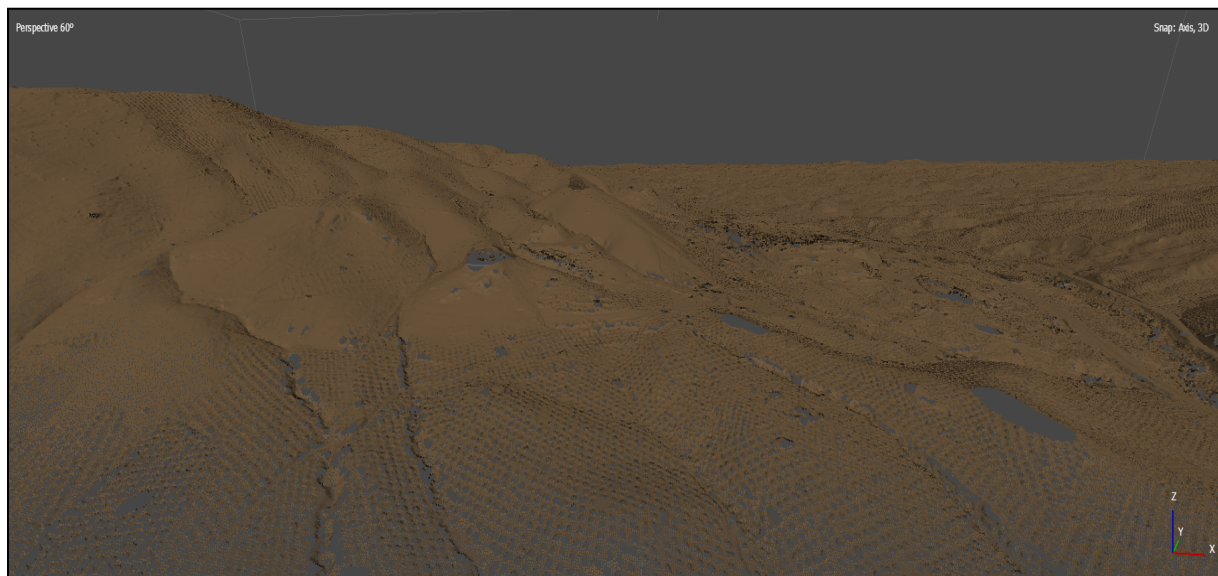


Figure 60. Misclassified ground points check

- **Noise and Outliers:** It is also crucial to Look for additional noise or outliers in the point cloud after the classification. These can be caused by various factors, including errors in image matching or classification, and by using filtering tools, it is possible to remove noise and outliers that don't belong to any meaningful class, the pink points represented in (Figure 61):

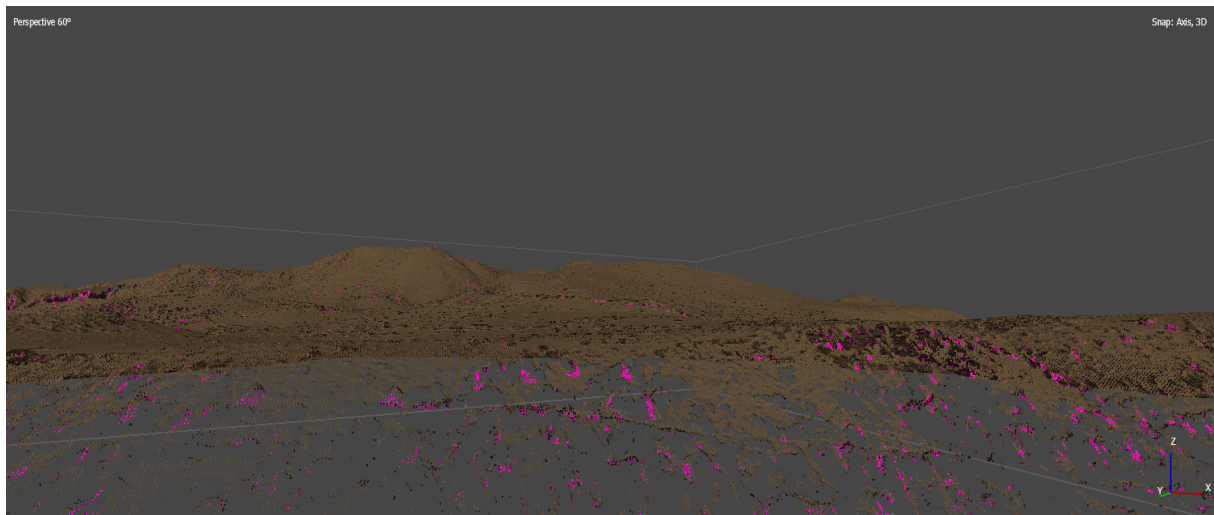


Figure 61. Noise and Outliers

- Edge artifacts or abrupt class transitions: These can occur near object boundaries or in areas with complex geometry, particularly transitions between stand-alone buildings and vegetation, see (Figure 62).



Figure 62. Edge artifacts or abrupt class transitions

- The quality of the dense cloud classification depends on various factors, such as the quality of the initial images, the settings used in Metashape, and the manual editing, which is important to conduct quality control at each step.

Further, quality control in dense cloud classification is crucial for generating reliable models and geospatial data

3.3.5. Digital Terrain Model and Digital Surface Model Generation

DTM (Digital Terrain Model) and DSM (Digital Surface Model) are two types of digital models that represent the surface of the Earth, but they are used for different purposes and represent different surfaces (Figure 63) below represents the difference between them .

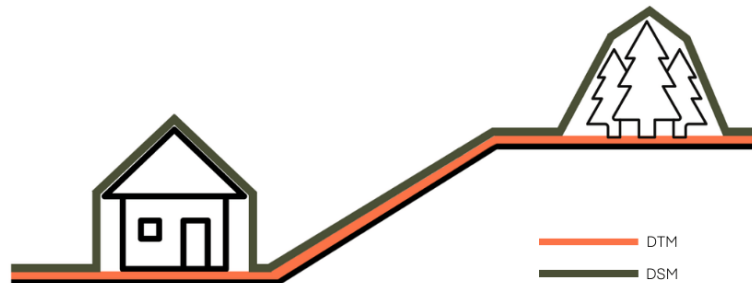


Figure 63. Difference between Digital Terrain Model and Digital Surface Model

3.3.5.1. Digital Surface Model (DSM)

A DSM represents the Earth's surface, including all objects on it. It captures the natural terrain as well as buildings, vegetation, roads, and other man-made structures.

It represents the top surface of the earth, including everything that is on it. So, a DSM would include the heights of buildings, trees, and other structures, which is why in the menu for generating the DSM, all the classes classified in the previous step were selected (Ground, Vegetation, and buildings), as indicated below.

In this case, the software will include these classes to include the heights of buildings, trees, and the ground, see (Figure 64).

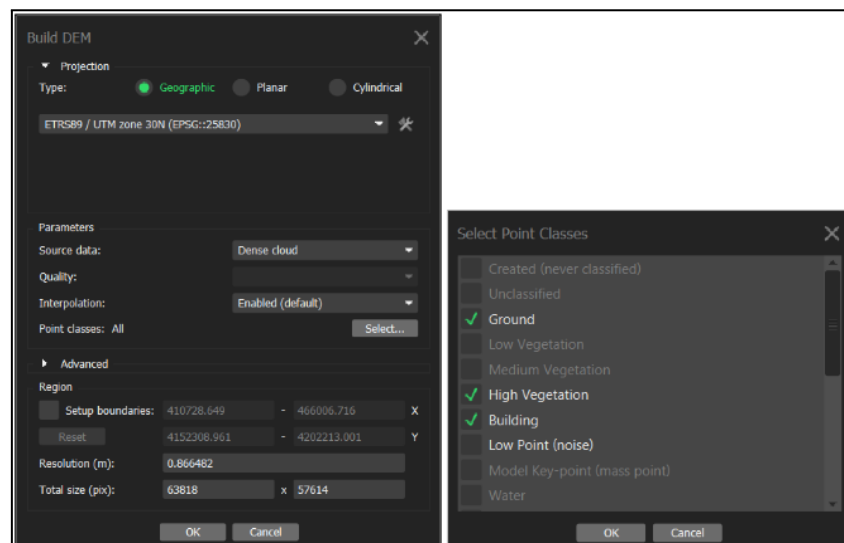


Figure 64. The menu for generating the DSM

(Figure 65) represented the generated DSM:

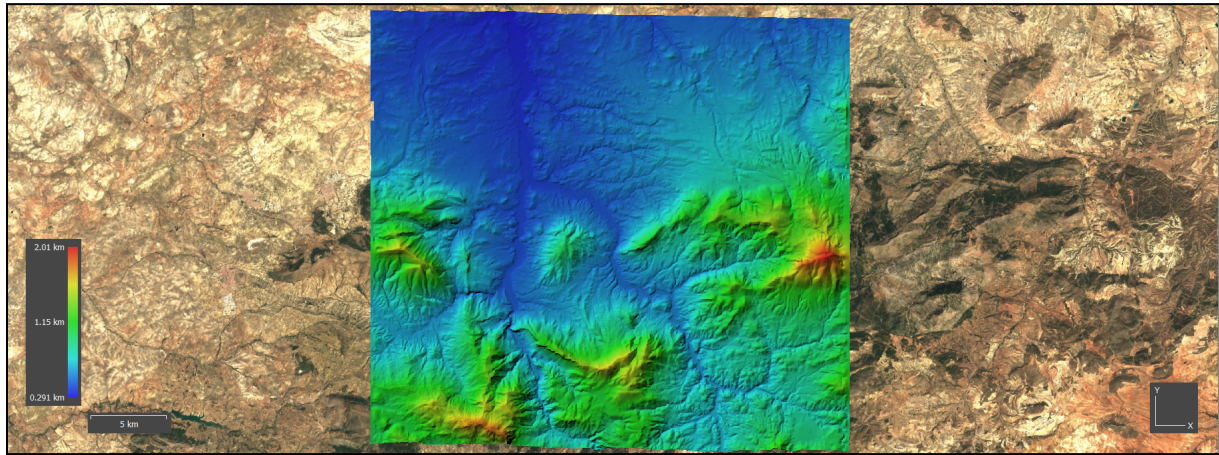


Figure 65. Generated DSM

→ DSM is often used for applications that require information about the entire surface, including the objects on it, such as urban planning, forestry, and wireless network planning.

3.3.5.2. Digital Terrain Model (DTM)

A DTM represents the bare ground surface of the Earth, excluding all buildings, vegetation, and other above-ground objects.

In this case, in the menu for generating the DTM, only the ground points are selected, so the model will only represent the ground level or terrain without any buildings, trees, or other structures, as indicated in (Figure 66).

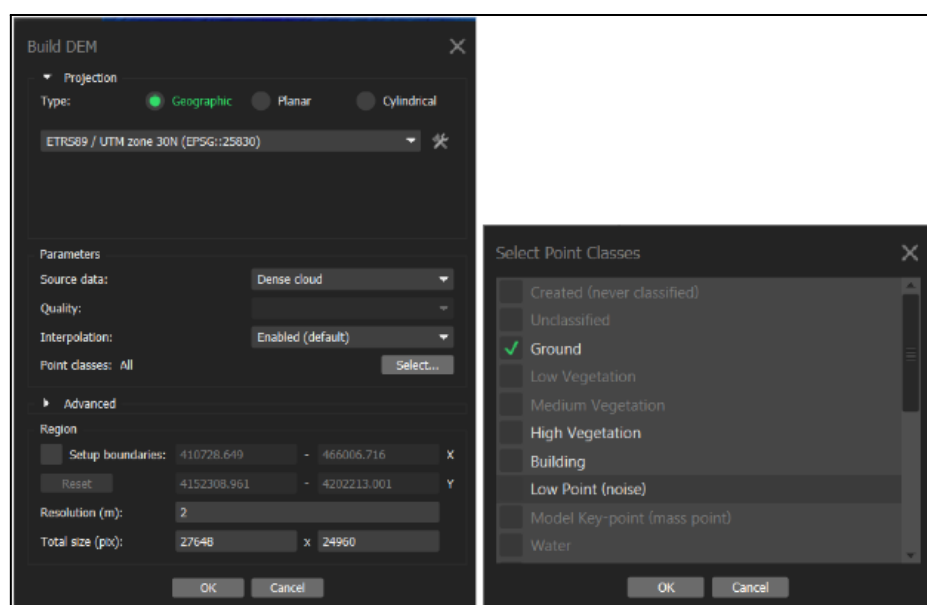


Figure 66. The menu for generating the DTM

(Figure 67) represented the generated DTM:

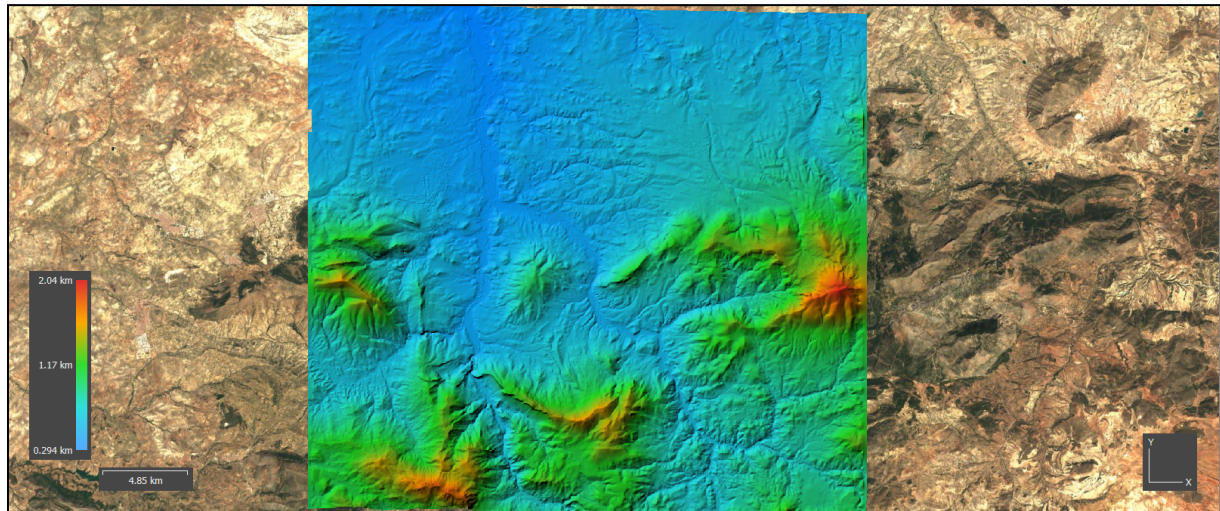


Figure 67. Generated DTM

→ DTM is often used for applications that require information about the natural terrain, such as hydrological modeling, land use planning, and geological applications.

Summary

To conclude, the main difference between a Digital Terrain Model (DTM) and a Digital Surface Model (DSM) lies in what they represent. A DTM represents the bare ground surface of the Earth, excluding all buildings, vegetation, and other above-ground objects. a DSM represents the Earth's surface, including all objects on it.

3.3.5.3. Quality control

There are several steps and considerations for conducting quality control on Digital Models.

- Inspecting the DTM and DSM: After generating the DTM and DSM, it is important to visually inspect them for any anomalies, check for any holes, spikes, or depressions that do not correspond to the real-world terrain, After reviewing the results, no anomalies were detected.
 - Checking the Accuracy: using reference data acquired from a previous mission to assess the accuracy of the DTM.
- The reference data is a Digital Terrain Model (DTM) downloaded from the National Center of Geographic Information (CNIG).

The comparison was done by using the Raster Calculator in QGIS to Calculate the difference between the generated DTM and the reference data using the expression ("Merged-DTM@1" - "PNOA_MDT25_ETRS89_HU30_0947_LID@1"), as indicated in (Figure 69):

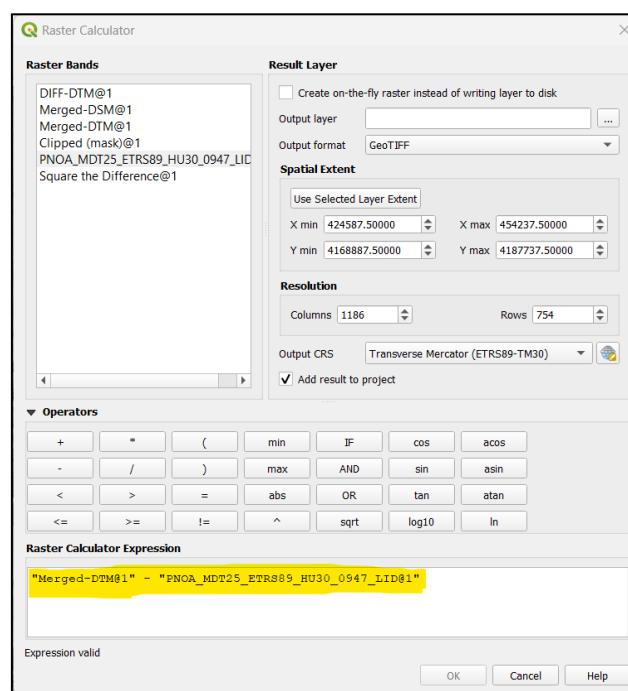


Figure 69. Raster Calculator

The figures below show the reference DTM, the generated DTM, and the difference between the two models; see (Figures 70 and 71).

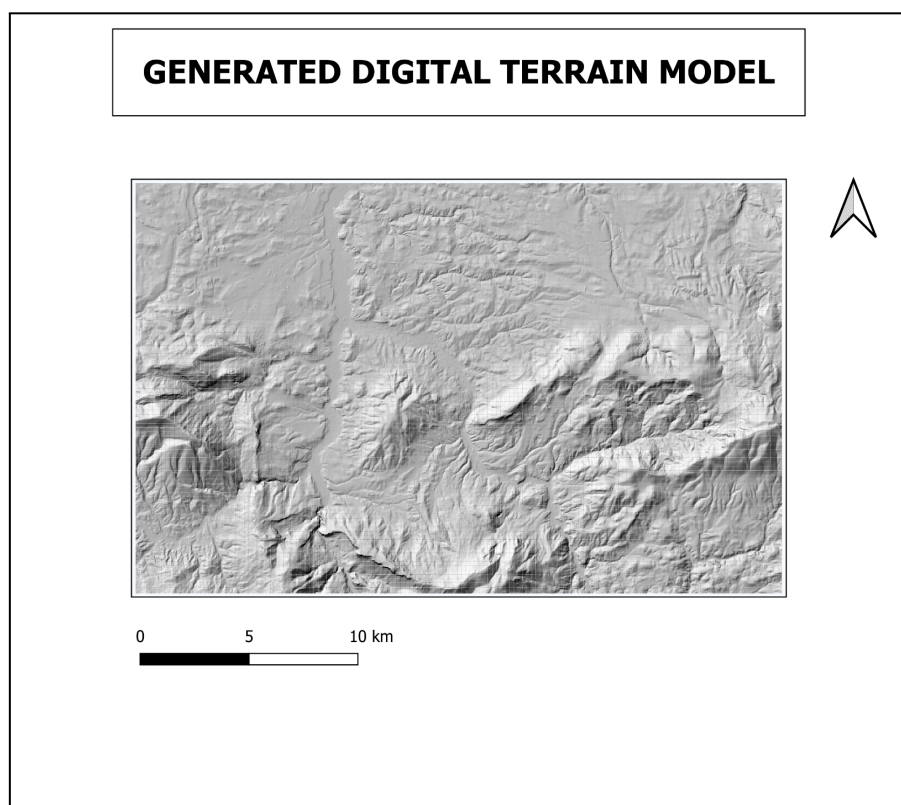


Figure 70. Generated DTM

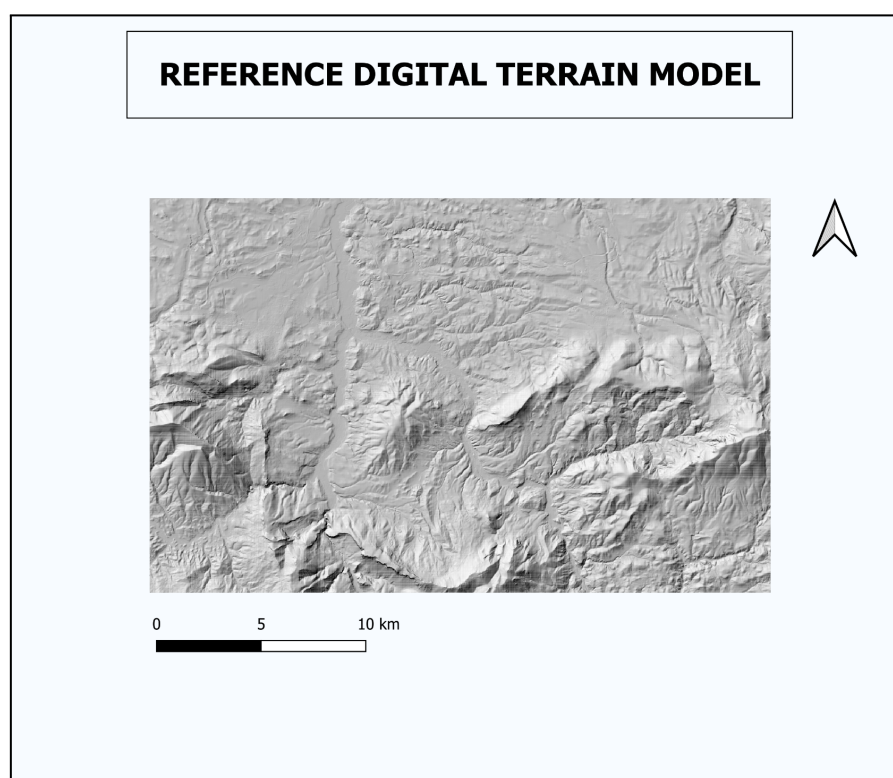


Figure 71. Reference DTM

This is the result of the Raster Calculator tool in QGIS, (Figure 72):

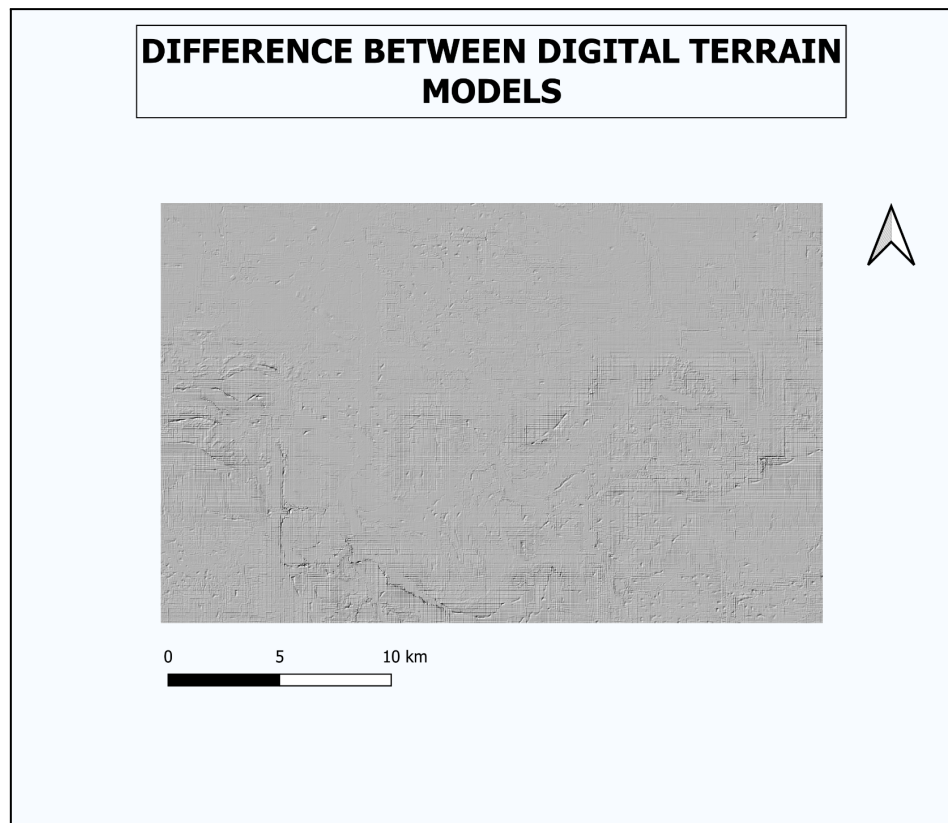


Figure 72. Difference between the Digital Terrain Models

By utilizing check points sourced from Iberpix, see (Figure 73), we successfully conducted an accuracy evaluation of our generated Digital Terrain Model (DTM). This assessment involved a meticulous comparison of our DTM with a trusted reference DTM obtained from a prior mission. These check points, with known and precise geographic coordinates, served as key reference markers.

In the terrain profiles provided below (Figure 74), we can assess the altimetric accuracy of the two models and analyze the discrepancies between them.

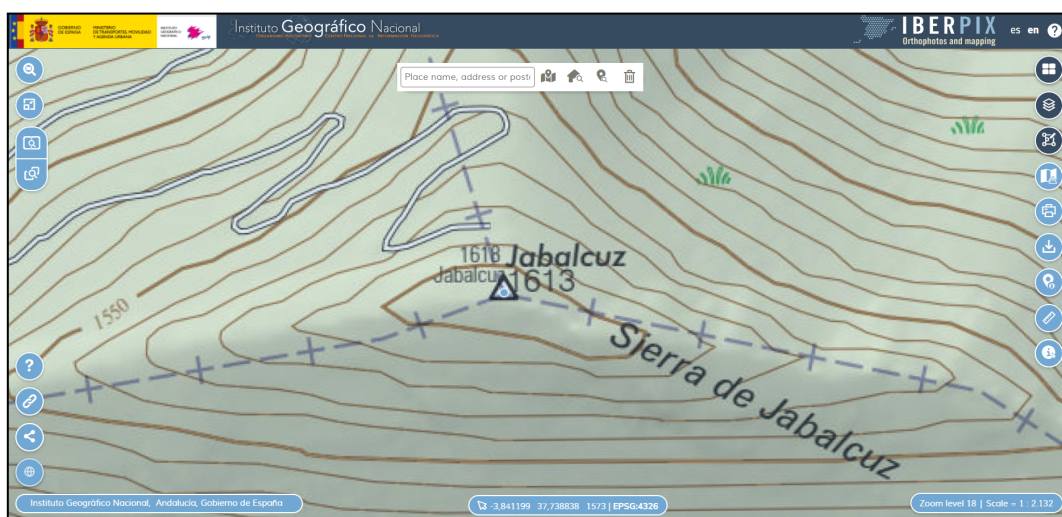


Figure 73. Difference between the Digital Terrain Models

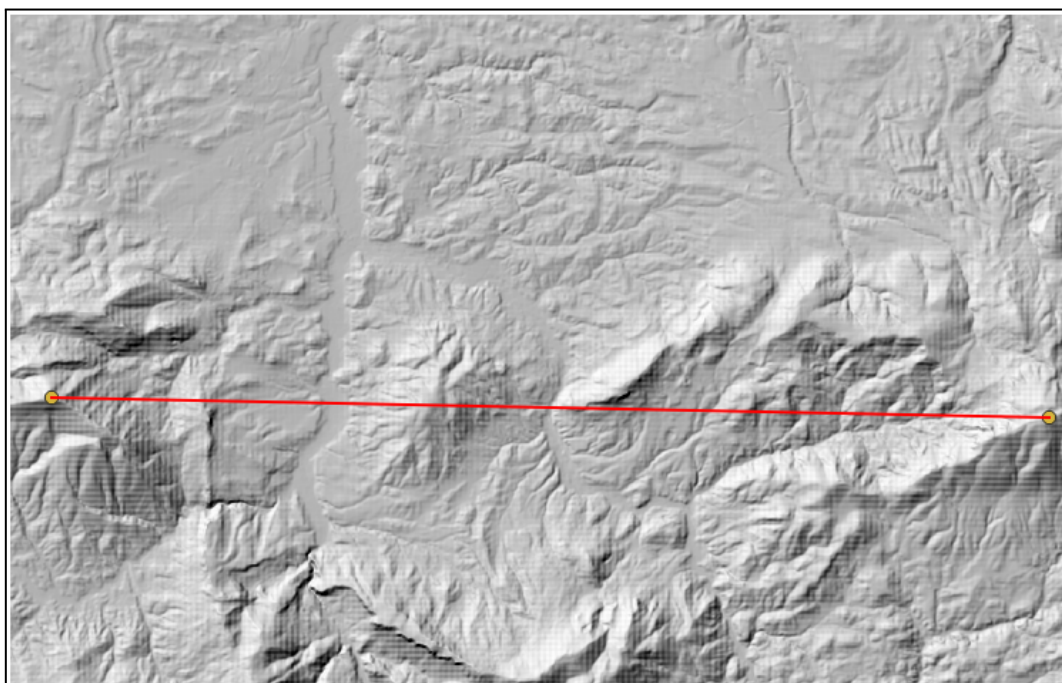


Figure 74. Difference between the Digital Terrain Models

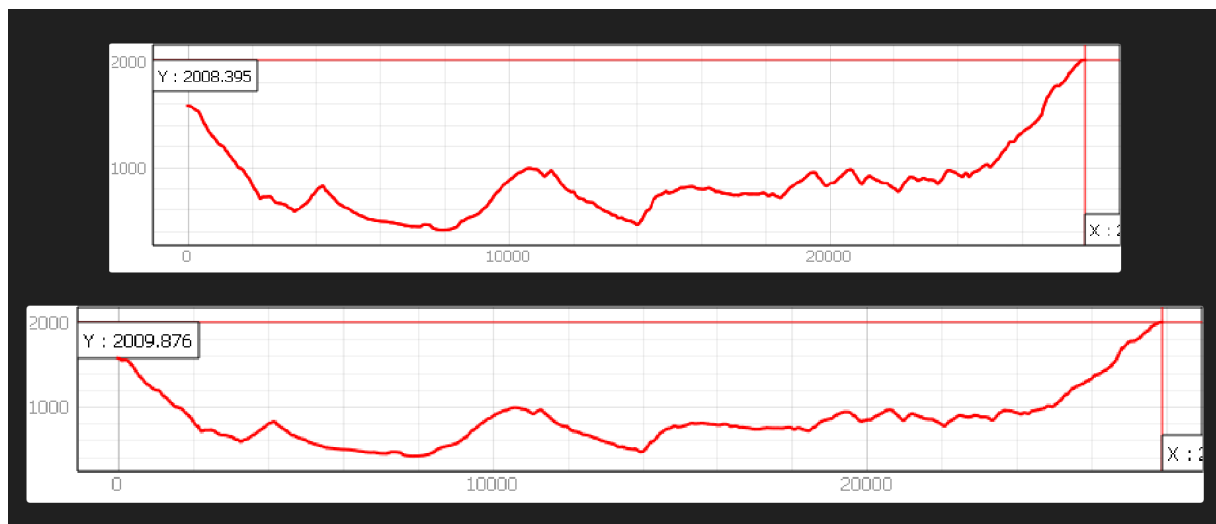


Figure 75. Difference between the Digital Terrain Models

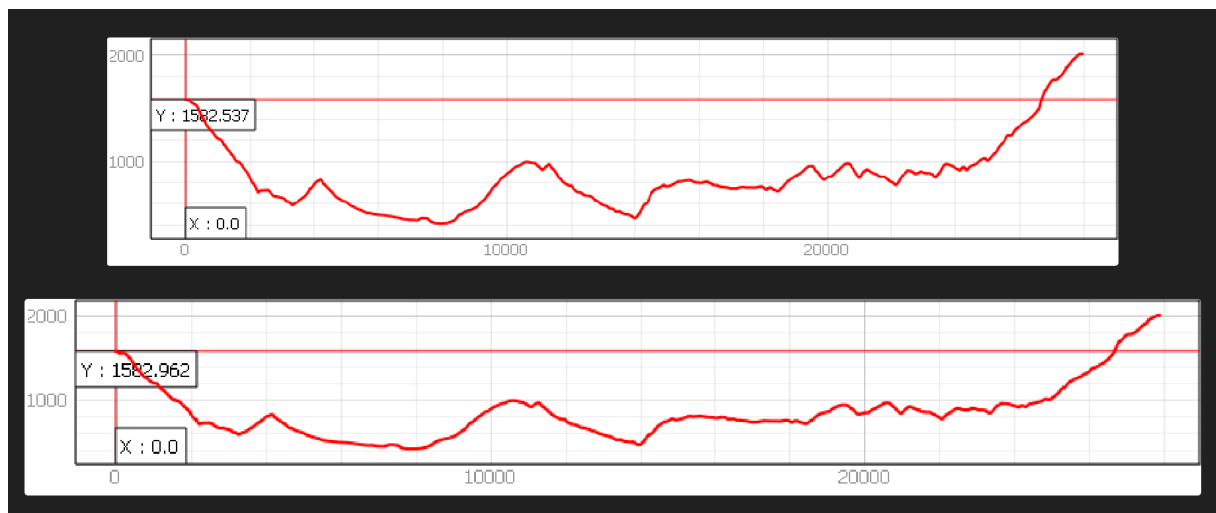


Figure 76. Difference between the Digital Terrain Models

- Inspecting the Orthomosaic: The orthomosaic is another product that can be used to check the quality of the DTM and DSM by inspecting it for any geometric distortions, blurring, or misalignments.

3.3.6. Orthomosaic Generation

Building an orthomosaic is a crucial step in photogrammetry, as it allows for the creation of a high-resolution, georeferenced representation of the surveyed area, see (Figure 73).

With the aligned images and Digital Terrain Model, the next step is to generate the orthomosaic. The orthomosaic is a stitched together image that accurately represents the surveyed area. It combines the color and texture information from the input images and projects them onto the DTM.

The settings for this project are as follows, as indicated in (Figure 77):

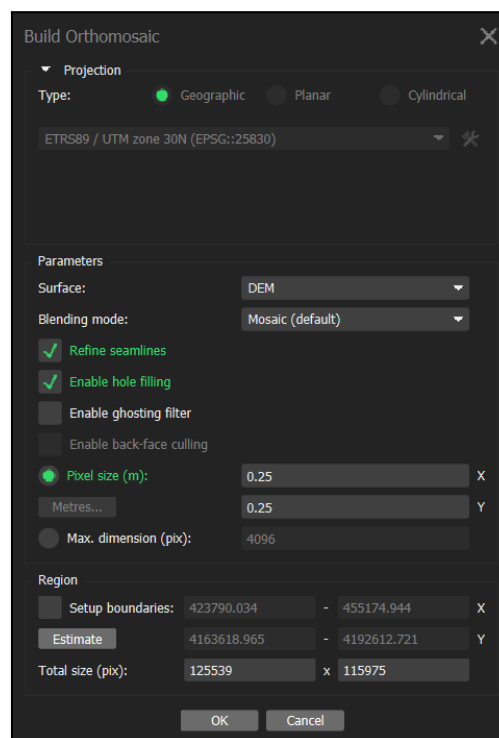


Figure 77. The settings for building the Orthomosaic

Blending mode:

Mosaic (default): implements an approach with data division into several frequency domains that are blended independently. The highest frequency component is blended along the seamline only, with each further step away from the seamline resulting in a smaller number of domains being subject to blending [17].

Pixel size:

The default value for pixel size in the Export Orthomosaic dialog refers to ground sampling resolution, which is 25 cm in this case.

Enable hole filling:

This option is enabled by default since it helps to avoid the salt-and-pepper effect in cases of complicated surfaces with numerous tiny parts shading other parts of the source surface model. Only in the case of very specific tasks might it be recommended to switch the function off [17].

Seamline refinement is the process of adjusting the boundaries between images in an orthomosaic to make the transitions as seamless as possible. In Agisoft Metashape, this is performed automatically during the orthomosaic generation process.

Refine seamlines:

The option is recommended to be used for DTM-based orthomosaics in order to automatically create seamlines to bypass buildings and other complex objects in order to avoid visual artifacts on the final image and time-consuming manual orthomosaic patching.



Figure 78. Generated Orthomosaic

3.3.7. Quality Assessment and Validation

Performing quality control for the generated orthomosaic involves several steps and considerations, which can include:

- **Visual Inspection:** Inspecting the orthomosaic visually for any noticeable artifacts such as blurring, ghosting, color mismatches, or seams, see (Figure 79).



Figure 79. Visual Inspection for the generated orthomosaic

by inspecting the Orthomosaic, no visible artifacts were detected, as shown in the figure above.

- **Geometric Accuracy:** We can see from (Figures 80 and 81) below that there were no distortions after generating the orthomosaic by comparing it to ground control points (GCPs).

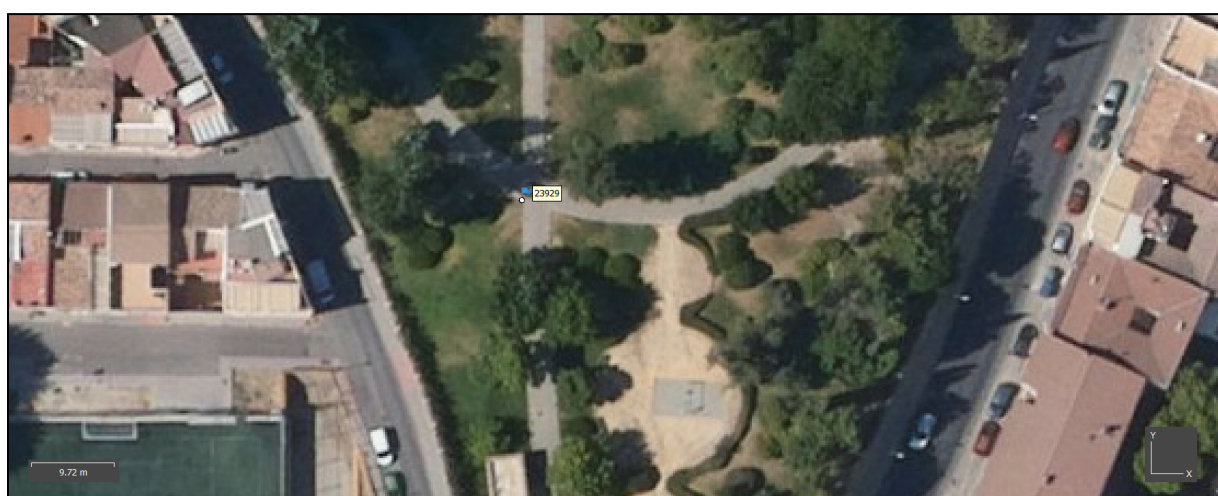


Figure 80. Geometric Accuracy for the generated orthomosaic 1



Figure 81. Geometric Accuracy for the generated orthomosaic 2

- Radiometric Consistency: Checking the radiometric consistency of the orthomosaic by comparing the color and brightness of the same features in the original images and the orthomosaic.
- The first figure below is one of the initial images used for this project (h50_0947_fot_022-0051_cog).
- The second figure is from the orthomosaic, representing the same area as the image.

By comparing both (Figures 82 and 83), no changes in color or brightness of the same features were detected.

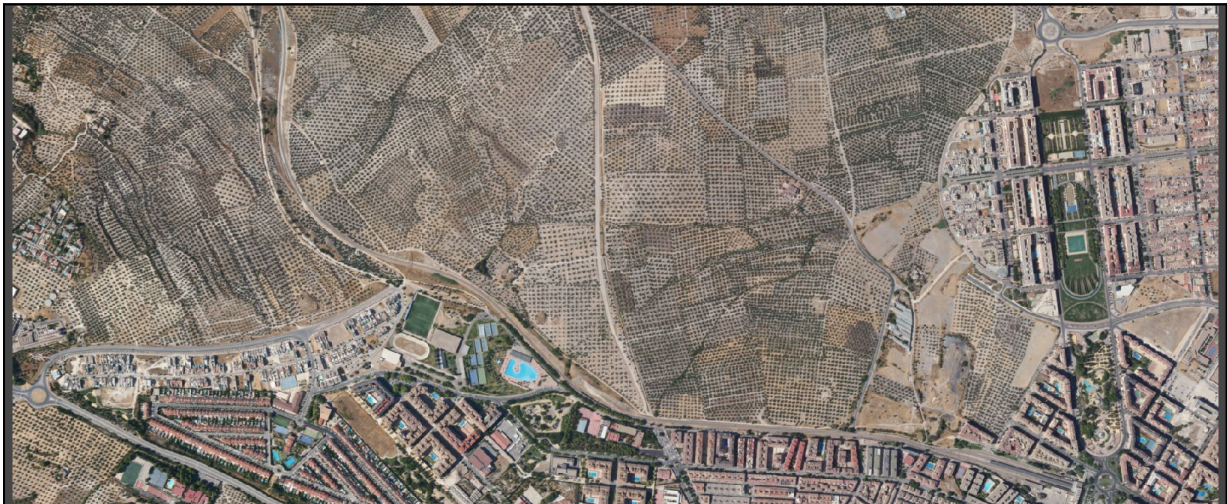


Figure 82. One of the initial images used for this project



Figure 83. The orthomosaic representing the same area as the image

- **Seamline Quality:** It is possible to visualize the seamlines in Metashape and assess their quality by checking for any noticeable seams or discontinuities in the orthomosaic. The transitions between images should be smooth and seamless, as shown in (Figures 84 and 85).



Figure 84. The initial images used for this project

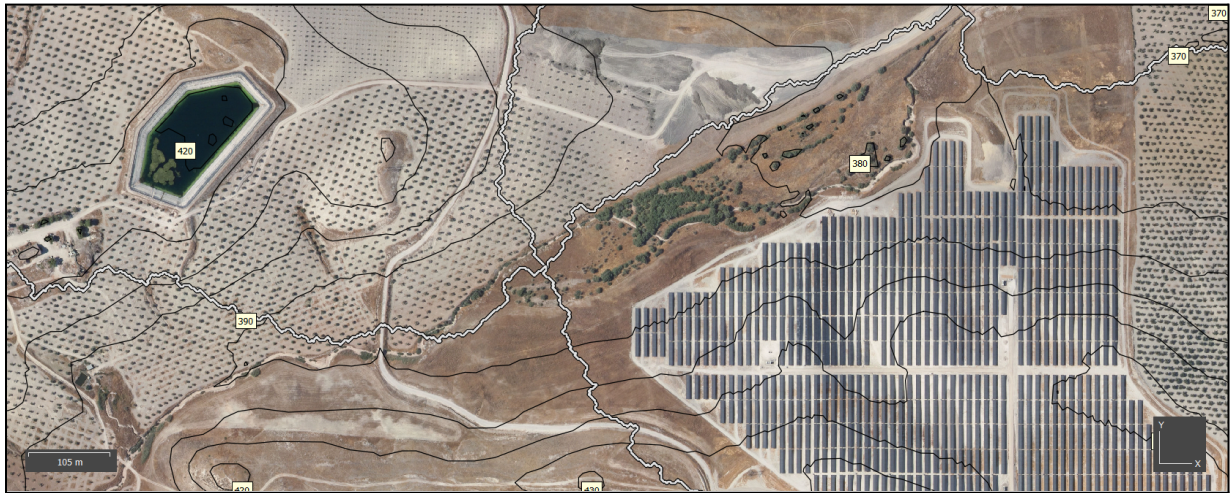


Figure 85. The orthomosaic representing the same area as the images

- **Overlap and Coverage:** by checking that the orthomosaic covers the entire area of interest and that there are no gaps or missing areas.
→ no such things as gaps or missing areas were found after inspecting the orthomosaic.
- **Resolution:** The spatial resolution of the orthomosaic is 25 cm/pixel, which is consistent across the entire image and meets the requirements of your project.

3.3.8. Final Output and Secondary Outputs

3.3.8.1. Final Output

Orthophotomaps are valuable resources for a wide range of applications including urban planning, land management, environmental monitoring, and geographic information systems (GIS). They are often overlaid with additional data layers such as road networks, place names, and boundaries to create comprehensive geographic information systems.

the orthophotomaps produced by the CNIG adhere to high standards of accuracy and quality, given their role as a national institution. They utilize advanced technologies, including high-resolution sensors and sophisticated image processing algorithms, to create orthophotos that are both highly accurate and detailed. These orthophotomaps would then be used by various governmental bodies, academic institutions, and private entities for a range of applications including, but not limited to, land use planning, infrastructure development, and environmental monitoring.

The final output of this project is an Orthophotomap, following the guidelines and rules put forth by the CNIG.

3.3.8.2. Secondary Outputs

There are mainly two secondary Outputs generated by this project:

Contour lines:

Contour lines are generated from the digital terrain model (DTM). Contour lines are a representation of elevation values on a map, connecting points of equal elevation (Figure 86).

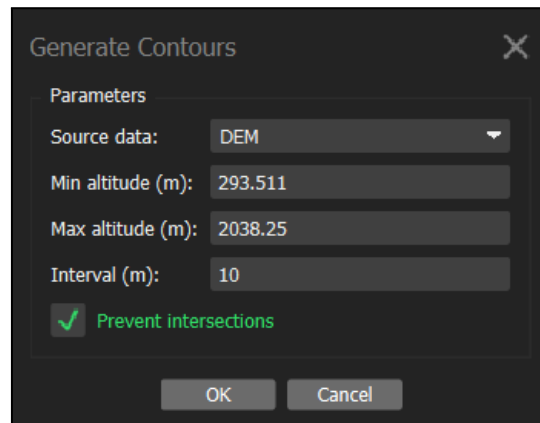


Figure 86. Generate Contour lines Tool

(Figure 87) shows the generated contour lines with Agisoft:

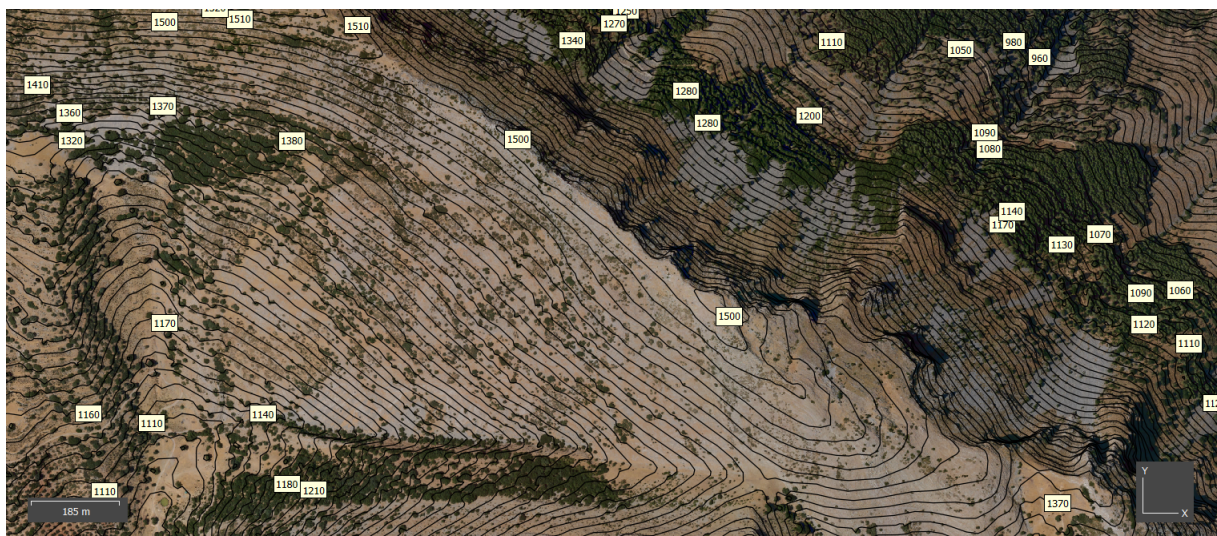


Figure 87. Generated contour lines with 10 m interval

After exporting the contours to a shape file, it is possible to visualize them and inspect them to ensure accuracy and consistency with the terrain.

→ This Map was produced with QGIS and shows the final result after introducing the shape file and checking for any consistencies, see (Figure 88):

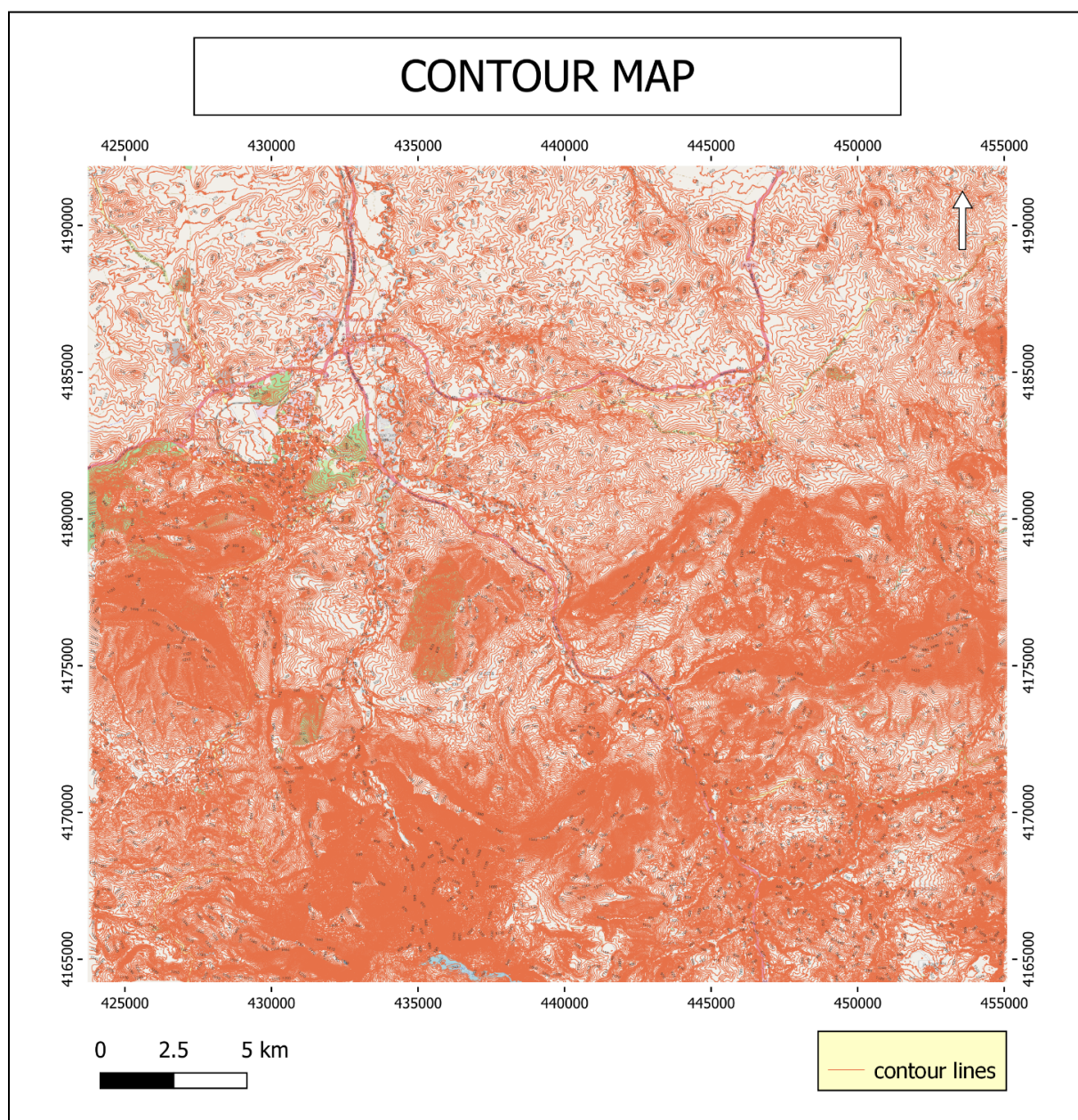


Figure 88. Contour Map

Prescription map:

Prescription maps are a type of digital map used in precision agriculture to optimize field-level management with regard to crop farming.

After generating the orthomosaic in Agisoft Metashape, it is possible to use the software's built-in tools to classify the vegetation in the images,

Based on this classification, a prescription map can be created directly in Metashape that will guide the application of water, fertilizer, pesticides, etc.

- using the built-in raster calculator in the software to transform RGB bands into indices to determine the distribution of vegetation in the orthomosaic already generated, as indicated in (Figures 89 and 90).

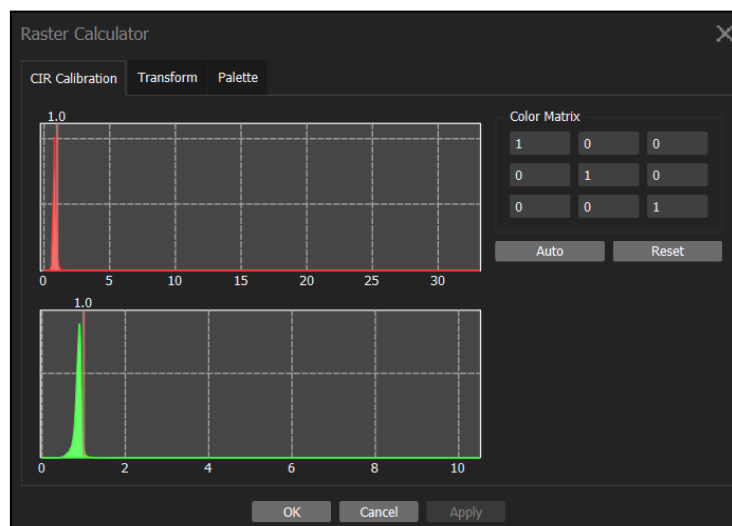


Figure 89. Rastor calculator

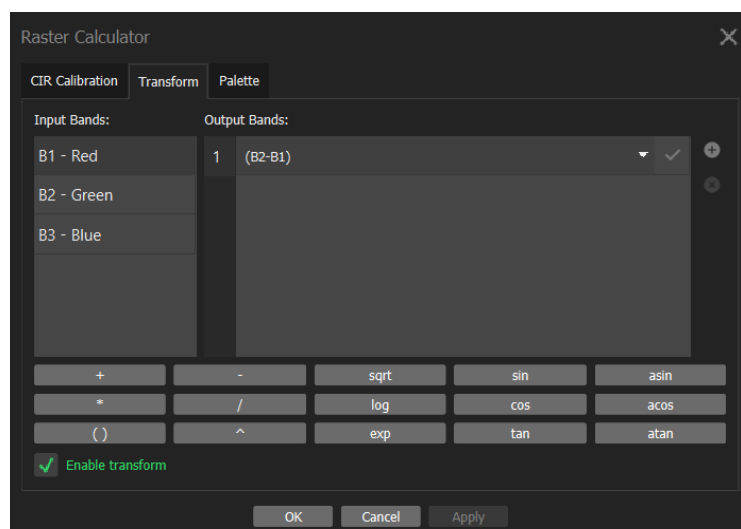


Figure 90. Transform RGB bands to vegetation indices

Vegetation indices are used to assess the density and health of vegetation using remote sensing data. The most common vegetation index is the Normalized Difference Vegetation Index (NDVI), which uses the red and near-infrared bands of the electromagnetic spectrum.

The formula to calculate NDVI using the red and near-infrared (NIR) bands is:

- $NDVI = (NIR - Red) / (NIR + Red)$

where:

- NIR is the reflectance value of the Near-Infrared band.
- Red is the reflectance value of the Red band.

Although in this project we only have a standard RGB camera and the images has been processed and the radiometric information was modified in order to obtain an "radiometrically continuous" mosaic, it is possible to attempt to estimate vegetation density using variations of the Greenness Index or Excess Green Index, even though these are not as accurate as NDVI, see (Figure 91).

In this case, the variation used is $ExG = Green - Red$, as indicated in the figure above.

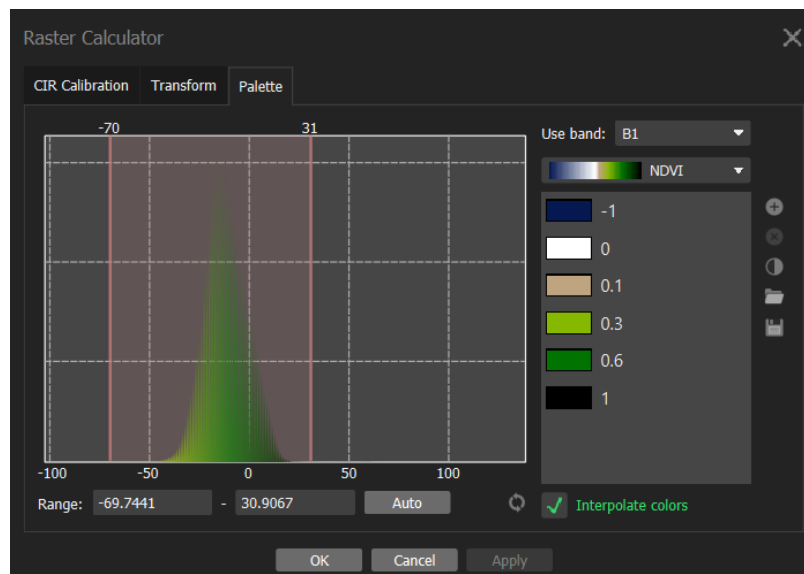


Figure 91. Color Interpolations

- It is possible to inspect the result of this interpolation in (Figure 92) below, where the RGB values were transformed by the software to represent the distribution of the vegetation throughout the Orthomosaic.

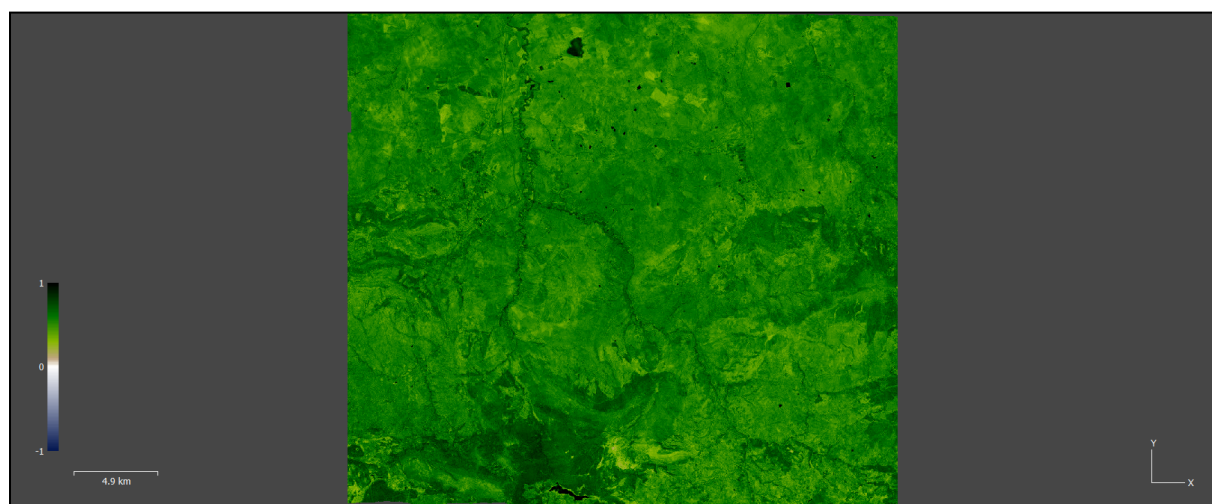


Figure 92. Distribution of the vegetation throughout the Orthomosaic

The next step was to simply generate the prescription map using the specified tool, see (Figure 93), and the parameters chosen here are:

- The cell size : 10 meters.
- The classes : 5 classes.

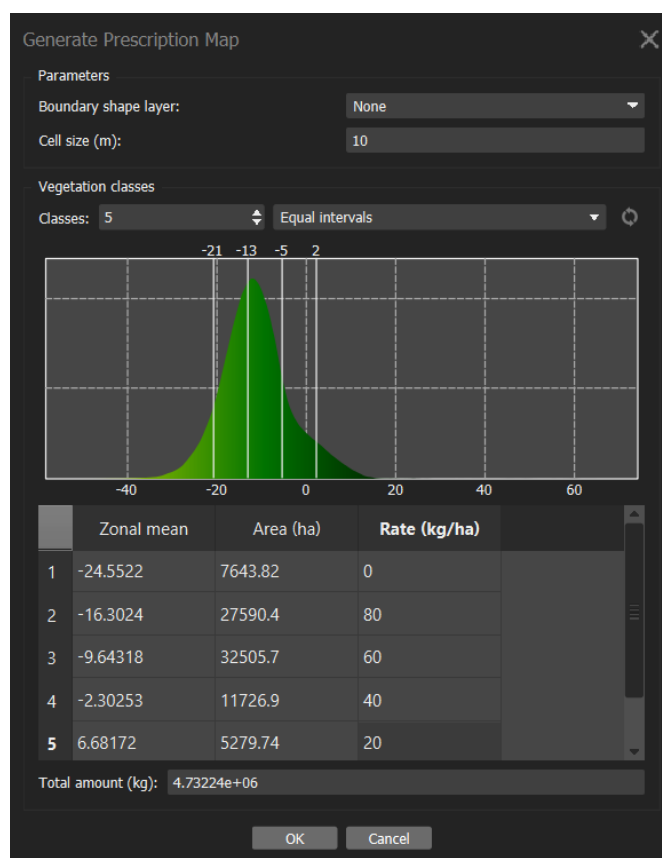


Figure 93. Generate the prescription map

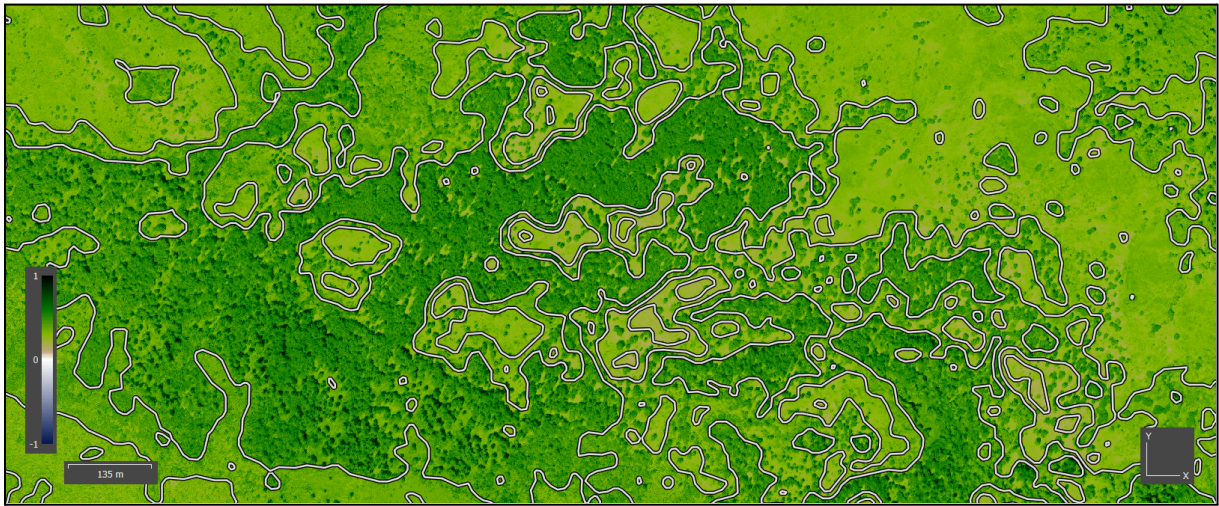


Figure 94. Result in Metashape

→ It is possible to visualize the result in Metashape as shown in (Figure 94), but the prescription map was exported as a shape file to analyze later with QGIS and finally produce an appropriate map with a legend describing the distribution of the vegetation throughout the study area as represented in the map below, (Figure 95).

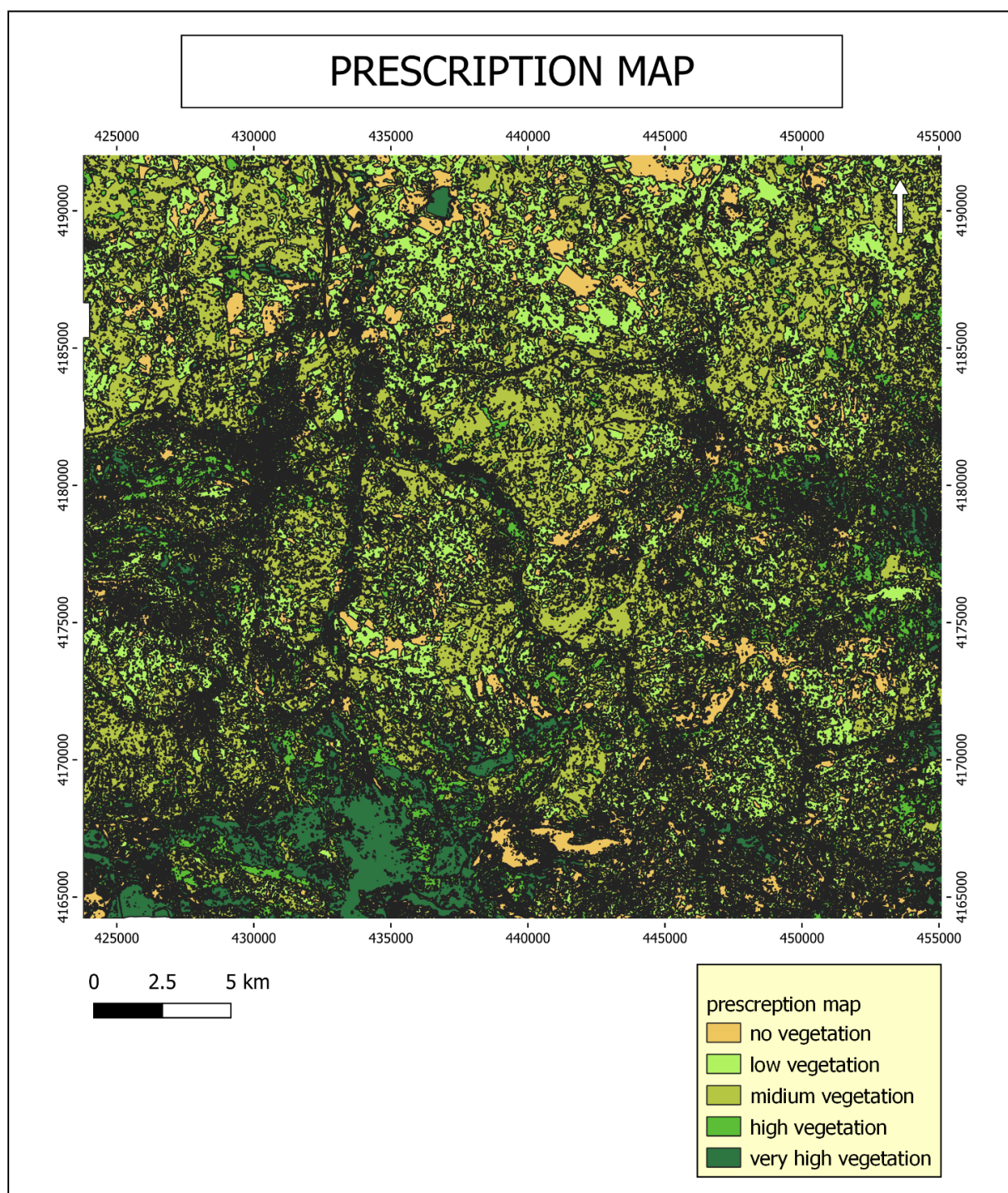


Figure 95. Prescription Map

3.4. Conclusion

In this Chapter, the emphasis was on the practical application and results of the methodologies outlined in the previous chapter. The chapter began with an introduction, followed by a discussion on data sources, pre-processing, GCP acquisition, and flight trajectory estimation. The workflow was then described in detail, covering every step from data preparation to the generation of the final and secondary outputs. All steps involved, including image alignment, point cloud generation, digital terrain model and digital surface model generation, orthomosaic generation, orthophotomap production, and quality assessment and validation, were comprehensively elucidated. Quality control measures at each stage were underscored to ensure the accuracy and reliability of the results.

In conclusion, Chapter 3 provided a meticulous account of the entire workflow, from data acquisition to the generation of final outputs. The emphasis on quality control throughout the workflow ensured that the final outputs were reliable and accurate. The chapter concluded with a discussion on the final and secondary outputs, which are pivotal in various applications, thereby showcasing the practicality and utility of the entire process.

General Conclusion

In conclusion, this project focused on the generation of digital elevation models (DEMs) and orthomosaic images, followed by the creation of an orthophotomap using photogrammetric techniques for the MTN 947 sheet in Andalusia, Spain. The objective was to create accurate and detailed representations of the terrain and land features in the specified area.

Photogrammetry has demonstrated its prowess as a potent instrument for attaining meticulous measurements and three-dimensional information from images, facilitating the generation of finely detailed Digital Elevation Models (DEMs) and orthomosaic images. The integration of contemporary technologies like drones and other aerial platforms has elevated the usability and economic efficiency of photogrammetry, thus endowing it with substantial worth across a spectrum of applications.

Throughout the project, various steps were undertaken, including image acquisition, GCP acquisition, flight trajectory determination, image alignment, dense cloud, DEM, orthomosaic generation, and finally orthophotomap creation. These steps required careful planning, accurate data processing, and quality control measures to ensure reliable and accurate results.

The generated DEMs, orthomosaic images, and finally the orthophotomap have significant applications in fields such as mapping, land use planning, environmental management, and more. They provide valuable insights into the topography and features of the MTN 947 sheet, enabling informed decision-making and efficient analysis.

Overall, this project has showcased the advancement of geomatics and surveying techniques, demonstrating the potential of photogrammetry for capturing detailed and accurate information about the Earth's surface.

It is crucial to recognize that continuous research and development in photogrammetry and related technologies will play a pivotal role in enhancing the accuracy, efficiency, and accessibility of geomatics and surveying applications. These advancements will undoubtedly unlock new possibilities for future projects and drive significant progress in the field. Furthermore, it's imperative to emphasize the importance of open data in this context.

Open data not only fosters transparency but also facilitates collaboration and innovation. By sharing data and metadata openly, we create an environment where researchers, professionals, and organizations can collectively work towards improving the outcomes of projects like this one. The absence of essential data and metadata can be a significant roadblock, but through open data practices, we can mitigate this challenge and ensure that the results of this project are continually refined and enhanced.

In conclusion, ongoing research, open data, and a commitment to improving the quality of data and metadata are fundamental aspects of advancing geomatics and surveying applications. They are the driving forces behind the evolution of this field, leading to more accurate, efficient, and accessible solutions for a wide range of projects and applications

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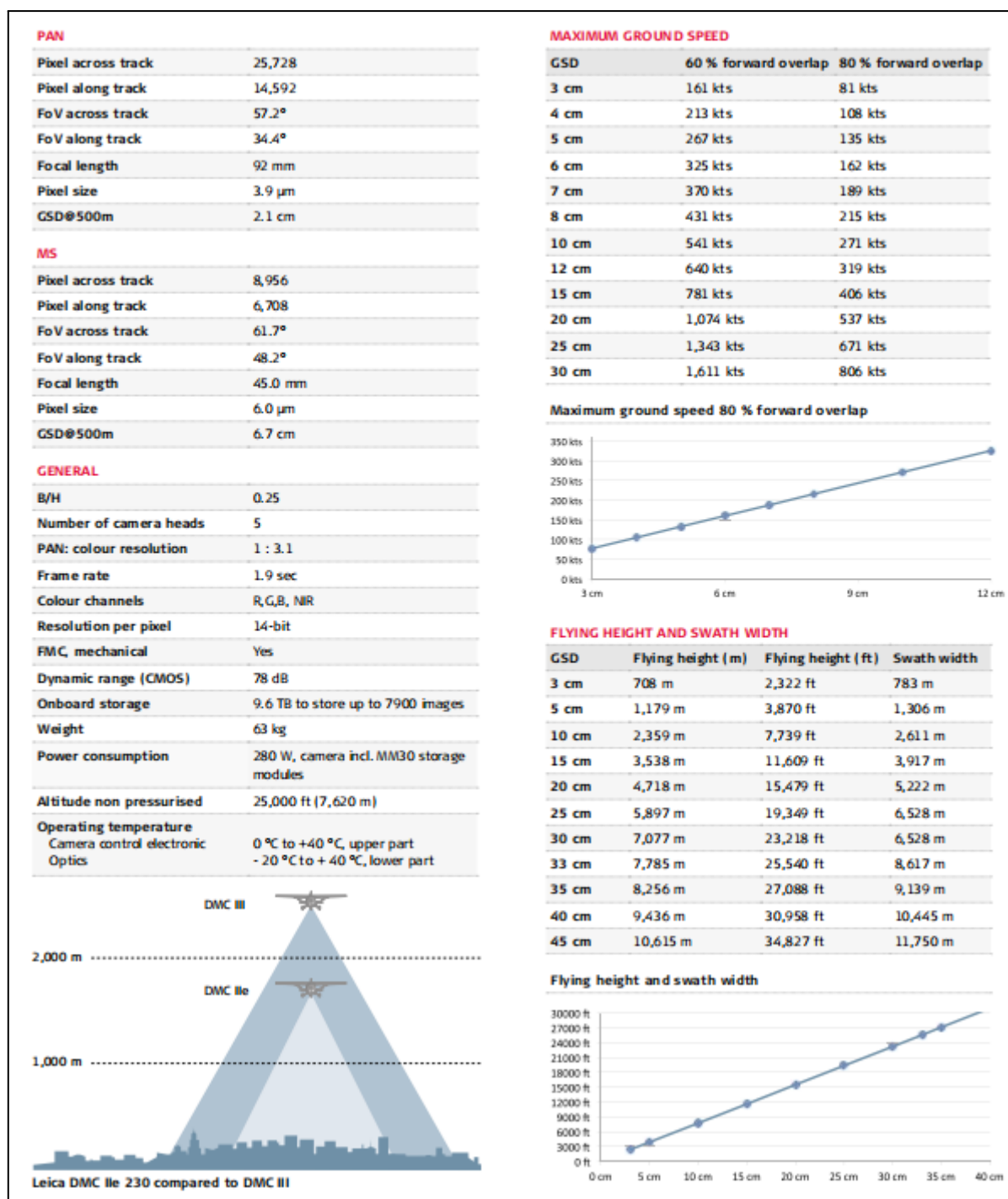
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Annex

1. Leica DMC III product specifications



2. Technical Specifications for Digital Photogrammetric Flight:

Plan Nacional de Ortofotografía Aérea

NegritaEspecificaciones Técnicas
Postproceso VUELO COMBINADO

Instituto Geográfico Nacional
Observación del Territorio



GOBIERNO DE ESPAÑA



MINISTERIO DE TRANSPORTES, MOVILIDAD Y AGENDA URBANA

Especificaciones Técnicas para
POSTPROCESO DE VUELO FOTOGRAMÉTRICO DIGITAL



Plan Nacional de Ortofotografía Aérea

Versión: 211103

Organismos participantes:

Instituto Geográfico Nacional (IGN) / Centro Nacional de Información Geográfica (CNIIG) (M^o Ties, Movilidad y Ag. Urbana)
Dirección General del Catastro (M^o Hacienda)
Fondo Español de Garantía Agraria (FEGA) (M^o Agricultura, Pesca y Alimentación)
Equipos Técnicos de las Comunidades Autónomas

Tamaño de píxel del vuelo
(GSD_{vf}): **0,18 m - 0,22 m - 0,35 m**

Tamaño de píxel de la imagen ortorectificada
(GSD_{of}): **0,15 m - 0,25 m**

GSD_{vf}: Ground Sample Distance (tamaño píxel en el terreno -metros-) del vuelo
GSD_{of}: Ground Sample Distance (tamaño píxel en el terreno -metros-) de la ortofoto

Descripción de este documento:

Título	Especificaciones Técnicas para el postproceso de vuelo fotogramétrico digital a 25 cm y 15 cm (PNOA) 2021
Identificador	211103 Especificaciones PNOA Postproceso 25cm.xlsx
Autor	Equipo Técnico Nacional Equipos Técnicos Autonómicos
Fecha	03/11/2021
Tema	Especificaciones Técnicas para el Plan Nacional de Ortofotografía Aérea
Estado	Definitivo
Objetivo	Armonización de los procesos, datos y documentos realizados en el marco del PNOA, entre distintos organismos y empresas
Descripción	Listado resumido de especificaciones de obligado cumplimiento por los organismos participantes y las empresa contratistas en la realización de los trabajos del Plan Nacional de Ortofotografía Aérea
Instituciones colaboradoras	Instituto Geográfico Nacional (IGN) / Centro Nacional de Información Geográfica (CNIIG) (M ^o Fomento) Dirección General de Catastro (M ^o Hacienda) Tragsa Fondo Español de Garantía Agraria (FEGA) Equipos Técnicos de las Comunidades Autónomas
Difusión	Equipos Técnicos de las Comunidades Autónomas Equipos Técnicos de los organismos de la AGE participantes Empresas contratistas
Documentos relacionados	Nomenclatura de carpetas y ficheros. Informes descriptivos de las distintas fases de producción.
Periodo de validez	2021 y posterior, hasta su sustitución por una nueva versión



Apartado	Ítem	Fase / Parámetro	Especificaciones	Detalles
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30/08/2023

211103 Espec PNOA POSTPROC 18-22-35 cm.xlsx

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Plan Nacional de Ortofotografía Aérea

NegritaEspecificaciones Técnicas
Postproceso VUELO COMBINADO

Instituto Geográfico Nacional
Observación del Territorio

Apartado	Ítem	Fase / Parámetro	Especificaciones	Detalles
1.	SISTEMA GEODÉSICO DE REFERENCIA			
	a	Sistema Geodésico de Referencia en la Península, Baleares, Ceuta y Melilla	ETRS89	Todo el trabajo se realizará en ETRS89 , basándose exclusivamente en vértices REGENTE de la Red Geodésica Nacional
	b	Sistema Geodésico de Referencia en Canarias	REGCAN95	Todo el trabajo se realizará en el sistema REGCAN95 , basándose en vértices REGCAN95
	c	Cotas ortométricas	Se utilizarán únicamente cotas ortométricas en todos los procesos de cálculo y en los productos finales con datos altimétricos	
	d	Modelo de geoides: Transformación de alturas elipsoidales a cotas ortométricas	Para realizar la transformación de alturas elipsoidales a cotas ortométricas, se utilizará el modelo de geoides EGM2008-REDNAP (Adaptación del geoides mundial EGM08 a España)	La Dirección Técnica entregará las herramientas de transformación y los ficheros del modelo de geoides
	e	Proyección cartográfica	UTM	Referido al Huso correspondiente a cada zona
	f	Huso UTM a emplear	Cada hoja se realizará en su Huso Las hojas que calgen entre dos Husos, se entregarán en ambos	
	g	Distribución de hojas	Distribución 1:5.000 con división en 8 x 8 de las hojas MTN50 oficiales	El corte de hojas se obtendrá aplicando con un rebase de 50 metros con respecto a las cuatro esquinas técnicas, redondeado a múltiplos de 10 m. La Dirección Técnica facilitará las coordenadas de las esquinas de las hojas, y de los cortes de las hojas, basadas en el Real Decreto 1071/2007, de 27 de julio.
2.	APOYO DE CAMPO			
2.1.	Configuración de los bloques de aerotriangulación			
	a	Tamaño mínimo de un bloque	2 hojas MTN50 en longitudinal x 2 hojas MTN50 en transversal	Otras configuraciones diferentes deberán ser consultadas previamente con la dirección técnica
	b	Tamaño máximo de un bloque	3 hojas MTN50 en longitudinal x 3 hojas MTN50 en transversal	Otras configuraciones diferentes deberán ser consultadas previamente con la dirección técnica
2.2.	Instrumentos a emplear			
	a	Receptores GNSS	Equipos de doble frecuencia	

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Plan Nacional de Ortofotografía Aérea		NegritaEspecificaciones Técnicas Postproceso VUELO COMBINADO		Instituto Geográfico Nacional Observación del Teritorio
Apartado	Ítem	Fase / Parámetro	Especificaciones	Detalles
2.3. Ejecución de los trabajos				
	a	Distribución de puntos con apoyo de campo para aerotriangulación con datos GNSS / INS de vuelo	Sensor matricial: - Puntos dobles en las esquinas del bloque - Un punto de chequeo en cada esquina de hoja MTN50 Sensor lineal: - Puntos dobles en las esquinas del bloque - Un punto de chequeo en el centro de la pasada	En caso de que ocurran incidencias en el registro de datos GNSS / INS, se aplicarán otras alternativas: Si los centros proyectivos se han procesado de manera relativa Apoyo de campo para aerotriangulación con datos GNSS de vuelo con pasadas transversales: - Puntos dobles en las esquinas del bloque - Un punto de chequeo en cada esquina de hoja MTN50 Las pasadas transversales se podrán reemplazar por cadenas de puntos de apoyo situados en las zonas de solape entre pasadas: Si los centros proyectivos no se han medido/procesado correctamente durante el vuelo: Apoyo convencional: - Puntos dobles en las esquinas del bloque - Un punto por cada 3 modelos en la primera y última pasada - Un punto por cada 5 modelos en el resto de las pasadas Los puntos de apoyo estarán situados fuera de la zona a ortoproyectar para evitar interferencias con la zona de vuelo. Al reducir las altitudes, tener en cuenta que las altitudes de los vértices REGENTE se refieren a la Cabeza del pilar, no a la plataforma En Canarias, se pueden utilizar también vértices ROI Las observaciones que se realicen para establecer enlaces con las redes oficiales, tendrán una duración mínima de 1 hora.
	b	Estaciones de referencia	Exclusivamente vértices de la Red REGENTE del IGN u otras estaciones que hayan sido observadas por método estático, a partir de REGENTE o de redes autonómicas oficiales enlazadas con REGENTE.	
	c	Método de observación de los puntos de apoyo	Método de posicionamiento estático rápido	
	d	Condiciones de observación de los puntos de apoyo	- Líneas base < 20 km en 90% de los casos - Número de satélites: 2-5 - Precisión en posición PDOP < 6 - Máscara de elevación > 15° sexagesimales - Tiempo de observación > 10 minutos - Mínimo de 120 épocas registradas	Tres coordenadas en posición Condicionado por el método y equipo utilizado, n° y geometría de los satélites
	e	Bases de datos de puntos de apoyo preexistentes	Podrán ser utilizados puntos de apoyo que pertenezcan a bases de datos de organismos cartográficos oficiales, siempre que cumplan las siguientes condiciones: - Que la ubicación de puntos esté de acuerdo con la distribución establecida en este pliego de especificaciones técnicas - Que hayan sido observados mediante técnicas GNSS en ETRS89 ó REGCAN95, cumpliendo con las especificaciones PNOA	
2.4. Precisiones				
	a	Precisión de las líneas-base	5 mm ± 1 parte por millón (mm/Km)	
	b	Precisión de los puntos de apoyo	- Planimetría: RMSE ≤ 0,10 m - Altimetría: RMSE ≤ 0,15 m	RMSE: Root Mean Square Error (Error Medio Cuadrático)

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2.5. Resultados finales				
	a	Planimetría	Coordenadas UTM (ETRS89 ó REGCAN95)	
	b	Altimetría	Cotas ortométricas	Ver apartados 1.c y 1.d
				Para los puntos de apoyo de archivo, se recalcularán las cotas ortométricas con el nuevo modelo de geoides EGM2008-REDNAP. Si no se dispone de las alturas elipsoidales, se calcularán éstas previamente a partir de las cotas ortométricas considerando el modelo de geoides empleado en los cálculos iniciales.
2.6. Productos a entregar (del apoyo realizado o del preexistente)				
	a	Fotogramas pinchados	Fotogramas digitales con: - los puntos de apoyo y chequeo señalados y rotulados - los vértices REGENTE empleados rotulados	Formato JPEG
	b	Ficheros GNSS del apoyo	- Fichero de las observaciones brutas GNSS registradas - Ficheros ASCII en formato RINEX - Un fichero para cada vértice REGENTE y cada punto de apoyo	No será necesario si se utilizan las bases de datos a que hace referencia el apartado 2.3.e
	c	Cálculo líneas base	Fichero ASCII con el resultado del cálculo de las líneas base	No será necesario si se utilizan las bases de datos a que hace referencia el apartado 2.3.e
	d	Cálculo y compensación de las coordenadas de los puntos de apoyo	Fichero ASCII	No será necesario si se utilizan las bases de datos a que hace referencia el apartado 2.3.e
	e	Gráficos del apoyo	Gráficos en formato shp de los puntos de apoyo y chequeo generado a partir de la bdd y vértices empleados.	Elementos que deben figurar en los gráficos:
				- Posición exacta de los Puntos de Apoyo fotogramétrico y su número de orden - Posición de los vértices geodésicos empleados con su identificador
	f	Reseñas de puntos de apoyo y vértices o estaciones de referencia desde las que se han realizado observaciones	Con los siguientes elementos:	
			- Coordenadas UTM X, Y, Huso cartográfico. - Cota ortométrica y altura elipsoidal. - Sistema de referencia (ETRS89 ó REGCAN95). - Datos y fotografías del Vértice Geodésico o estación de referencia desde el que se ha realizado la medición (una general y otra de detalle donde se pueda observar la colocación de la antena sobre el pilar). - Fotografías del punto de control levantado. - Altura de antena y del elemento observado. - Croquis y reseña original de campo del elemento con indicación del Norte	
	g	Base de datos de puntos de apoyo	Según modelo proporcionado por la dirección técnica	Está integrada en una tabla incluida en la base de datos de aerotriangulación
	h	Informe descriptivo del proceso de apoyo de campo	Según documento "... Informe POSTPROCESO PNOA.xls"	

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Apartado	Ítem	Fase / Parámetro	Especificaciones	Detalles
3. AEROTRIANGULACIÓN				
3.1. Ejecución de los trabajos				
	a	Método	Obligatoria digital, utilizando parámetros GNSS / IMU de vuelo Sistema de referencia altimétrico: se utilizarán exclusivamente cotas ortométricas , tanto en el proceso de cálculo como en los resultados finales	
	b	Medición de puntos de enlace	Mínimo 12 puntos de enlace en cada modelo (2 en cada zona de Von Grüber)	Garantizando que al menos 1 punto de cada zona de solape transversal que enlace modelos, enlace también pasadas. Para sensores de barrido, se establecerán al menos 3 cadenas de puntos a lo largo de cada pasada distribuidos uniformemente, una central y dos en los extremos, garantizando que todos los puntos se midan en las imágenes nadir, anterior y posterior, y que los puntos extremos situados en las zonas de solape, sirvan además de enlace entre pasadas.
	c	Ajuste del bloque	Ajuste simultáneo por haces de rayos, con parámetros GNSS / IMU	
	d	Zona a recubrir	Para cada Comunidad Autónoma , se aerotriangularán completas todas las hojas 1:5.000 incluidas total o parcialmente en el territorio de esa comunidad	Los expedientes de contratación no detallarán exactamente las hojas a aerotriangular
	e	Puntos de chequeo	Como comprobación del cálculo de la aerotriangulación, se incluirán puntos de chequeo de precisión al menos 1/3 del RMS final del producto, pudiendo incluirse los vértices geodésicos de la red de orden inferior (ROI), a los que habrá que transformar previamente sus coordenadas ED50 a ETRS89.	
	f	Desviación estándar a priori de los puntos de apoyo y centros de proyección	La desviación estándar a priori de los P.A se establecerá entre 1/3 y 1/2 del tamaño del píxel. La desviación estándar a priori de los Centros de Proyección se establecerá entre 0,10 m y 0,15 m.	
	g	Bloque perteneciente a dos husos distintos	En el caso de que un bloque quede comprendido entre dos husos distintos se calculará a la aerotriangulación en el huso de mayor superficie. Las ortofotos necesarias de cambio de huso se reproyectarán posteriormente, garantizando que no aparezcan cuñas.	
3.2. Precisiones				
	a	Precisión interna del ajuste del bloque	RMSE < 1/2 del tamaño del píxel del sensor (micras)	
	b	Precisión planimétrica final	RMSE < GSD_of (metros)	GSD_of : Ground Sample Distance (tamaño del píxel en el terreno -metros-) de la ortofoto
	c	Precisión altimétrica final	RMSE < GSD_of (metros)	
	d	Residuo máximo en los puntos de control	< 1,5 veces el GSD_of	
3.3. Productos a entregar				
	a	Datos del cálculo de la aerotriangulación	Ficheros de entrada y salida del cálculo	Con toda la información de ajuste, residuos, coordenadas resultantes, etc...
	b	Gráficos del canevas	En formato shp con la posición exacta de los puntos del canevas, generados a partir de la bbdd de AT	
	c	Base de datos del vuelo aerotriangulado	Parámetros de orientación de los fotogramas (X, Y, Z, Q, Φ, K) En caso de sensor de barrido, ficheros de soporte, orientación y calibración (*.sup, *.ads, *.odf.adj, *.cam)	Según criterio de signos y orígenes , y formato que entregará la dirección técnica
	d	Informe descriptivo del proceso de aerotriangulación	Según documento "... Informe POSTPROCESO PNOA.xls"	

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Apartado	Ítem	Fase / Parámetro	Especificaciones	Detalles	
4. MODELOS DIGITALES DE ELEVACIONES (MDE) POR LIDAR O CORRELACIÓN AUTOMÁTICA					
4.1. Modelo Digital del Terreno (MDT)					
	a	Objetivo	Obtener un modelo del terreno a nivel del suelo natural Sistema de referencia altimétrico: se utilizarán exclusivamente cotas ortométricas, tanto en el proceso de cálculo como en los resultados finales		
	b	Obtención de un MDT	El MDE se obtendrá mediante correlación automática o a partir de modelos digitales de elevaciones preexistentes, siempre que reúnan las siguientes condiciones: - Cumplirán estrictamente las precisiones exigidas en este pliego de especificaciones técnicas. - Dichos Modelos Digitales del Terreno serán objeto de revisiones sistemáticas con observación estereoscópica para su actualización - La actualización se realizará a la fecha del vuelo PNOA que se esté ortoproyectando.	En los casos en los que puedan ser utilizados modelos digitales de elevaciones preexistentes, la Dirección Técnica se encargará de facilitarlos.	
	c	MDT en formato GRID	Se procederá a obtener un MDT de malla regular mediante interpolación El paso de malla del MDT será de 5m x 5m	Todos los puntos de la malla tendrán coordenadas X,Y UTM enteras, múltiplos del paso de malla.	
	d	Precisión de los MDT: error medio cuadrático	RMSE ≤ 1 m (GSD_vf de 0,18m), ≤ 1 m (GSD_vf de 0,22m) , o ≤ 1,5 m (GSD_vf de 0,35m)		
	e	Precisión de los MDT: error máximo	GSD_vf de 0,18 m: ≤ 2 m en el 95% de los casos No habrá ningún punto con error superior a 4 m GSD_vf de 0,22 m: ≤ 2 m en el 95% de los casos No podrá haber ningún punto con error superior a 4 m GSD_vf de 0,35 m: ≤ 3 m en el 95% de los casos No podrá haber ningún punto con error superior a 6 m	No podrá	
	f	Líneas de ruptura de elementos naturales ("breaklines")	Trazado manual estereoscópico	Se trazarán mediante trazado manual estereoscópico en aquellos lugares en los que no quede suficientemente definido el relieve con la malla de puntos LIDAR o de correlación , En las zonas de agua, (mar, embalses y lagos) la cota del MDT será constante e igual a la de la orilla.	
	g	Corte de ficheros	De acuerdo al corte rectangular establecido por hojas MTN25	Las coordenadas de las esquinas de hoja serán las oficiales aprobadas por el Consejo Superior Geográfico (Comisión de Normas Cartográficas, Real Decreto 2007)	
4.2. Modelo Digital de Superficie para ortofoto (MDO)					
	a	Objetivo	Obtener un modelo a partir del cual se obtengan unas ortofotos correctas geoméricamente, incluso en las carreteras, viaductos, etc.		
	b	Método de obtención	A partir del MDT introduciendo las líneas de ruptura		
	c	Líneas de ruptura de elementos artificiales ("breaklines")	Trazado manual estereoscópico	Se trazarán mediante trazado manual estereoscópico, en aquellos elementos artificiales como presas, terraplenes, etc., en los que no quede suficientemente definido el relieve con la malla de puntos. Adicionalmente, se introducirán LR artificiales para definir puentes y viaductos	
	d	MDO en formato GRID	Se procederá a obtener el MDO de malla regular mediante interpolación del MDT + las Líneas de Ruptura El paso de malla del MDO será de 5m x 5m.		

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	e	Precisión de los MDO: error medio cuadrático	RMSE ≤ 1 m (GSD_vf de 0,22m) , o $\leq 1,5$ m (GSD_vf de 0,35m)	GSD_vf: Ground Sample Distance (tamaño del píxel en el terreno -metros-) del vuelo fotogramétrico
	f	Precisión de los MDO: error máximo	GSD_vf de 0,18 m: ≤ 2 m en el 95% de los casos No podrá haber ningún punto con error superior a 4 m GSD_vf de 0,22 m: ≤ 2 m en el 95% de los casos No podrá haber ningún punto con error superior a 4 m 0,35 m: ≤ 3 m en el 95% de los casos No podrá haber ningún punto con error superior a 6 m	GSD_vf de
	g	Corte de ficheros	De acuerdo al corte rectangular establecido por hojas MTN25	
4.3. Productos a entregar				
	a	Ficheros del MDT	Grid editado, en formato ASCII (X,Y,Z). Paso de malla 5m x 5m	
	b	Ficheros del MDO	Grid editado, en formato ASCII (X,Y,Z). Paso de malla 5m x 5m	
	c	Líneas de ruptura del terreno ("breaklines")	Fichero shape	Se entregarán las líneas de ruptura naturales y artificiales en dos capas distintas
	d	Informe descriptivo del proceso de generación de MDE	Según documento "... Informe POSTPROCESO PNOA.xls"	
5. ORTOFOTO				
5.1. Ejecución de los trabajos				
	a	Método	Flujo de trabajo digital	- Generado a partir del MDO (Modelo Digital de superficie para Ortofoto) - Interpolación bilineal ó bicúbica - Ortorectificación de las imágenes de 4 bandas
	b	Ortofotos a generar	Ortofotos multispectrales RGBI	
	c	Tamaño de píxel	0,15 m y 0,25 m	
	d	Profundidad de color	16 bits por banda	
	e	Orientación de las imágenes	Norte UTM	
	f	Radiometría interna de las ortofotos	Las imágenes procesadas deben hacer un uso efectivo de todos los bits según la resolución radiométrica de cada cámara, evitando la aparición de niveles digitales vacíos y saturaciones en los extremos del histograma. La valoración de estos parámetros se realizará sobre la imagen rescalada linealmente a 8 bits que mantendrá su aspecto, debiendo ser el número de niveles digitales vacíos inferior al 10% y las saturaciones en los extremos del histograma para cada banda inferiores al 0,5%	- Para el cálculo de las estadísticas radiométricas se considerarán únicamente las zonas terrestres, no se tendrán en cuenta zonas sin recubrir fotográficamente que formen parte de una hoja, ni zonas de mar. - No se requiere la generación de las imágenes GeoTIFF de 8 bits, ni su entrega.

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Apartado	Ítem	Fase / Parámetro	Especificaciones	Detalles	
	g	Equilibrado radiométrico del conjunto de imágenes	- Unidad para el equilibrado: zonas de trabajo - Se deberá garantizar continuidad cromática entre todas las hojas de las zonas de trabajo ("ortofoto continua") e individualmente en cada hoja 1:5.000, preservando el color natural sin dominantes. - Se eliminarán de la imagen los efectos producidos por "hot spot", vignetting y cualquier otro que empeore la calidad de la imagen, como manchas y destellos - La Dirección Técnica dará instrucciones para la realización del equilibrado.	- Si se aplica "dodging", debe ser lo más suave posible para no "aplanar" la radiometría de la imagen	
	h	Mosaico	-Se ortoprojectarán todas las fotos , para utilizar sólo la parte más central de cada una - Se recomienda el trazado automático de la línea de mosaico mediante algoritmo de "mínimos cambios radiométricos" con edición manual.	El mosaico se realizará sin volver a remuestrear ninguna ortofoto : cada píxel del mosaico final ha debido ser interpolado una sola vez en todo el proceso.	
	i	Zonas censuradas por motivos de seguridad militar	Las zonas eliminadas por la censura se mantendrán tal como vienen en la fotografía original, con su resolución degradada, sin enmascarar		
	j	Zonas de mar	- No se enmascarará ninguna parte de las fotos existentes - Las zonas sin fotografiar se enmascararán con un color liso similar al agua más próxima - Se utilizarán todos los fotogramas de zonas de mar realizados en el vuelo fotogramétrico cuyos fotocentros estén incluidos en la zona de trabajo, orientándose con los parámetros de orientación directa obtenidos en vuelo en el caso de no haber sido aerotriangulados.		
	k	Corte de imágenes por hojas	- Según distribución de hojas 1:5.000 que entregará la dirección técnica - Rectángulo circunscrito con rebase mínimo de 50 metros con respecto a las 4 esquinas técnicas, debiendo ser las coordenadas de las esquinas múltiplos de 10 metros . - Se considerará esquina superior izquierda de la imagen, la esquina superior izquierda del píxel superior izquierdo .	Distribución 1:5.000 con división en 8 x 8 de las hojas MTN50 oficiales	
	l	Sistema geodésico de referencia	Las ortofotos serán generadas en ETRS89 (REGCAN95 en Canarias), incluidos los mosaicos finales		
5.2. Precisión geométrica					
	a	Error medio cuadrático	GSD_vf de 0,18 ≤ 0,30 m GSD_vf de 0,22 ≤ 0,50 m 0,80 m	GSD_vf de 0,35 ≤	El control se realizará mediante el levantamiento con GNSS de una muestra de 5 puntos sobre algunas zonas de trabajo elegidas al azar, a realizar sobre un 10 % de los bloques fotogramétricos. Criterio de rechazo: detección de problemas en más de un 5 % de las ortofotos
	b	Error máximo en cualquier punto	No podrá haber ningún punto con un error superior a: GSD_vf de 0,18 ≤ 0,60 m GSD_vf de 0,22 ≤ 1,00 m 1,60 m	GSD_vf de 0,35 ≤	En puntos bien definidos con precisión 1/3 del RMS
	c	Discrepancias máximas entre ortofotos de fotogramas contiguos y deformaciones	2 píxeles		
5.3. Productos a entregar					
	a	Ortofotos RGBI sin comprimir, equilibradas radiométricamente, mosaicadas y cortadas según división de hojas 1:5.000	Formato GeoTIFF , de acuerdo con las especificaciones INSPIRE sobre ortomágenes		
	b	Fichero TFW en ETRS89 ó REGCAN95 de cada GeoTIFF	La esquina superior izquierda del píxel superior izquierdo de cada hoja tendrá obligatoriamente coordenadas UTM (ETRS 89 ó REGCAN95) exactas, múltiplo de 10 metros.	Las coordenadas que deben figurar en el fichero TFW serán múltiplos de 10 m con un incremento de + 1/2 píxel en x y -1/2 píxel en y , ya que se refieren al centro del píxel. De esta forma, los múltiplos enteros de 10 m corresponderán a la esquina superior izquierda del píxel	
	c	Líneas de mosaico	En formato shape con identificación del fotograma		
	d	Informe descriptivo del proceso de generación de ortofotos	Según documento "... Informe POSTPROCESO PNOA.xls"		

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Apartado	Ítem	Fase / Parámetro	Especificaciones	Detalles
6 GRABACIÓN Y ARCHIVO DE PRODUCTOS				
6.1. Ejecución de los trabajos				
	a	Grabación productos y documentos	Se realizará la grabación de todos los productos y documentos en discos duros SATA	Previamente a la entrega, se comprobará que el modelo de los discos duros SATA se adaptan a los interfaces eSATA de la dirección técnica.
	b	Almacenamiento de los ficheros de proyecto	La empresa adjudicataria deberá guardar los ficheros del proyecto durante todo el período de garantía, por si fuera necesario rehacer alguna fase de los trabajos.	
	c	Número de copias	- Se entregarán dos copias de cada producto, debiendo utilizarse marcas diferentes de discos para cada copia de los ficheros	
	d	Medios y estructura de almacenamiento	Los productos y documentos serán grabados de acuerdo con la estructura de archivo que aparece en el documento "Nomenclatura de carpetas y ficheros" (Carpetas / Subcarpetas / Ficheros)	
	e	Entregas parciales. Entregas provisionales de algunos productos	La empresa irá realizando entregas parciales a la Dirección Técnica, de fases del trabajo terminadas, con ámbitos correspondientes a los bloques de aerotriangulación en los que se haya entregado que se realice dividido la zona de trabajo, de forma que se puedan ir efectuando las tareas de control de calidad paralelamente. Las entregas provisionales de algunos productos se podrán realizar mediante la transferencia de ficheros por FTP (File Transfer Protocol) previo acuerdo con la Dirección Técnica	Se remitirá el cuadro de control de envío de productos acompañando a cada entrega que se realice
	f	Nomenclatura de ficheros	Todos los ficheros a entregar deberán cumplir la nomenclatura detallada en el documento "110131 Nomenclatura POSTPROCESO PNOA.xls"	
6.2. Productos a entregar				
	a	Listado de los ficheros contenidos en cada medio de almacenamiento	Fichero ASCII con detalle de carpetas, subcarpetas y ficheros	Mediante comando MS-DOS: dir /s > [nombre de fichero].txt o cualquier otro procedimiento similar
	b	Informe descriptivo del proceso de archivo	Según documento "... Informe POSTPROCESO PNOA.xls"	
7 CONTROL DE CALIDAD				
7.1. Ejecución de los trabajos				
	a	Control de calidad de los trabajos realizados	Se garantizará que los procesos de trabajo y los productos generados cumplen con las presentes especificaciones técnicas, debiéndose realizar un control de calidad que consiga estos objetivos documentándolo adecuadamente.	
7.2. Productos a entregar				
	a	Informe descriptivo del proceso de control de calidad	Según documento "... Informe POSTPROCESO PNOA.xls"	
	b	Informe resumen	Documento en el que se detallarán los controles de calidad internos aplicados y resultados de los mismos para comprobar la calidad radiométrica y geométrica de las ortofotos generadas	
8 ENVÍO DE PRODUCTOS				
8.1. Productos a entregar				
	a	Cuadro de control de envío de productos	Según modelo del documento facilitado por la Dirección Técnica	

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3.Camera calibration certificate



Calibration Protocol
DMC III



Camera Calibration Certificate
No: DMC III 27541



For

**ICGC – Institut Cartografic i Geologic de
Catalunya**

Parc de Montjuic, S/N
Barcelona 08038

Spain

This calibration certificate complies with DIN 18740-4

CalibProtocol_DMCI_27541_2019.docx Document Version 3.0

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DMC III Calibration

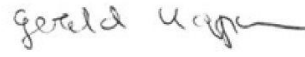
Protocol

Camera: DMC III
Manufacturer: Leica Geosystems Technologies, D-73430 Aalen, Germany
Reference: PAN
Serial Number: 00128300 (PAN Head)
Date of Calibration: 29. April 2019
Date of Report: 30. April 2019
Number of Pages: 48

This camera system is certified by Leica Geosystems Technologies and is fully functional within its specifications and tolerances.

Date of Calibration: April 2019

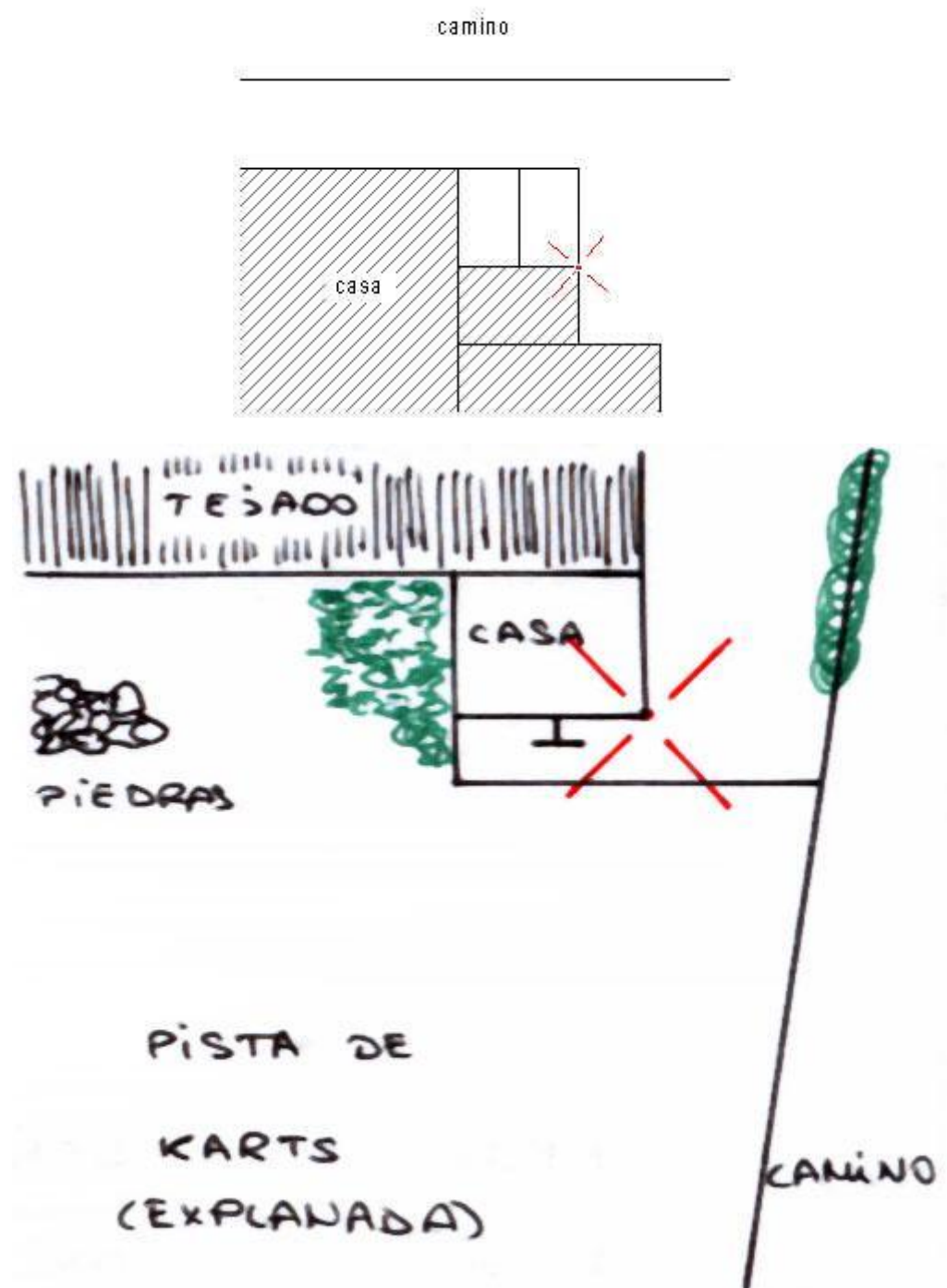
Date of Certification: April 2019

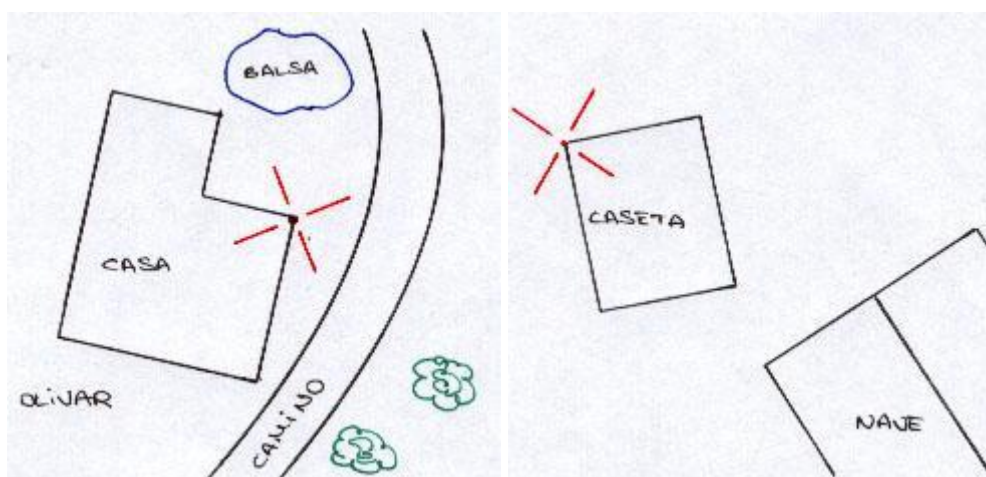


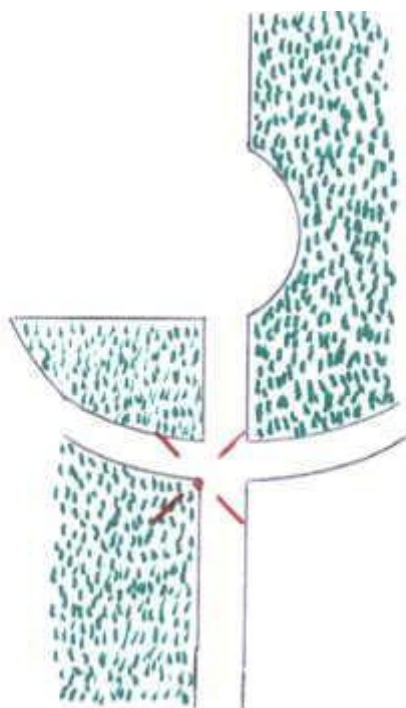
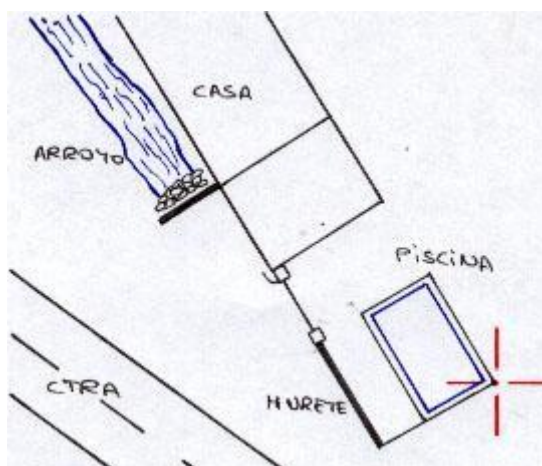
Dipl.Ing. Christian Mueller, Product Manager

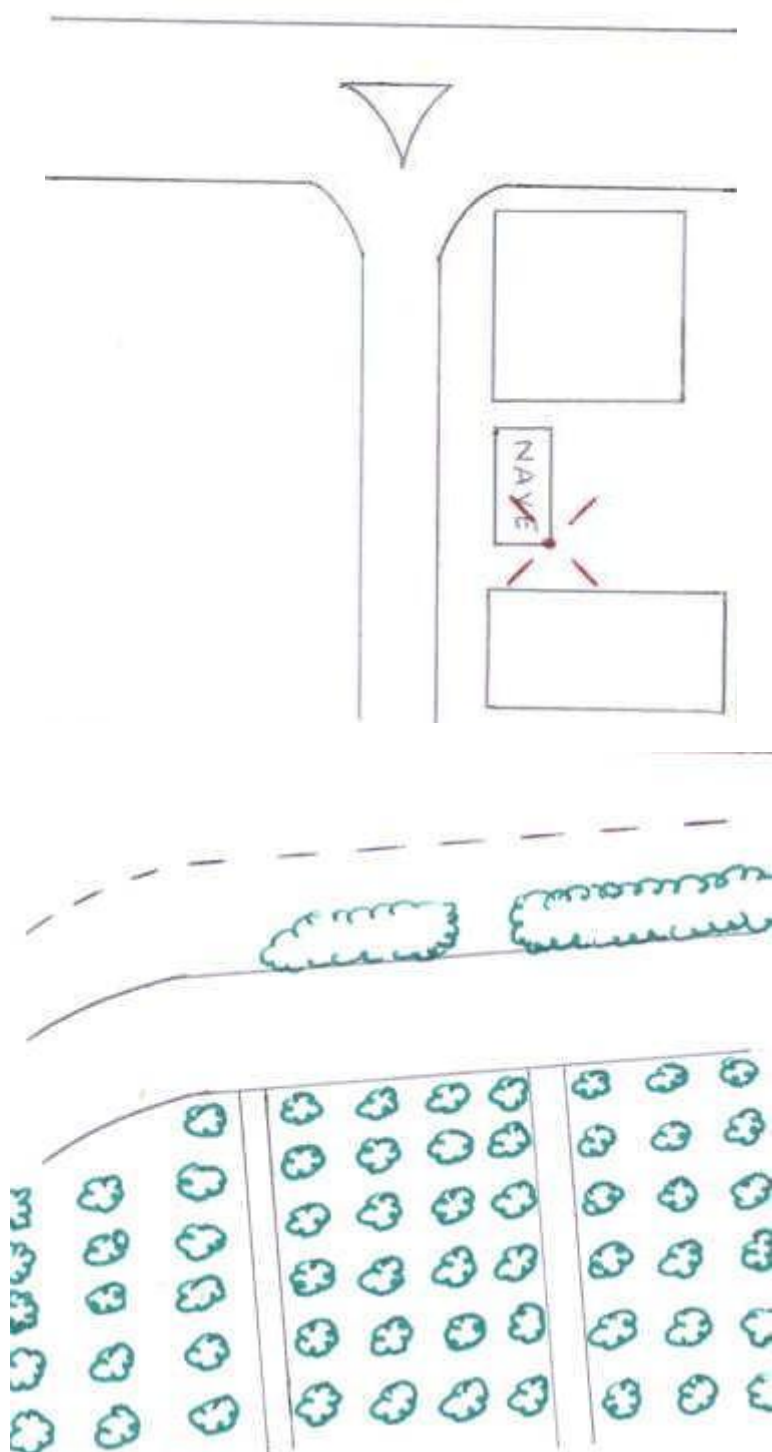
Dipl.Ing. Gerald Kapoun, Technical Consultant

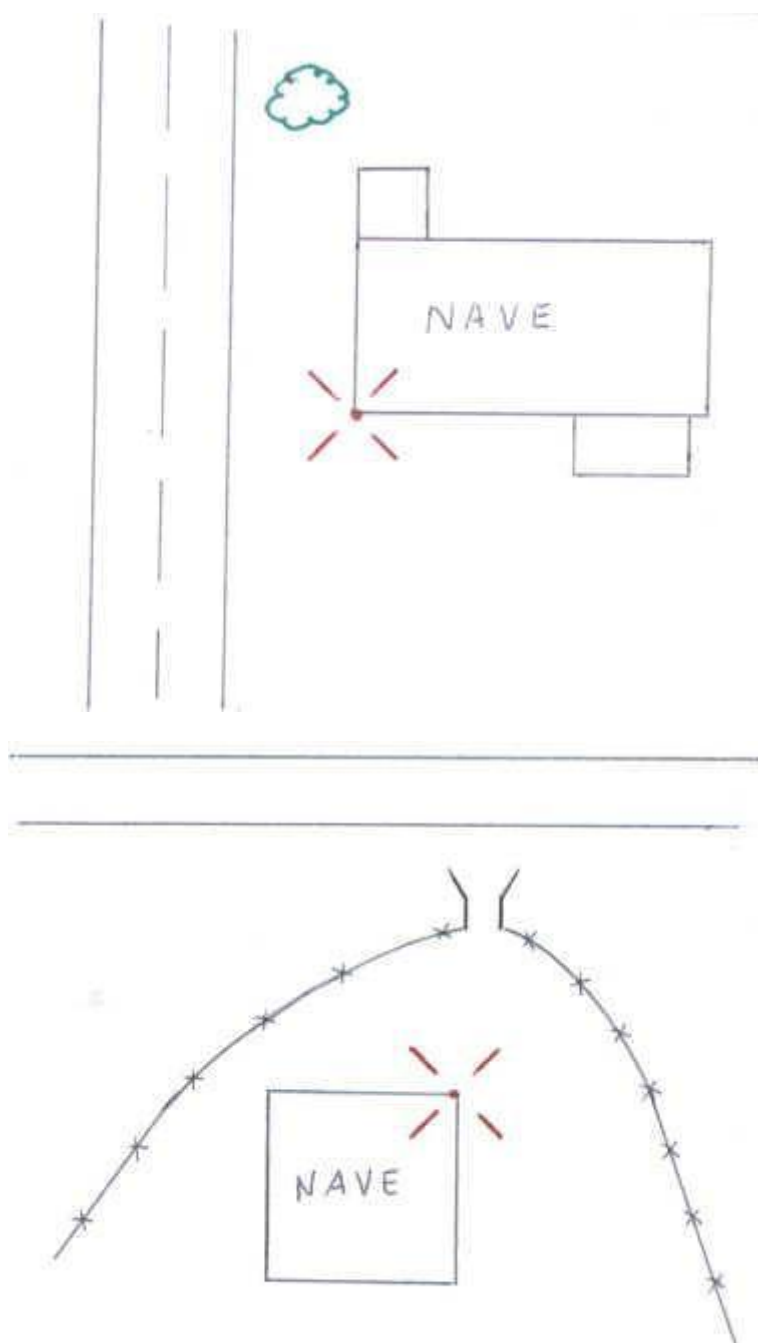
4. GCP information (sketch)

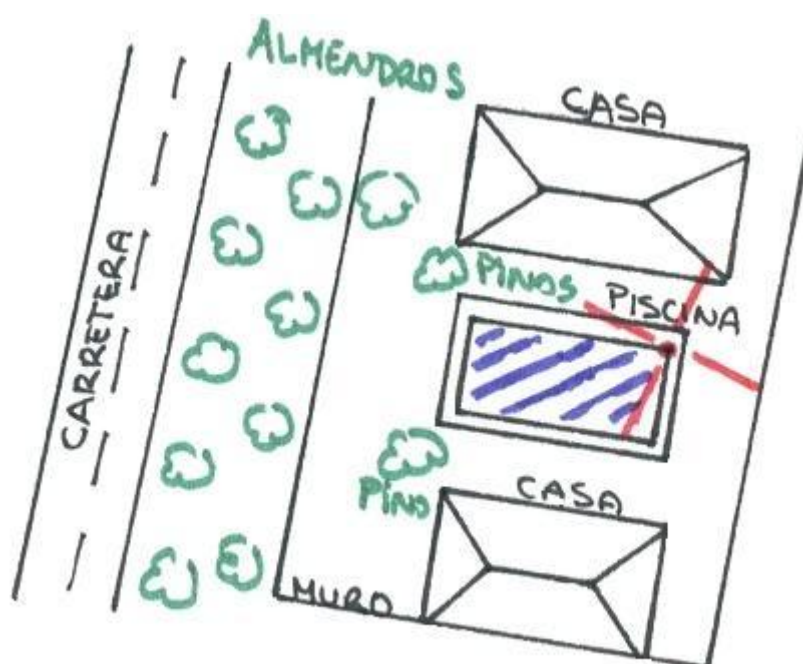
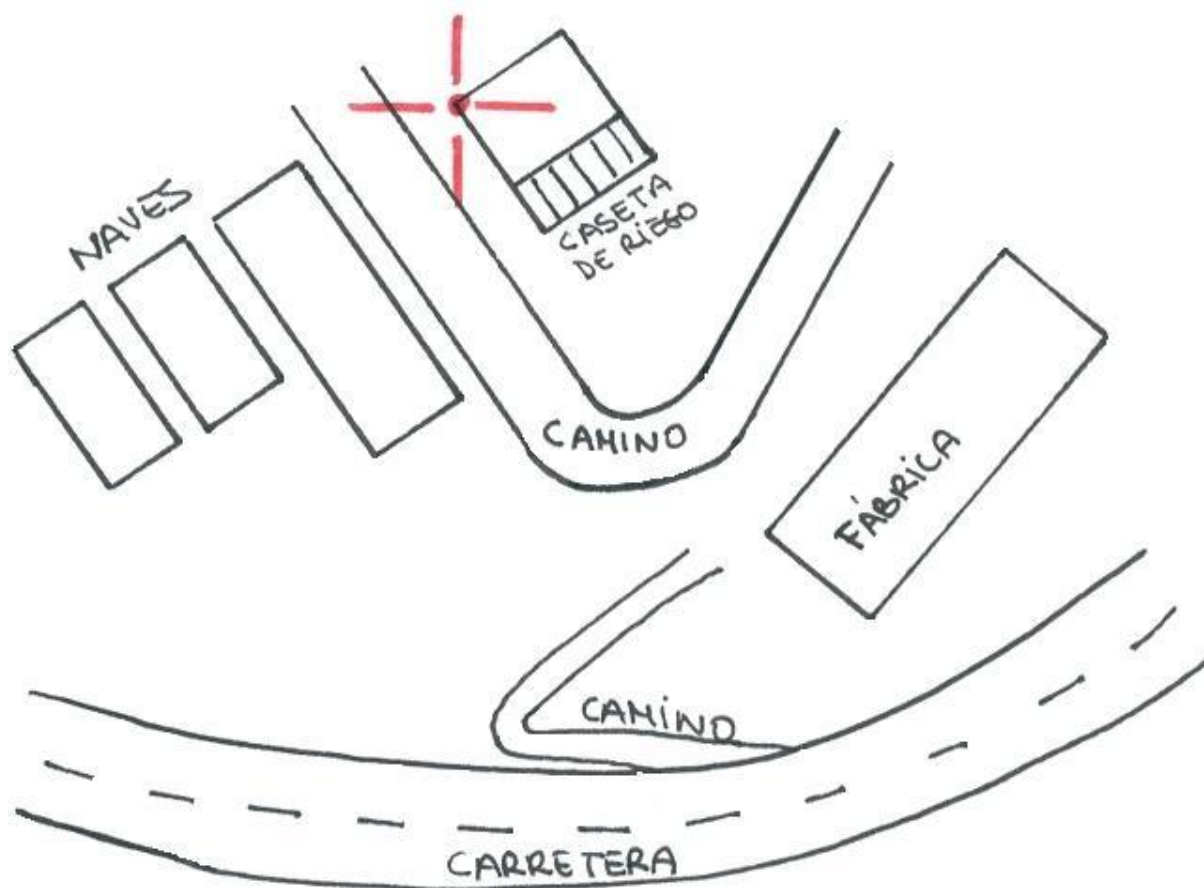


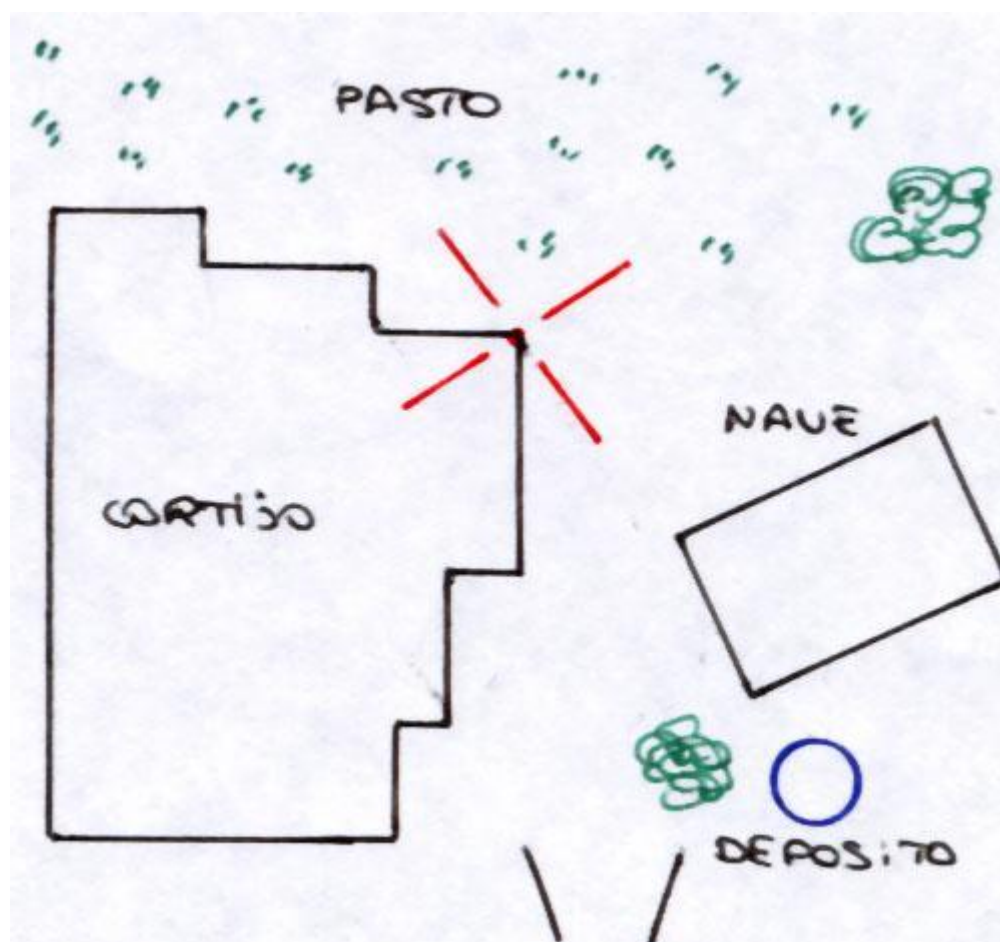
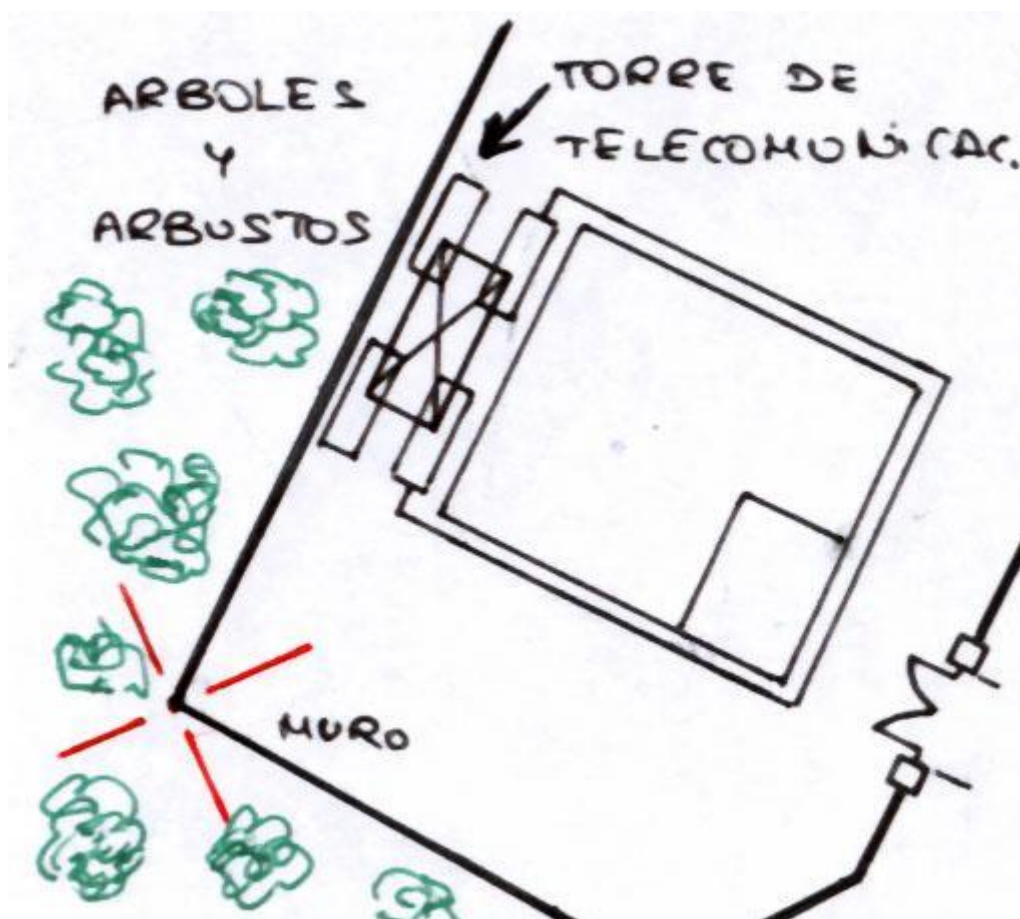


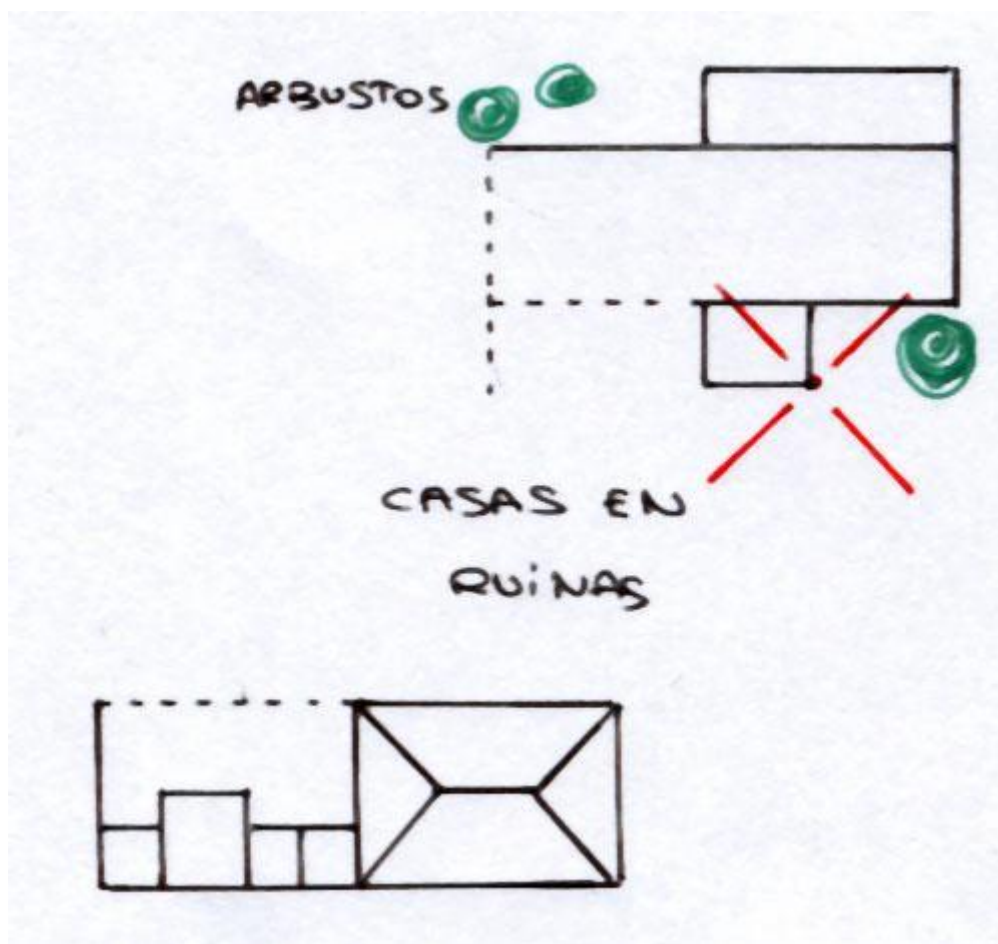


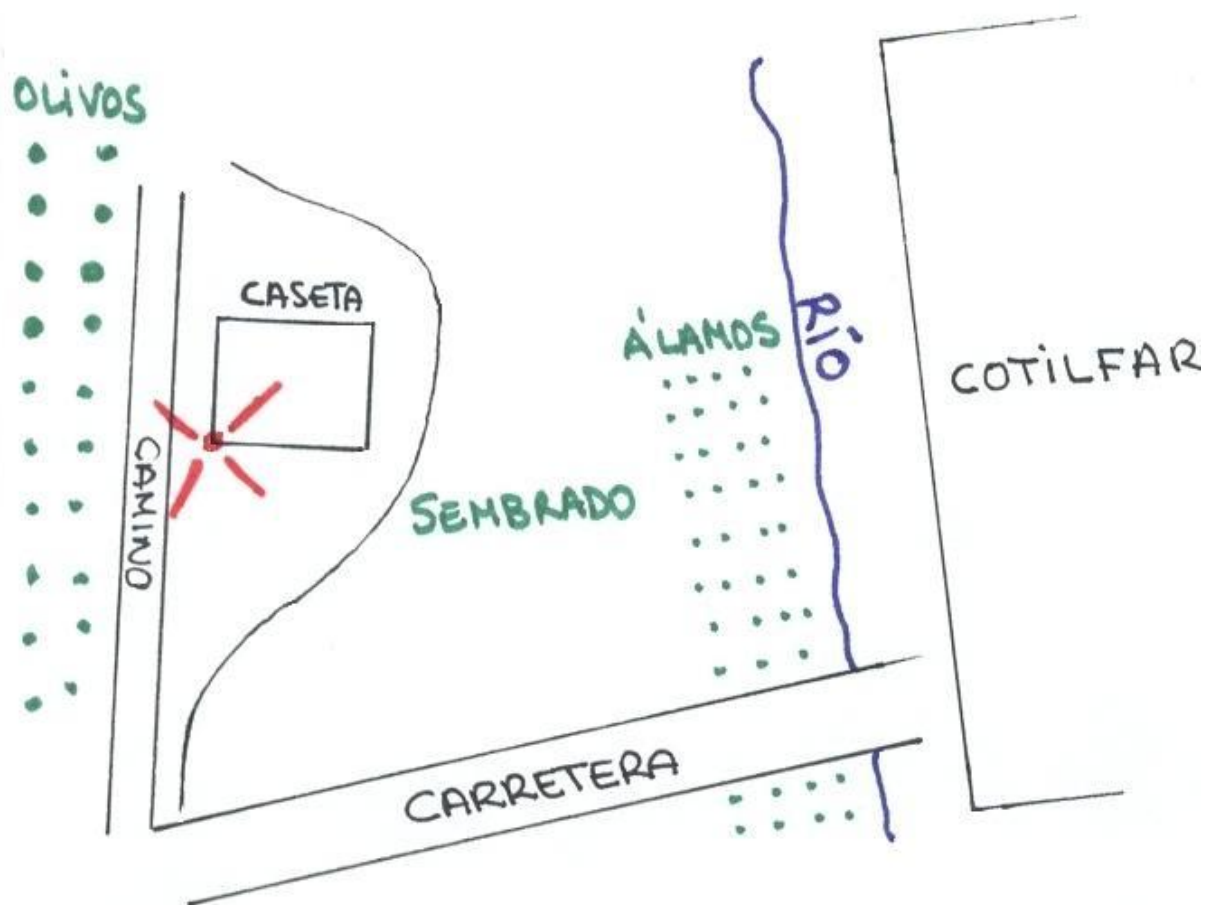
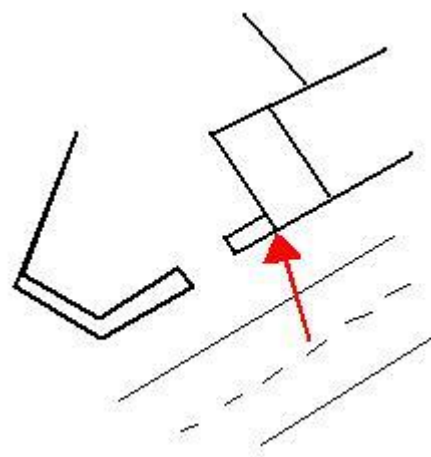
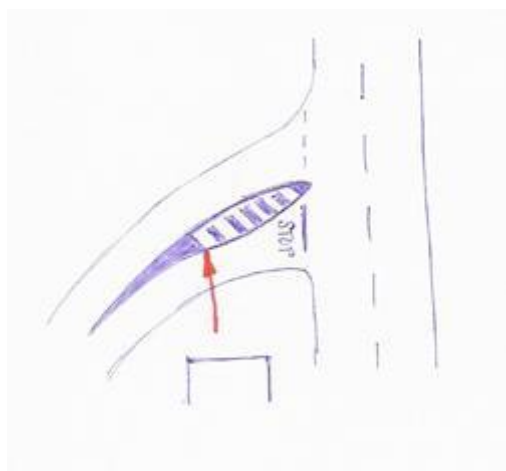












ABSTRACT

Photogrammetry is a versatile technique that leverages overlapping images to extract precise 3D data, enabling accurate measurements of objects. This report delves into the application of photogrammetry in generating digital elevation models (DEMs) and orthomosaics, focusing on the MTN 947 sheet in Andalusia, Spain. The project, conducted in collaboration with the Department of Cartography, Geodesy, and Photogrammetry at the University of Jaén, highlights the synergy between academic expertise and practical geospatial exploration.

The project's objective is to produce high-resolution orthophotomaps that offer insights into elevation variations, facilitating informed decisions in urban planning, environmental management, and infrastructure development. The process unfolds through meticulous steps: data acquisition, GCP integration, image alignment, dense cloud generation, DEM creation, orthomosaic generation, and thorough quality control.

The project's outcomes make valuable contributions to the geomatics and surveying sectors. This report also functions as a guide for upcoming projects in photogrammetry and geospatial exploration. The principal objective of the project surpasses mere product acquisition, as it strives to showcase our proficiency in obtaining these products from open data sources.

Keywords: Photogrammetry, Digital Elevation Model (DEM), Orthomosaic, Remote Sensing, Geomatics, Terrain Mapping.

Resumen

La fotogrametría es una técnica versátil que aprovecha las imágenes superpuestas para extraer datos 3D precisos, permitiendo mediciones precisas de objetos. Este informe examina la aplicación de la fotogrametría en la generación de modelos digitales de elevación (DEM) y orthomosaics, centrándose en la hoja MTN 947 en Andalucía, España. El proyecto, realizado en colaboración con el Departamento de Cartografía, Geodesia y Fotogrametría de la Universidad de Jaén, destaca la sinergia entre la experiencia académica y la exploración geoespacial práctica.

El objetivo del proyecto es producir orthophotomaps de alta resolución que ofrezcan información sobre las variaciones de la elevación, facilitando decisiones informadas en la planificación urbana, la gestión ambiental y el desarrollo de la infraestructura. El proceso se desarrolla a través de pasos meticulosos: adquisición de datos, integración de GCP, alineación de imágenes, generación de nube densa, creación de DEM, Generación ortomosaica y control de calidad exhaustivo.

Los resultados del proyecto aportan valiosas contribuciones a los sectores de la geomática y la observación. Este informe también sirve de guía para futuros proyectos en fotogrametría y exploración geoespacial. El objetivo principal del proyecto va más allá de la mera adquisición de productos, ya que se esfuerza por mostrar nuestra competencia en la obtención de estos productos a partir de fuentes de datos abiertos.

Palabras clave: Fotogrametría, Modelo de Elevación Digital (DEM), Ortomosaico, Remote Sensing, Geomática, Mapa de Terreno.