Contents and Planning

(Wednesday Morning)

Part I: UAV Image Gathering

- T1. The Image as a Projection. Controlling the Exposure. Planning the Mapping Mission.
- P1. Study Case #1: *Planning a multi-rotor mapping flight of a vineyard*.

(Wednesday - Thursday)

Part II: 3D Image SfM Reconstruction and Indirect Georeferencing

- T2. Aero-triangulation. Precise georeferencing with ground control points.
- P2. Study Case #1. *Aero-triangulation and indirect georeferencing. Precision and accuracy analysis.*

(Thursday)

Part III: RTK / PPK Direct Georeferencing

- T3. Introduction. Indirect Vs Direct Georeferencing.
- P3. Study Case #2.

(Thursday - Friday)

Part IV: 3. Digital Mapping Products: DTM, DSM, orthos…

- P4. Study Case #1. *Point cloud generation, visualization and edition. Surface digital models. Terrain digital models. RGB and IR orthoimagery generation. Other photogrammetric products.*

3D Image Reconstruction

Your flight plane has been successful! We have lots of photos of the vineyard!

- Copy the Photos to your computer, to the folder SanClemente. Ask the professor where are it. The size is too big for upload to Ariadna server. View the photos.

- That we are going to do in this practice is to generate a 3D model of the vineyard!, let´s start!

3D image reconstruction of an object is the creation of three-dimensional models from a set of photographs of the object. This is a very complex process that has several stages:

1.- Aerotriangulation or Alignment. It´s the simultaneous determination of:

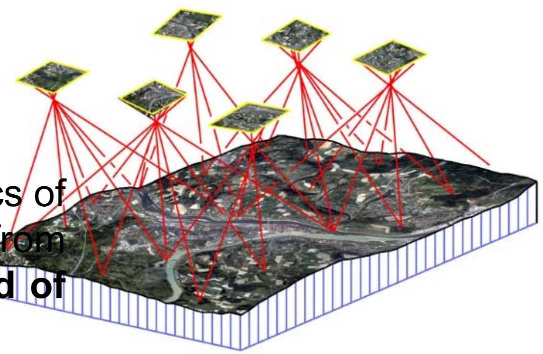
a. The position and orientation of the camera when shooting each photo
b. Internal geometry of the camera (**autocalibration**).
c. Coordinates of some points of the object (**Tie Points**)

2.- Georeferencing. It includes all necessary operations to provide to the 3D model a reference system. There are two basic types of georeferencing

a) **Direct**: By using the coordinates of the photos
b) **Indirect**: By using coordinates of points on the ground

3.- Densification. Once the positions and orientations of the photos and the characteristics of the projection (camera calibration) are known, it is possible to intersect common rays from several photographs to retrieve many 3D points which together will form a **dense cloud of points.**

4.- Modeling. A point cloud is a discrete, heterogeneous and a heavy raw product. During the modeling stage, point clouds are transformed into other digital models such as raster, parametric surfaces or triangles models.



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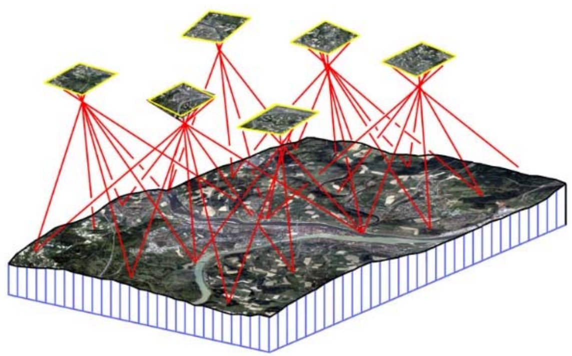
What is Georeferencing?

- All operations to give to the model a (good) reference system
  - Local
  - Geographic
  - Geographic projected
- Additional advantages of georeferencing operations
  - Help during Matching Features in SfM.
  - Better camera calibration → removing systematic errors



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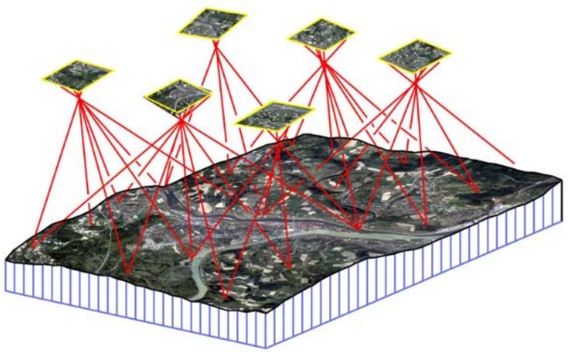
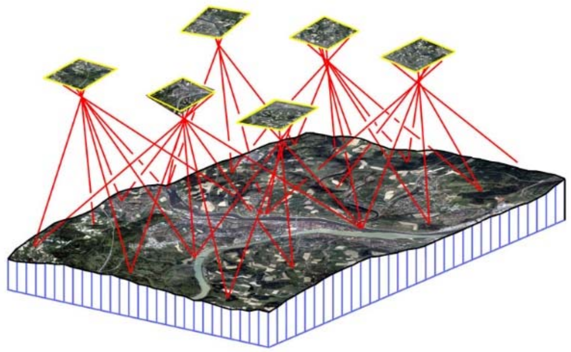
Georeferencing classification

- Indirect georeferencing
  - Ground Control Points
- Direct georeferencing
  - Single-code GNSS receiver
  - Real Time Kinematic
  - Post Processed Kinematic



Indirect Georeferencing

- Indirect georeferencing
  - Ground Control Points usage
- Direct georeferencing
  - Single-code GNSS receiver
  - Real Time Kinematic
  - Post Processed Kinematic



CONTROL POINTS

Control points are visible elements in photographs of which their precise coordinates are known. They serve to georeference the photogrammetric model.

- Landscape elements (stones, plants, corners, poles)
- "ad hoc" targets → Presignaling

<u>**Presignaling**</u> has to be done before flight, which is difficult with conventional photogrammetry, but easy with photogrammetry with UAV images.

Advantages:

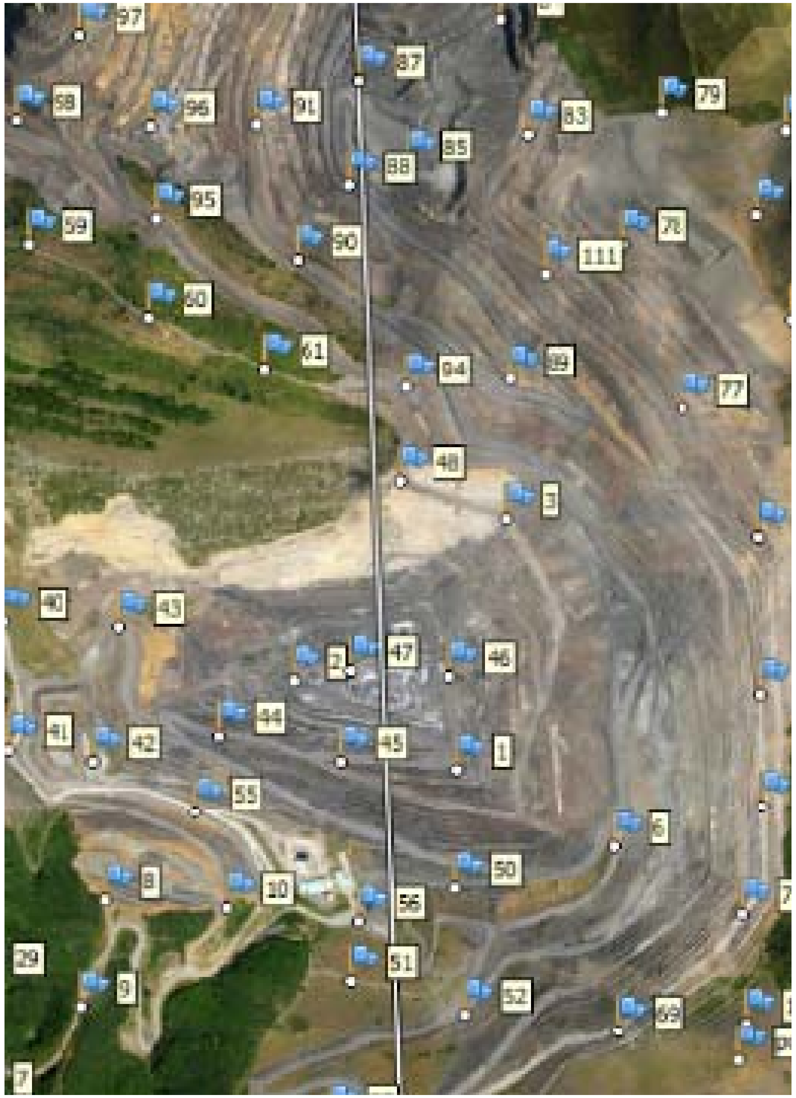
- The visibility of the control is guaranteed
- Flat signaling elements are used
- Once the flight is done, it is not necessary to return to the field

Recomendations:

- High reflectivity materials such as white - grey plastics
- Round or square targets
- Large size, around 10-15GSD side or diameter

GROUND CONTROL POINTS

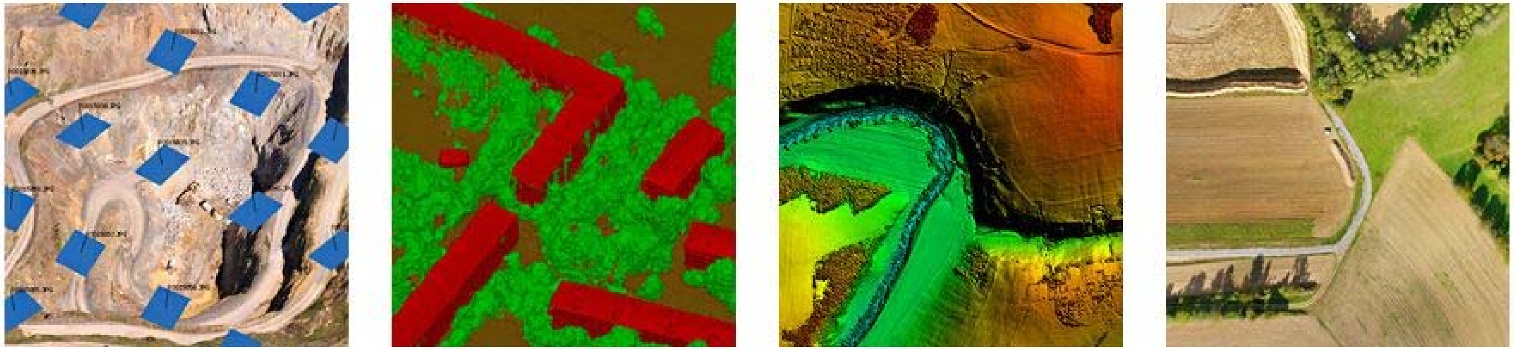
- The **more control**, the **better accuracy**
- GCPs must be distributed homogenously across the whole interest area, preferably in the form of a diamond grid, since this layout minimises the distance between any two GCPs
- When few points are available most should be on the **periphery** of work, but some must also be at the **center** of the survey



GROUND CHECK POINTS

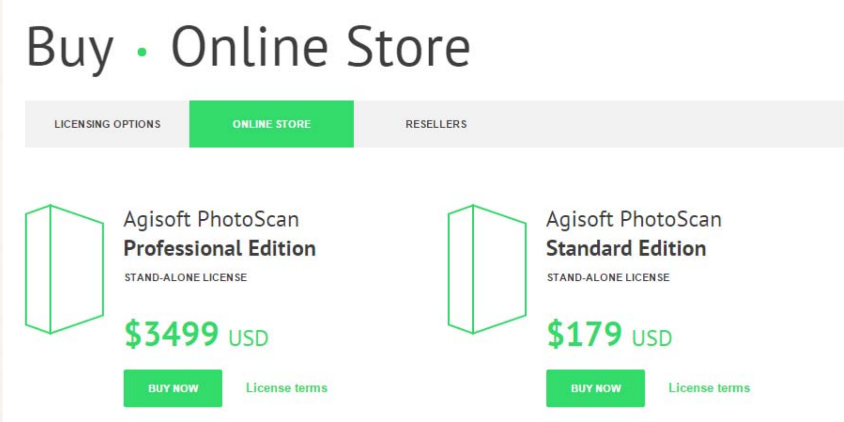
- GChPs are exactly the same. Only difference is that they are not being used during Bundle adjustment.
- The accuracy of a project must be measured at **checkpoints**, not at control points
- The maximum accuracy to be expected is:
  * Planimetry, GSD
  * Vertical, GSD * 3

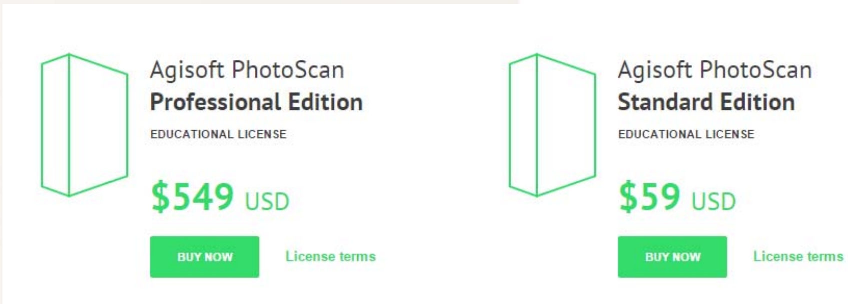
Agisoft Photoscan



- Russian Commercial Software
- Available in DEMO version.
  - You can do everything, except to save the work.
  - When you close the software, you lose the work
- Available a 30 days trial
- Educational license for 600€
- There are two version. We need the Professional Edition (The more expensive, of course)

- Exceptional results
- Easy of use
- Economic for academia
- **Highly recommended**
- Other good alternatives:
  - Pix4D
  - Photomodeler Scanner





Setup of Agisoft Photoscan

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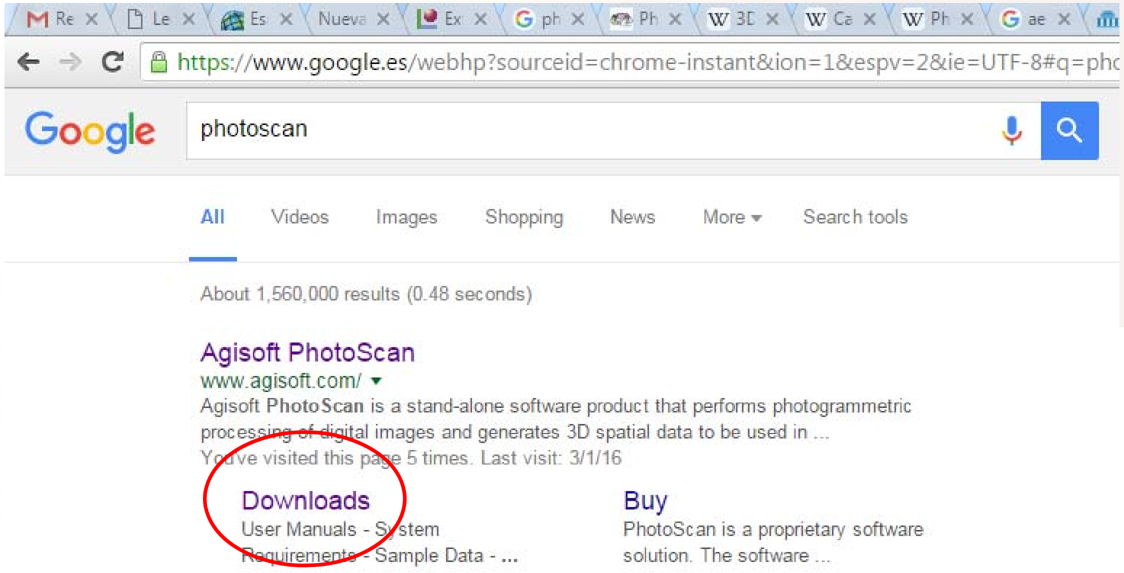
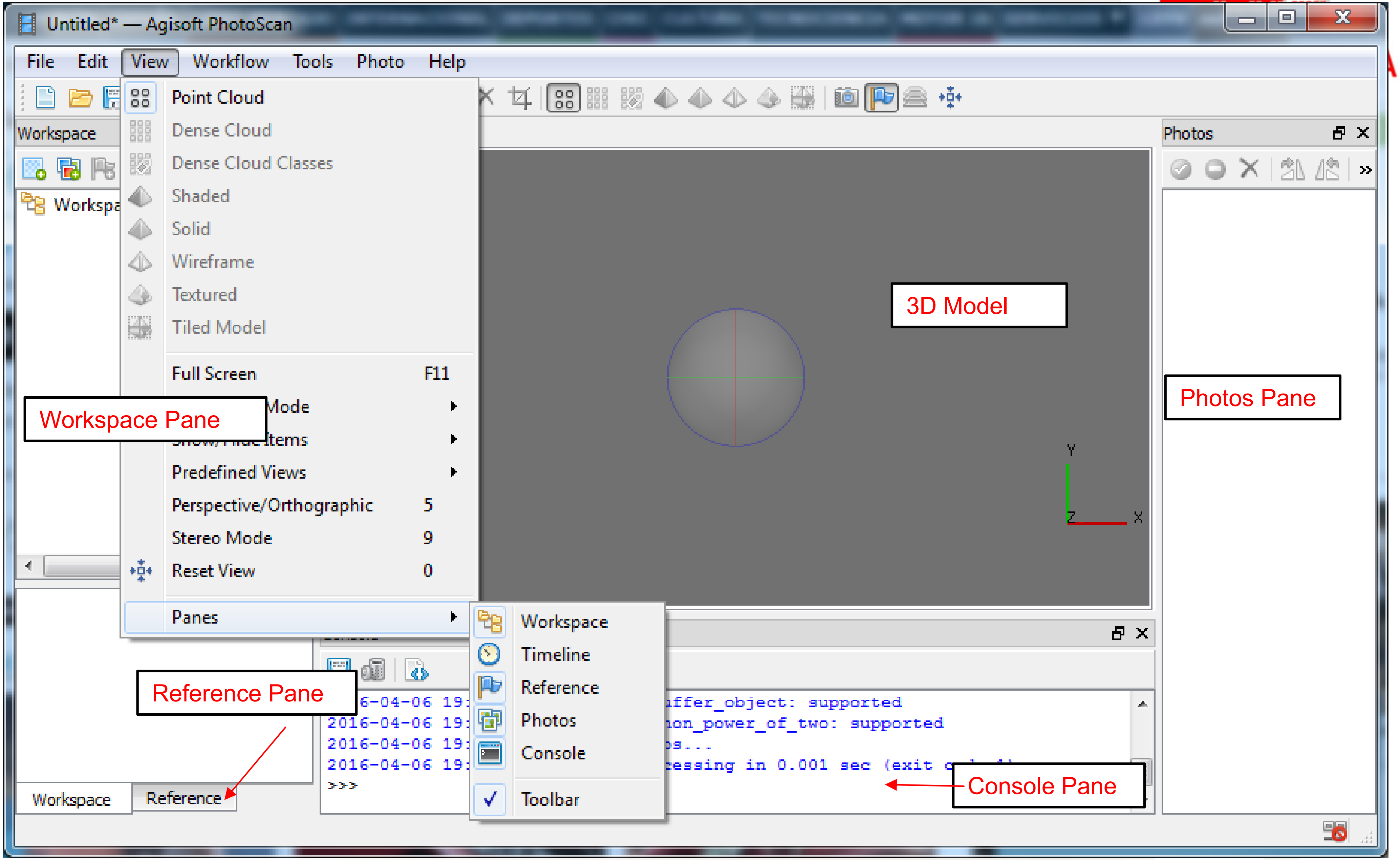
1. Setup of Photoscan



Agisoft Photoscan - Structure



Adding Photos I

1.- Verify that you have all photos in the SanClemente Folder:
E:\Geo4D\Unit3\Data\SanClemente\IR
E:\Geo4D\Unit3\Data\SanClemente\RGB

2.- Open Photoscan. If you own a license it´s a good moment to save the (empty) project. File → Save. Name the project *SanClemente00.psx*. It´s a good idea to save in the *SanClemente* folder. If you don´t have license don´t worry. It´s not necessary to save it.

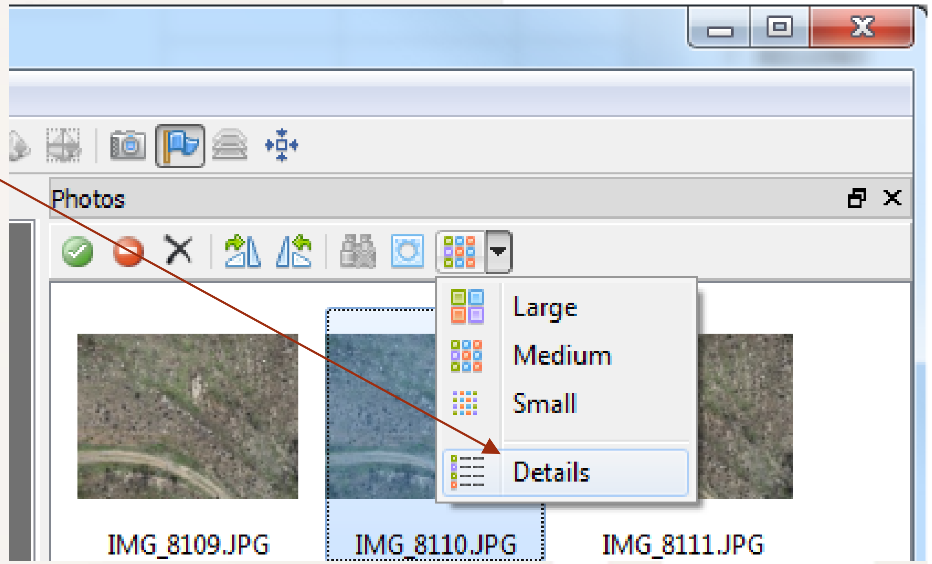
3.- **Import aerial RGB photos in the project** Menu Bar→Workflow→Add photos...

- Visualize the photos with a double click in the files in the Workspace Pane.
- Disable the 7 first and 17 last photos. These have been taken when the UAV was taking-off and when was landing.

4.- **Blurry picture detection**. As the multi-rotor is always moving, could be a percentage of photos that are no sharp enough. The best option is to disable the worst photos. Photoscan has an utility that measure the sharpness. The algorithm recounts sudden luminosity jumps and calculate an index from 0 to 1 where 0=completely blurred photo and 1=completely sharp photo.

- Select all the photos within the Photos Pane: ***click right button***→ Estimate Image Quality → Selected Cameras → OK. Depending on computer power, it can be last between 1 and 5 minutes.

- Enlarge the Image Pane → Click the arrow on the last icon (mosaic of colors) and select Details. Now you see a table with all the details of the images. Enlarge the Image Pane again until the column quality is displayed. Click the column head quality. Photos will be sorted in increasing quality. If there is any quality picture with <0.5 disable it directly. Check the photos that are between 0.5 and 0.75. Disable in the case they are too much oblique or blurred. Decision is subjective and different criterions or decisions are OK. If you are in doubt ask professor. About 5-8 pictures should be disable.



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Adding Photos II

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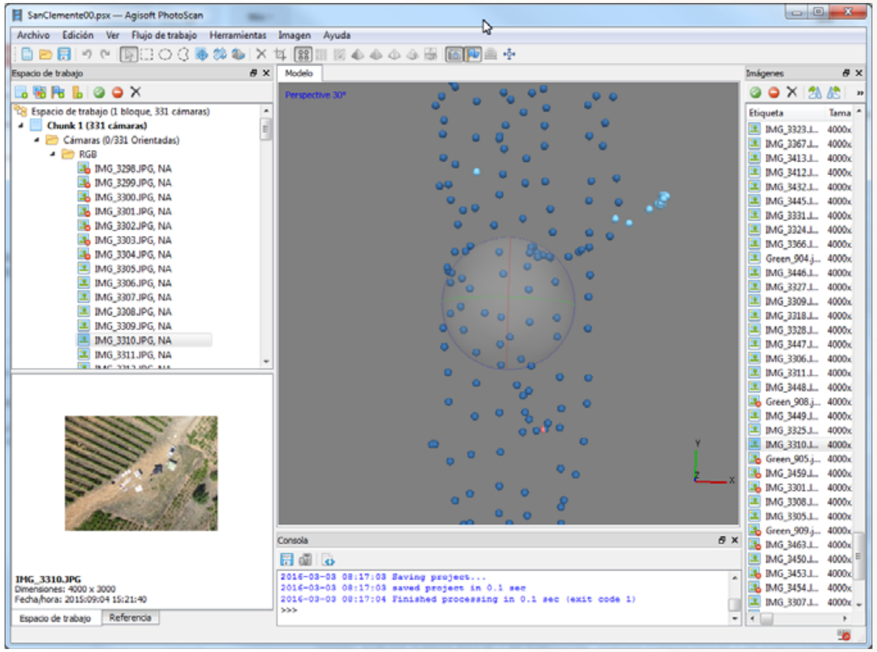
5.- In the project we will work with photographs of two different cameras: RGB and Infrared. Before adding IR photos in the project you should create two different groups of cameras.
In the Workspace Pane select all the photos. Click on the Right Button → Move Cameras → New Camera Group. Rename the folder as *RGB*. Click Right Button → Rename

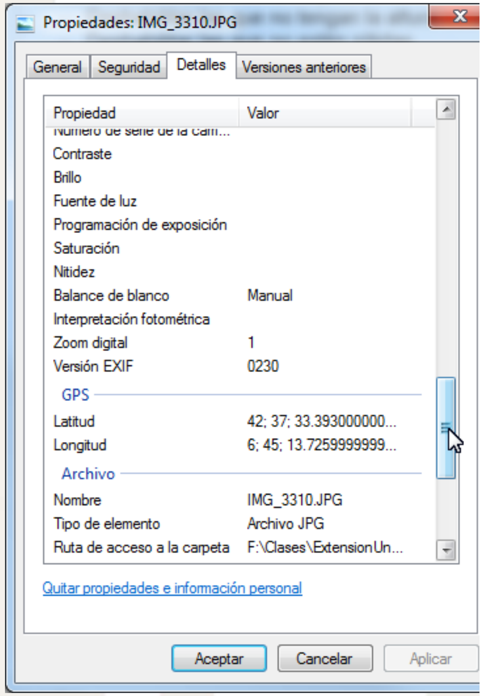
6.- Create a new camera group and rename it as **IR**.

7.- Click right button in IR folder → Add photos...
- Import all photos in SanClemente/IR/ folder
- Check quality
- Disable the blurred or very convergent photos (about 10 photos)

8.- The camera RGB has a small GPS sensor that injects the geographical position of the camera when the picture is taken. Thus, it is possible to geo-reference the project, although this is a very rude georeferencing.



Blue circles in the Model Panel represent the positions of the cameras at the time of shooting. The information is stored as metadata EXIF at the time of taking the photograph.
To check if a photo contains geographical information in the EXIF metadata:
- With Windows Explorer navigate to the JPG file. Right button→ Properties → Details, down the scroll bar to the chapter GPS.
- **Task**: Check if IR photos have georeferencing information.



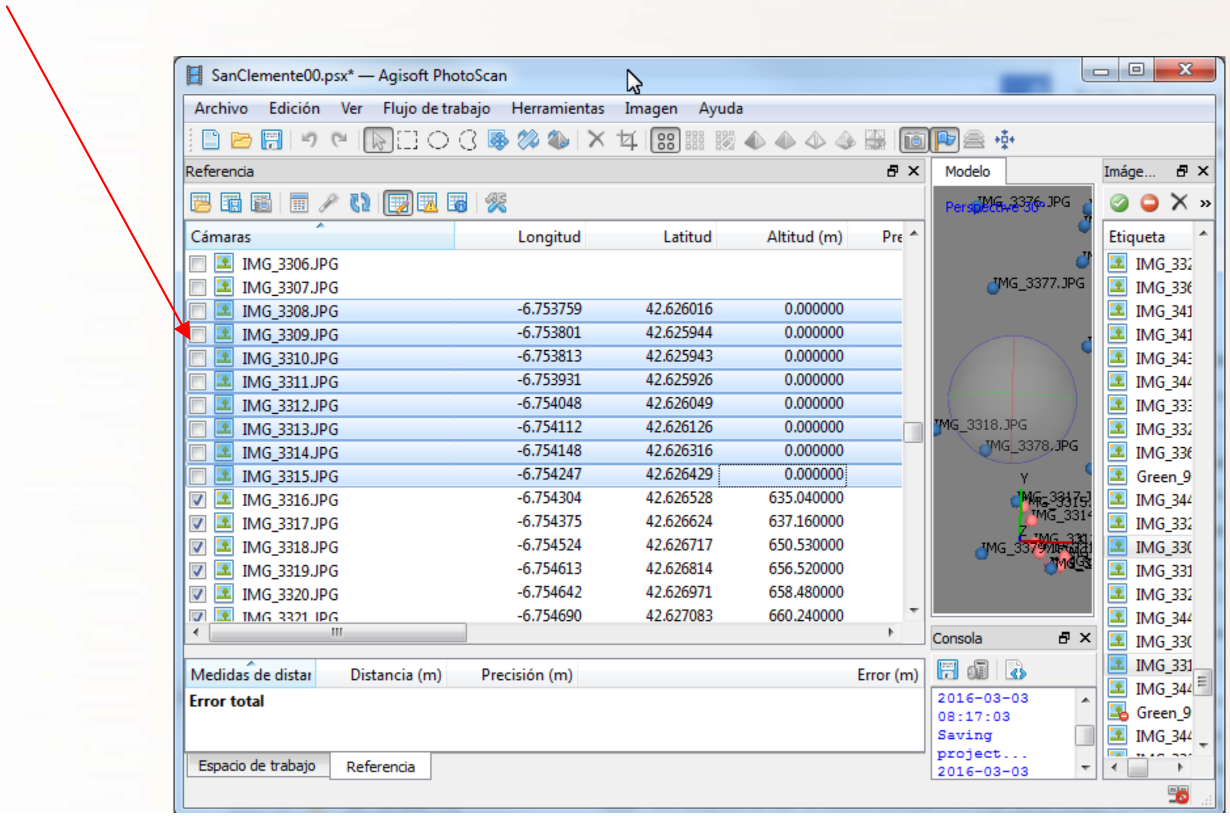
Adding Photos III

9.- In PhotoScan it is possible to see the geographical location of the pictures. This requires Go to ***Reference Pane***. Enlarge the panel until the columns of longitude, latitude and altitude, Accuracy and Error are showed.

IR photos doesn´t have geographic information. Look for the RGB photos.

- Note that the first 10 RGB photos don´t have geographical position. This is because the GPS camera takes a minute to calculate the position. The photos that are taken at the beginning will not have known position.
- Note that RGB photos 11th to 18th (IMG_3308.JPG to IMG_3315) altitude is 0, while the lower altitude of the vineyard is 635m AGL. This is because the GPS camera in the first minutes only solve position in 2 dimensions, since it has not yet managed to track the required number of satellites for a 3D position.

- For the reason explained, it is necessary to **uncheck** photos that have an altitude = 0.



Adding Photos IV

10.- **Geometrical calibration of the camera.**

You can see the basic parameters describing the “rectangular pyramid”. These approximate data are extracted from the EXIF metadata of JPG files.

In the Menu bar →**Tools → Camera calibration**.

IR photos haven't metadata because the files are not the original jpgs: they had a Matlab postprocessing to remove the blue and red channel.

- Change the name “*unknown”* to Canon Powershoot S100 IR
- Copy the pixel size (mm) from the RGB camera.
- Copy the Focal Length (mm) from the RGB camera.

Note that in *initial values* tab, in both cameras, there is only the focal length (pixel units according to x and y sides). All the distortion parameters are = 0 since now we don´t have information about it. We will get these data during next processing step. After the “Alignment” or “Aerotriangulation”, the *Adjusted* tab will have the autocalibrated and precise values.

Also, the distortion plots will be accessible. *Right click on Canon Powershoot… → Distortion Plot*

Click OK

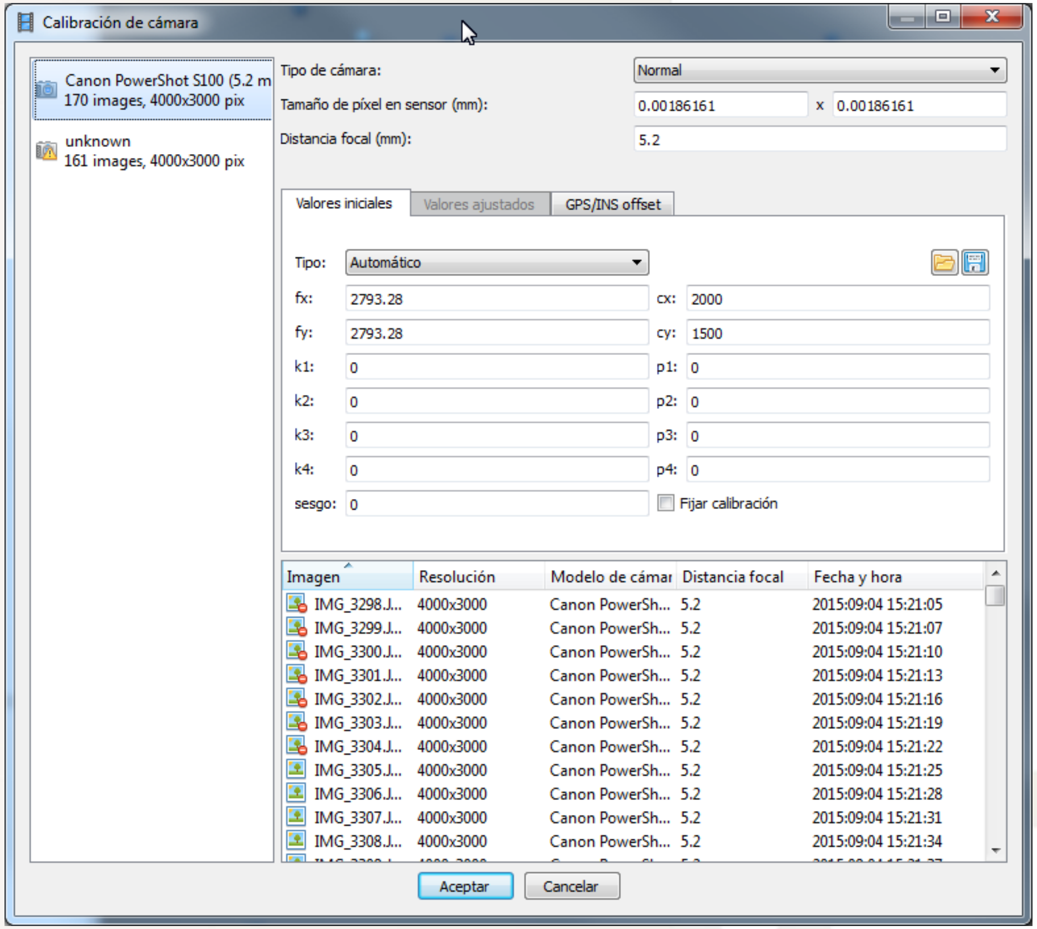
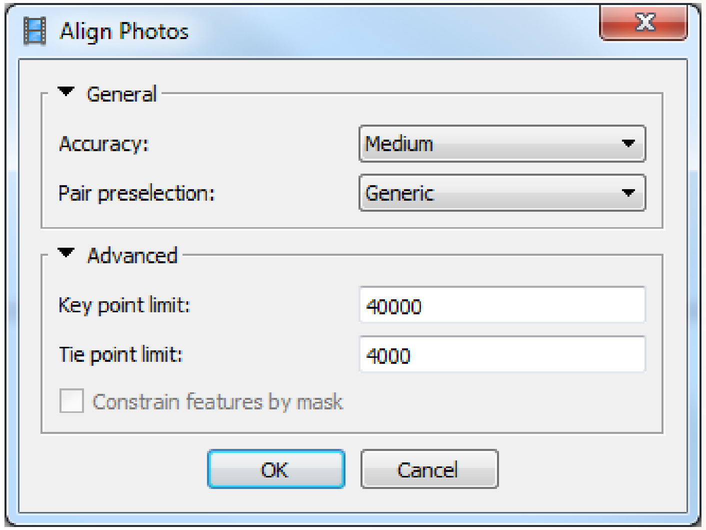


Photo Alignment I

11. In the workspace pane rename Chunk 1 (xxx cameras) to Zone_I. A project can be subdivided into subprojects. This is useful for very large projects with hundreds or thousands of photos in which the calculation time would be too high. In this practice we will work only with a single subproject, since 331 photos can be considered a medium-small project.

12. Everything is ready for the "Alignment" or Aerotriangulation step. In the Menu bar→Workflow→ Align Photos.



Accuracy.
Selecting accuracy: Medium the Alignment process will work with image resolutions of ¼ of original.
In Accuracy Highest the Alignment process will work with images at full resolution. The processing time will be very high. Generally, it is not worthy at all.
In most projects, working at medium resolution provides enough accuracy. The extra time in processing at high or highest is not compensated by much better results. In this practice, we´ll use **medium accuracy**.

Pair Preselection
When Pair Preselection is Disabled the Alignment Algorithm seeks points homologous in all possible combinations of photos. This results in a high time processing that grows exponentially with the number of images.

There are two ways to reduce the processing time: In **Generic** option a quick, rude alignment is performed at low resolution. With the resulting images overlaps, a second round of alignment process is done at the selected final accuracy.
In the **Reference** option, from the geolocation of the photos (extracted from the EXIF metadata), the overlaps are predicted. The alignment step only is done with photos that overlap. In this practice, we´ll use the Generic option.

Key point limit and Tie point limit
These options limit the number of tie points used per photo. The more points the better accuracy, but the processing time will grow exponentially. The default values work well in most projects.

- Click **OK**.

Photo Alignment II

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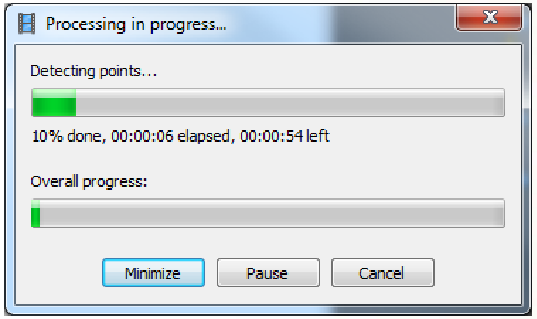
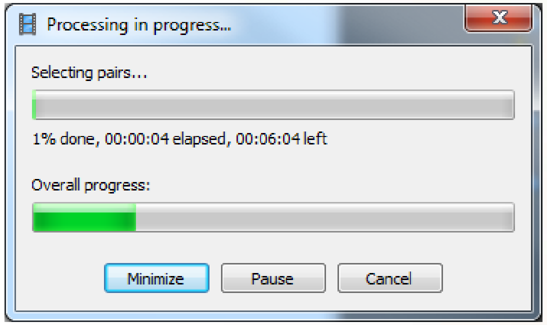
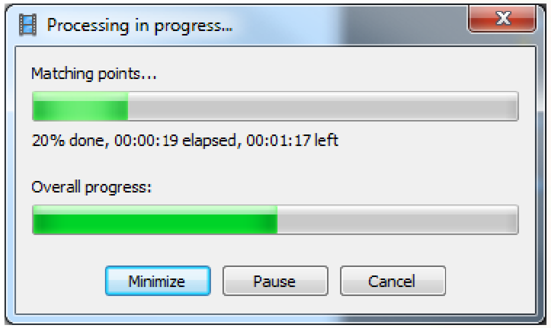
13. The alignment process is the most sophisticated piece of software in Photoscan. The algorithms behind the Alignment are recent (4-5 years) and represent the real revolution in low altitude photogrammetry.



The algorithm begins by searching "Spots" or "Local Features" or simply "Points". These "Local Features" are points in the photo that can be described with attributes based on its environment, so that those same points can be found in other photos taken from other points of view. After analyzed the entire photo, 40000 local features with best descriptors are selected.



Next Step is selecting pairs with overlaps at low resolution. Only if generic option Is selected in pair preselection.



With the pairs pre-selected, the software look for homologous local features in different photos, at the selected accuracy.

Photo Alignment III

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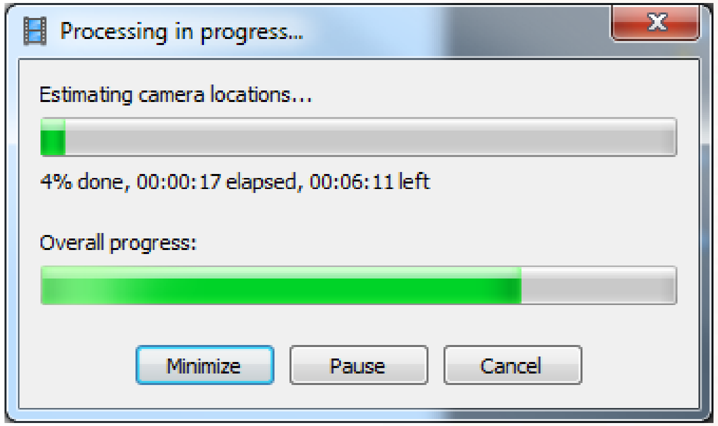
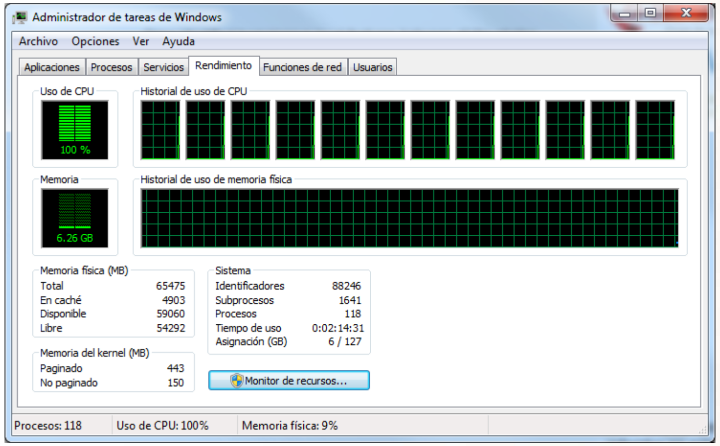


Once identified homologous local features between all the photos, the proper orientation step is performed. In this step, the position (X,Y,Z) and the orientation (3 angles) of every photo is calculated. Also, the internal geometry of the camera is refined (Autocalibration), obtaining the distortion camera parameters.



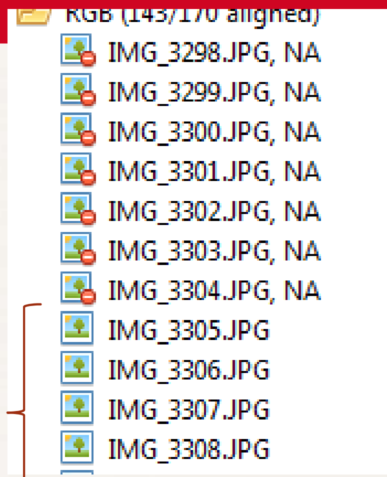
You will note that your processor is working at full power all the time. If you are working with a laptop be careful in future projects: they are not designed to work many hours at 100% processor power.

Alignment is a long time processing step. It can last 30-90 minutes. If you don´t want to wait, you can jump this step by loading the SanClemente01.psx project.

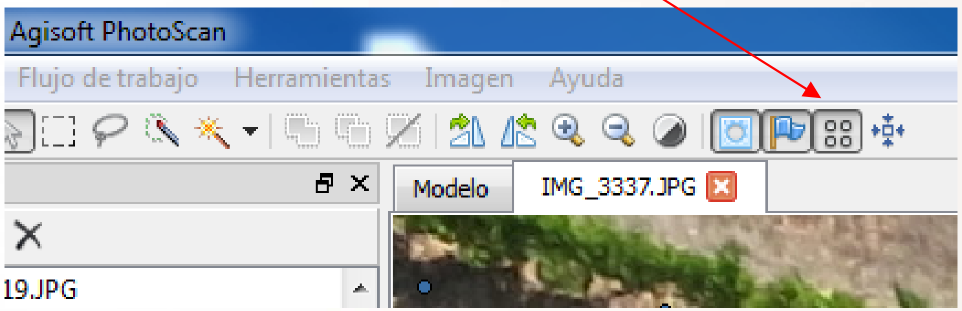
Photo Alignment II

After the Alignment step is finished, it is possible to view the local features.

14. In the workspace, double click on an Aligned Photo



Activate the local features point view.



You will see white and blue circles. All are local features. The Blue circles have homologous local features in other photos. The white not.

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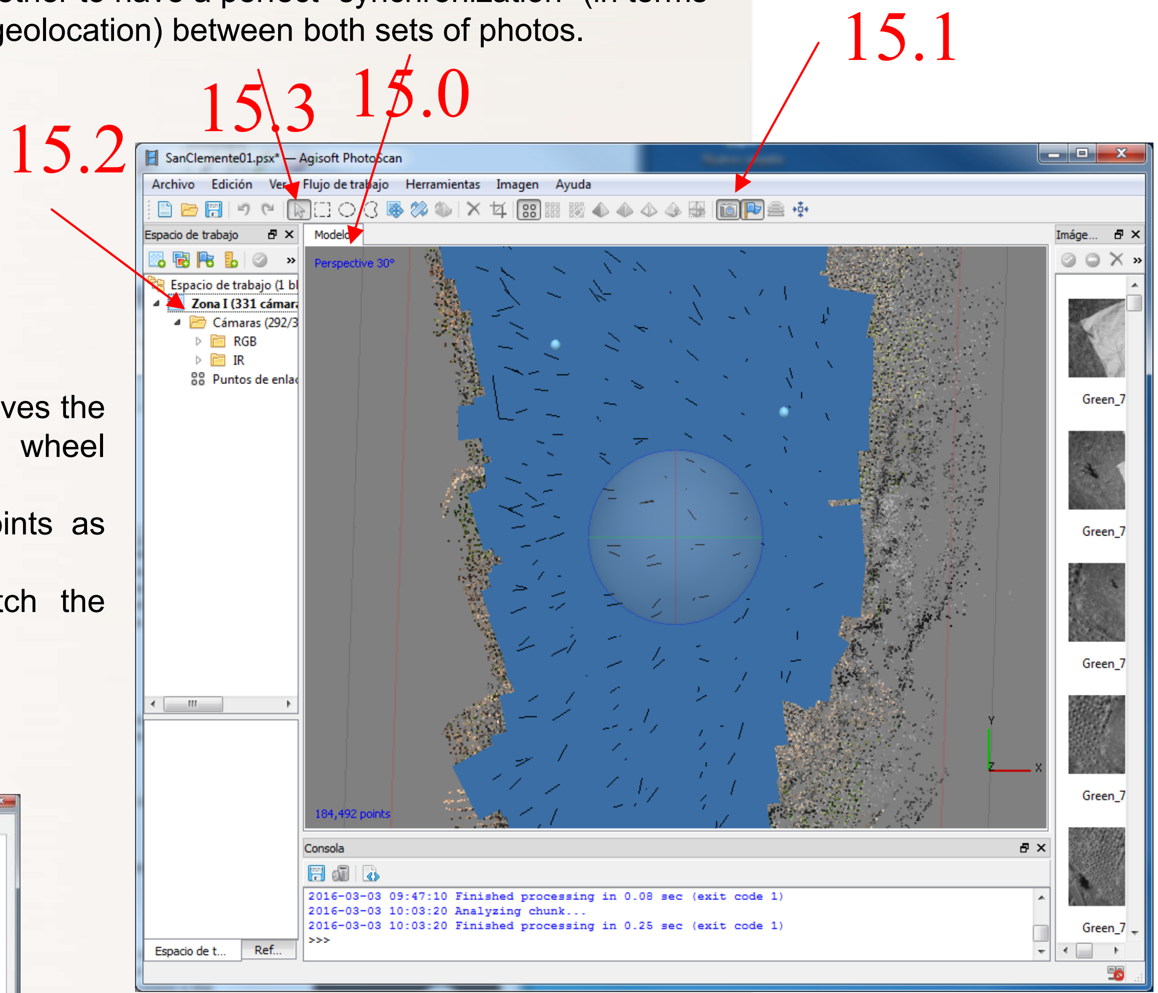
Photo Alignment IV

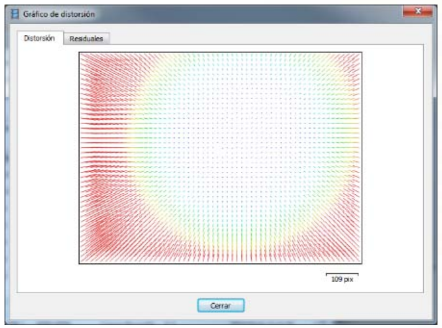
15. Close the photo tab or click in the Model Tab (15.0). An aerial view of the tie point cloud and oriented cameras is displayed.
- 15.1 Try the *Show / hide cameras* command.
- 15.2 Show statistic of the Zone_1: Right Click on Zone_1 → Show Information. Answer the next questions:

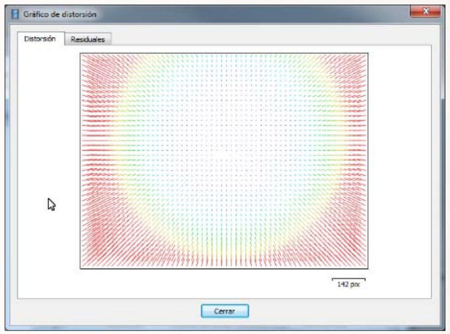
• Total # of photos: ___________
• Total # of aligned photos: ___________
• # points in the tie point cloud: _________
• Processing Time: ___________
• RMS: __________

Note. Colors of the tie point cloud are strange because RGB photos are mixed with NIR photos. Later we´ll split them. Now, we need to process them together to have a perfect “synchronization” (in terms of geolocation) between both sets of photos.



- 15.3 Rotate and move the model. Keeping the left button moves the model. Keeping Right button rotate the model. With the wheel changes the scale.
- 15.4 Open multiple RGB and IR images. Display the points as explained in paragraph 13.
- 15.4 Display the new plots of camera distortions. Watch the numerical values of distortion model.





Precise Georeferencing I

15.b) The 3D model is geo-referenced with the EXIF data from the RGB camera. To view the coordinates of the photos is necessary to go to the Reference Pane. Here, a new list with the photos is showed. Enlarge the panel. Look for RGB photos (starting with IMG_). In the second column appear Longitude, Latitude, Altitude, Accuracy and Error.

Note that errors are around 5 to 20 meters. The RMS average error is showed at the end and is about 10 meters. This error is unacceptable for almost any project. This is normal when using autonomous L1 geolocation GPS from camera or from UAV.

Referencia

Cámaras	Longitud	Latitud	Altitud (m)	Precisión (m)	Error (m)	Yaw
IMG_3440.JPG	-6.754228	42.626951	660.940000	10.000000	2.957924	
IMG_3441.JPG	-6.754274	42.626970	659.860000	10.000000	4.201102	
IMG_3442.JPG	-6.754266	42.626996	658.560000	10.000000	6.201943	
IMG_3443.JPG	-6.754250	42.627001	656.910000	10.000000	8.578326	
IMG_3444.JPG	-6.754230	42.626978	655.810000	10.000000	10.914881	
IMG_3445.JPG	-6.754192	42.626970	654.110000	10.000000	14.357149	
IMG_3446.JPG	-6.754149	42.626961	652.770000	10.000000	18.601305	
IMG_3447.JPG	-6.754042	42.626974	648.840000	10.000000	17.673445	
IMG_3448.JPG	-6.753977	42.627002	644.980000	10.000000	18.850862	
IMG_3449.JPG	-6.753913	42.627027	642.580000	10.000000	22.005892	
IMG_3450.JPG	-6.753781	42.627089	636.750000	10.000000		
IMG_3451.JPG	-6.753658	42.627159	631.980000	10.000000		
IMG_3452.JPG	-6.753527	42.627232	629.000000	10.000000		
IMG_3453.JPG	-6.753434	42.627288	626.740000	10.000000		
IMG_3454.JPG	-6.753413	42.627303	625.450000	10.000000		
IMG_3455.JPG	-6.753423	42.627309	624.280000	10.000000		
IMG_3456.JPG	-6.753427	42.627313	621.840000	10.000000		
IMG_3457.JPG	-6.753427	42.627318	619.620000	10.000000		
IMG_3458.JPG	-6.753428	42.627307	618.170000	10.000000		
IMG_3459.JPG	-6.753427	42.627288	617.430000	10.000000		
IMG_3460.JPG	-6.753429	42.627279	616.210000	10.000000		
IMG_3461.JPG	-6.753418	42.627291	614.110000	10.000000		
IMG_3462.JPG	-6.753419	42.627306	612.650000	10.000000		
IMG_3463.JPG	-6.753407	42.627304	610.940000	10.000000		
IMG_3464.JPG	-6.753400	42.627300	608.880000	10.000000		
IMG_3465.JPG	-6.753407	42.627303	608.070000	10.000000		
IMG_3466.JPG	-6.753415	42.627297	606.920000	10.000000		
IMG_3467.JPG	-6.753426	42.627305	607.130000	10.000000		
Error total					**10.625536**	

Marcadores | Longitud | Latitud | Altitud (m) | Precisión (m) | Error (m) | Proyecciones | Er

Precise Georeferencing II

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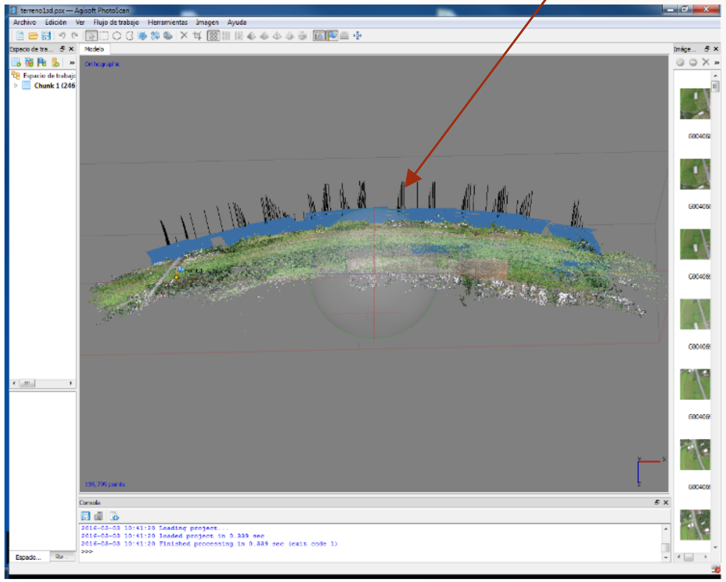
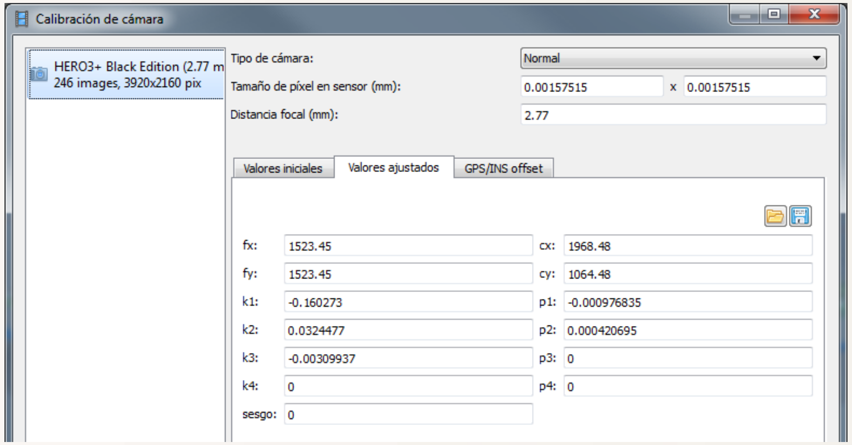
UNIT 3. Digital mapping using high spatial resolution remote sensors (UAVs)

16. As explained before the resulting model is roughly geo-referenced through the low precision camera GPS information. But even if the GPS would be very high precision (including RTK systems) and perfectly synchronized with camera, ALL 3D MODELS ARE CURVED. This occurs because of the geographical position of the camera is only used by Photoscan to make a simple similarity transformation: A change of scale, three rotations and three translations. The information of the geolocation of the photos is not used by Photoscan to autocalibrate the camera. As a consecuence, ALL 3D RECONSTRUCTED MODELS WILL BE DEFORMED (even if you do not notice) .



In this other project, you can notice the curved model!



The only way to ensure good geometrical reconstruction of the terrain, is

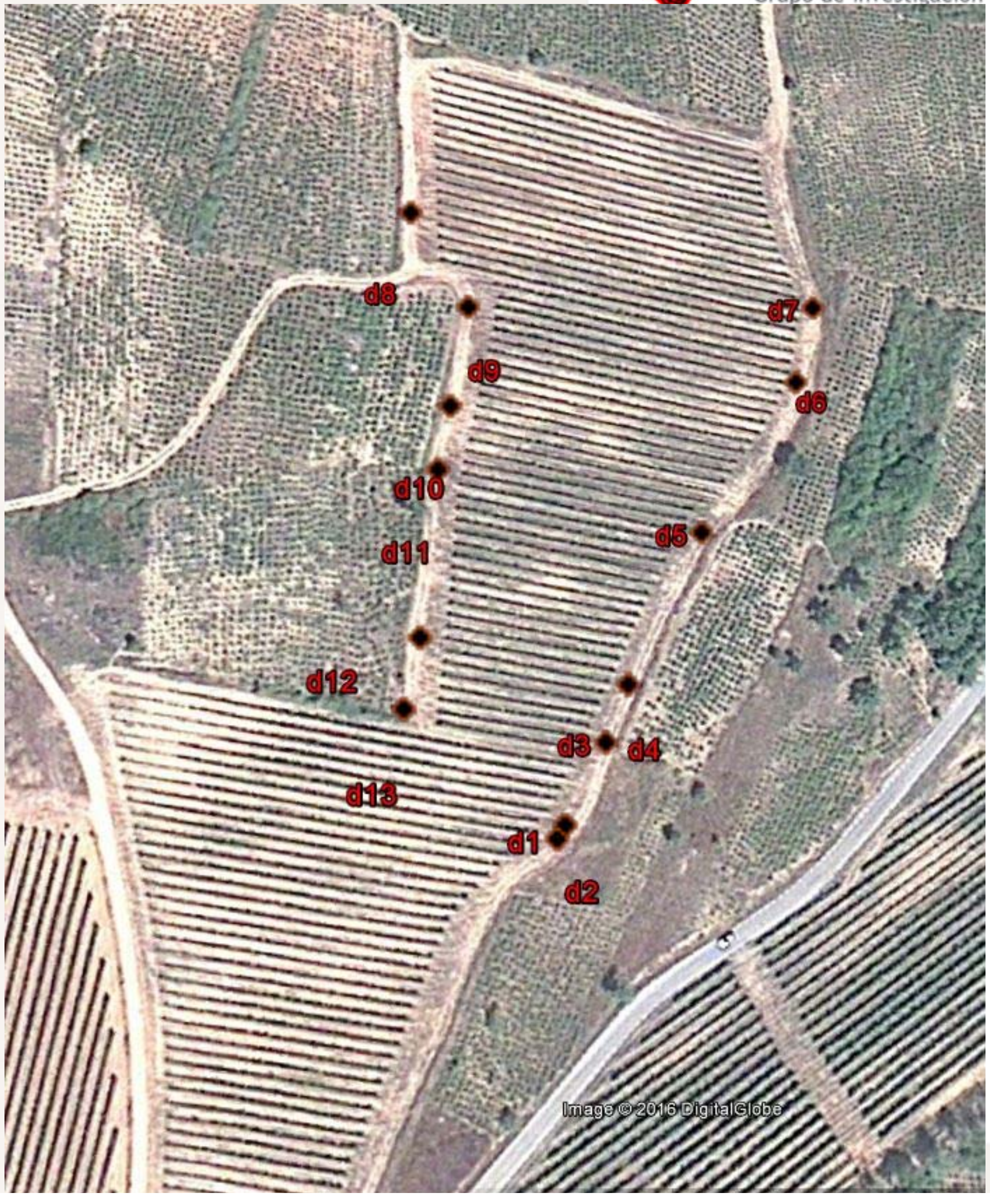
- **Using pre-calibrated camera and preserving the geometry of the camera before and during the flight. (Something difficult in compact cameras)**
- **By using Ground Control Points,** with accurate coordinates.

Precise Georeferencing IV

Note. If you need to start the project here open the file SanClemente01.psx

17. All around the vineyard, circular targets of 80cm diameter were located before the flight. The precise coordinates of the center of all targets were taken with a dual-frequency GNSS survey-grade Leica GS08Plus. These coordinates are in a text file called *SanClemente_GCP.txt* that should be in your SanClemente folder. There is also a KMZ file (open with Google Earth) where you can check the approximate location of the points.

- Open and analyze the SanClemente_Apoyo.txt file with Notepad.exe
- (Optional). Open the KMZ with Google Earth.



Precise Georeferencing V

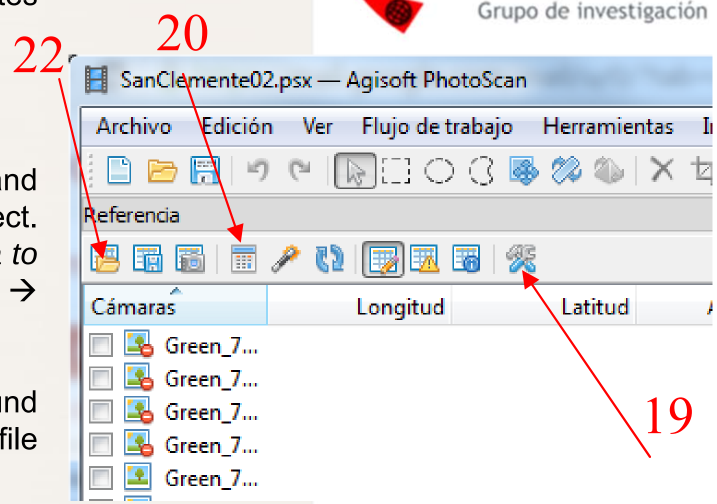
Note. If you need to start the project here open the file SanClemente01.psx

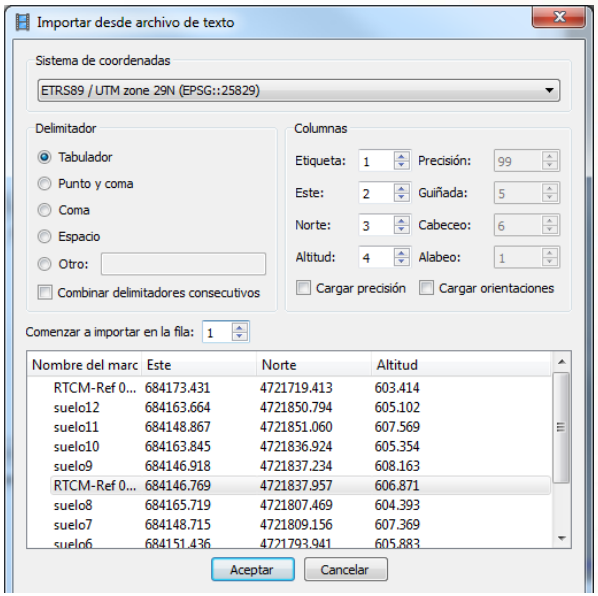
18. Go to the Reference Pane. Enlarge the panel until all columns of the central markers area are showed. On the top area, the imported (from EXIF) photo locations are showed. These coordinates are in WGS84.

19. Click on the **Change Reference Settings** (19). Select WGS84(EPSG::4326). → OK.

20 y 21. Coordinates of GCP in *SanClemente_Apoyo.txt* are in other reference system: ETRS89 and they are projected on the zone 29N. This is the reference system that we want to use in the project. It is necessary to change the current (WGS84) reference system. *Click on Convert reference data to another coordinate system* (20) → …***more*** → **Filter** by 25829 → Select *ETRS89/UTM zone 29N*. → OK.→ OK. Note the new coordinates of photos; they are now projected.

22. Once the reference system is correctly stablished, we will proceed to import the GCP (Ground Control Points) coordinates. Click on 22 (Import reference data from file) and select the file *SanClemente_GCP.txt*.





23. Use Tab as delimiter, Column 1 as Tag, column 2 as Easting, column 3 as Northing and 4th as Altitude.

- There will be a warning, because the points are not yet created. Click Yes to All to create all the GCPs.
- Clear points beginning with RTCM. These points are not GCP. It are virtual reference stations created during the RTK survey. **(Right Button → Delete markers → Yes)**
- Points tagged as “suelox” are soil sampling points. Don´t delete these.

Precise Georeferencing VI

"MEASURING" PHOTOS

To give precise coordinates to the 3D model it is necessary to "constrain" the 3D model with points in the ground that have known coordinates. These points are called Ground Control Points. The best way to locate GCPs in the 3D model is through photos.

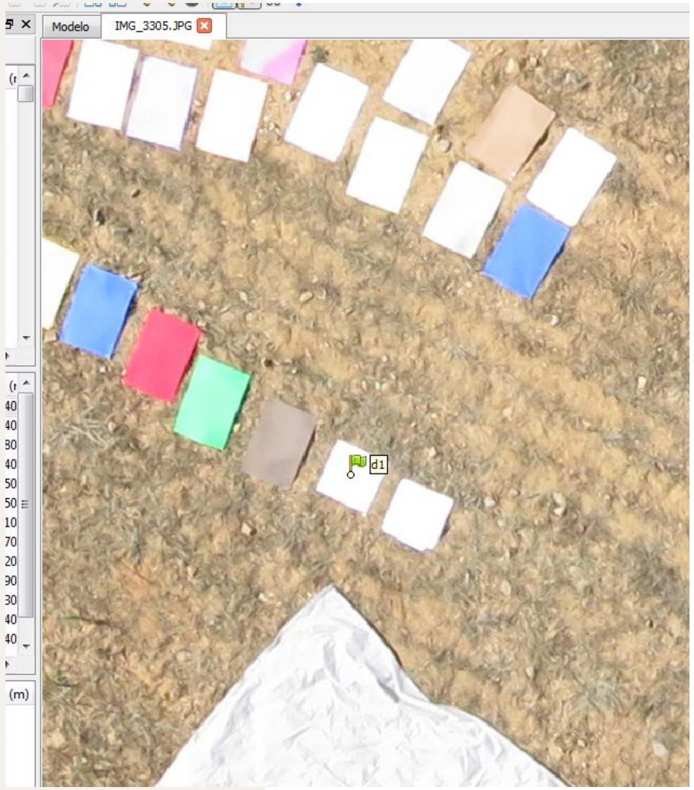
24. Open the photo IMG_3305.JPG. Zoom in on the white square target image.
Right Button→ Place marker→ d1

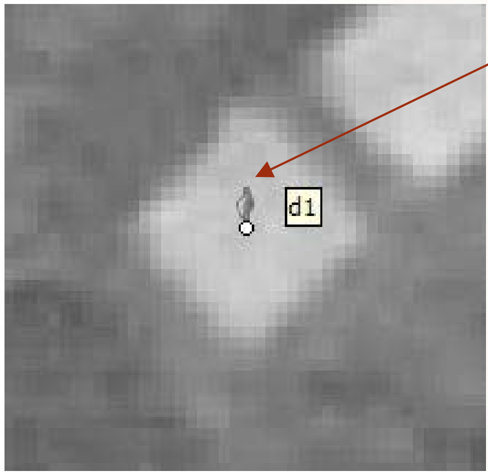
25. Improve the location of the target holding the point with the mouse.

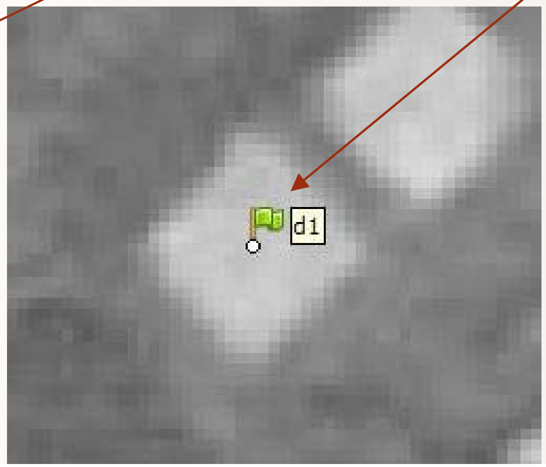
26. Repeat 24 y 25 over IMG_3307.JPG.

27. With two "measured" photos, the 3D GCP is totally defined. The software can reproject this 3D point in all the photos in which this target (d1) appear: To do Right clic→ Filter photos by markers.

- The right pane (Photos Pane) will show all the images in which the target d1 appear.
- Open the photo Green_754.jpg. Near the squared target there is a "fumarole". This is the reprojection of the point to the photo. It is necessary to "measure" the point. Hold the point with the mouse and center it in the square target. Now, it is measured, and a green flag appear.







Precise Georeferencing VII

UNIT 3. Digital mapping using high spatial resolution remote sensors (UAVs)

- Proceed in the same way with all the images in the image panel. Note. If the point can not be well measured it is better not measure; not use that photo. For example photo 3331.

Second Point: d8

28. In the upper panel of Reference, open the photo IMG_3321.JPG. The circular target in the photo is the marker d8; assign it. Repeat with the photo IMG_3333.JPG.

Repeat the paragraph 27 with the d8 marker.

Third Point: d7

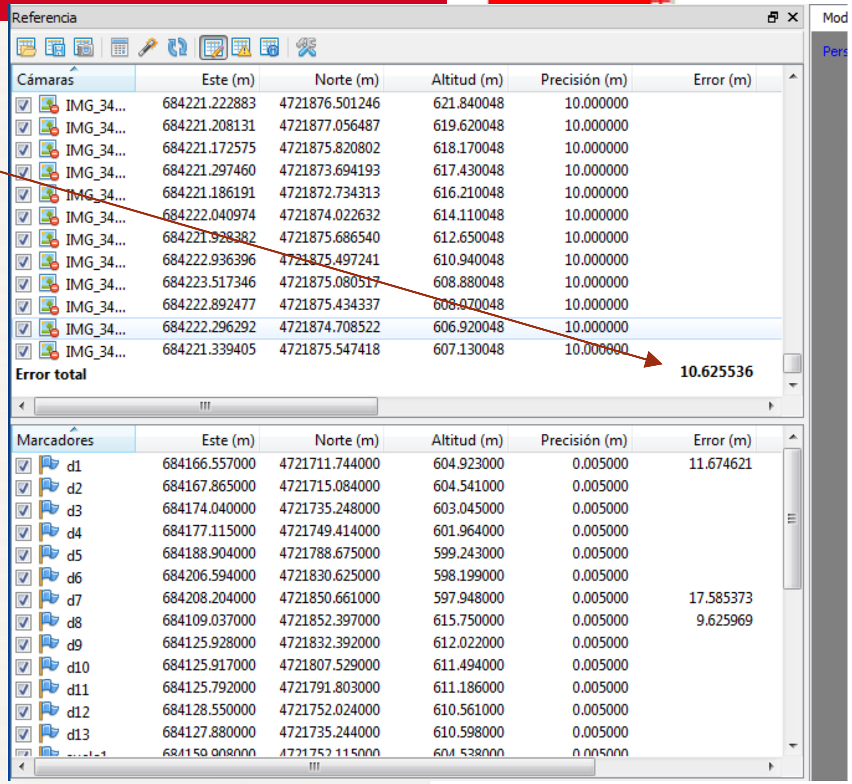
29. In the upper panel of Reference, open the photo IMG_3427.JPG. The circular target in the photo is the marker d7. Assign. Repeat with img_0834.jpg.

Repeat the paragraph 27 with the d7 marker.

Precise Georeferencing VIII

Recalculating Georeferencing Parameters

30. Go to Reference Pane and display the RMS Total Error in the location of the photos and targets, as shown in the figure:



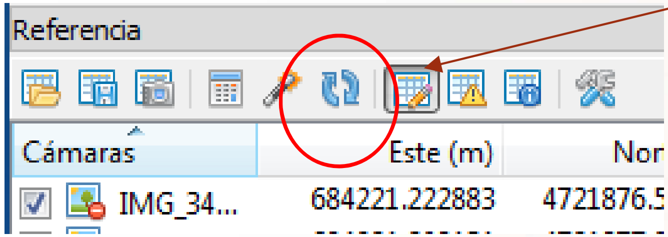
Referencia

Cámaras	Este (m)	Norte (m)	Altitud (m)	Precisión (m)	Error (m)
IMG_34...	684221.222883	4721876.501246	621.840048	10.000000	
IMG_34...	684221.208131	4721877.056487	619.620048	10.000000	
IMG_34...	684221.172575	4721875.820802	618.170048	10.000000	
IMG_34...	684221.297460	4721873.694193	617.430048	10.000000	
IMG_34...	684221.186191	4721872.734313	616.210048	10.000000	
IMG_34...	684222.040974	4721874.022632	614.110048	10.000000	
IMG_34...	684221.928382	4721875.686540	612.650048	10.000000	
IMG_34...	684222.936396	4721875.497241	610.940048	10.000000	
IMG_34...	684223.517346	4721875.080517	608.880048	10.000000	
IMG_34...	684222.892477	4721875.434337	608.070048	10.000000	
IMG_34...	684222.296292	4721874.708522	606.920048	10.000000	
IMG_34...	684221.339405	4721875.547418	607.130048	10.000000	
Error total					**10.625536**

Marcadores	Este (m)	Norte (m)	Altitud (m)	Precisión (m)	Error (m)
d1	684166.557000	4721711.744000	604.923000	0.005000	11.674621
d2	684167.865000	4721715.084000	604.541000	0.005000	
d3	684174.040000	4721735.248000	603.045000	0.005000	
d4	684177.115000	4721749.414000	601.964000	0.005000	
d5	684188.904000	4721788.675000	599.243000	0.005000	
d6	684206.594000	4721830.625000	598.199000	0.005000	
d7	684208.204000	4721850.661000	597.948000	0.005000	17.585373
d8	684109.037000	4721852.397000	615.750000	0.005000	9.625969
d9	684125.928000	4721832.392000	612.022000	0.005000	
d10	684125.917000	4721807.529000	611.494000	0.005000	
d11	684125.792000	4721791.803000	611.186000	0.005000	
d12	684128.550000	4721752.024000	610.561000	0.005000	
d13	684127.880000	4721735.244000	610.598000	0.005000	

Note that errors in targets are approximately 10.6, 17.6 and 9.6 meters. These errors are the differences between the true coordinates of the target and that calculated from the 3D model, which so far, is only georeferenced using the EXIF coordinates of the photos.

31. Let´s update the model georeferencing by using the 3 GCPs measured. Click the command "*Recalculate georeferencing parameters*".



Note how errors in targets d1, d8 and d7 are reduced, while grow in photos. Now, Photoscan only consider control points geolocation to georeferencing the model.

Now, the georeferencing of the project is defined with 3 points; the model has been adjusted to these 3 points and therefore errors on these GCP are very small; around millimeters. This does not mean that the model has an accuracy or precision of millimeters or even centimeters; we are simply using very few points. To get a better idea of the model accuracy is necessary to use more GCP.

Other Points

32. Once 3 GCP are measured, the 3D model it is completely georeferenced (3 GCP are the minimum number). The next step is to repeat paragraph 27 for all the remaining control points. Recalculate the georeferencing parameters and observe errors while adding more GCP. On d2 right click → Filter by markers. On the Photos Pane open each photo and measure the GCP.

Note1. The d2 target was moved by the wind, so it is better not to use it. Skip to d3

Note2. Before pass to the next slide it is necessary to measure all of GCP. This is a time consuming task!

If you don´t have enough time, open the SanClemente02.psx project and continue with the next slide.

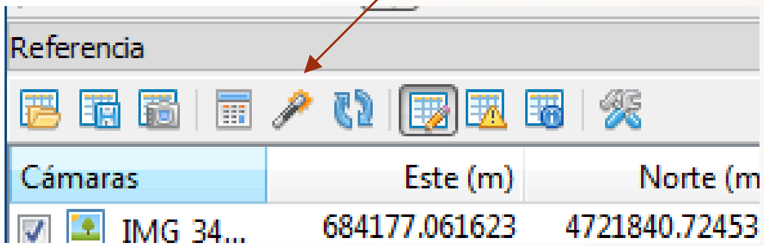
Precise Georeferencing IX

33. Once you measure all GCP in all photos you´ll obtain similar results to these:

	Enoc	Your result
- RMS error on photos:	14,3m	______________
- RMS Error in GCPs:	2,2cm	______________
- Worst GCP:	3,6cm.	______________

34. It is possible to improve the 3D model by using the measured GCPs. That really will be improved, will be the calibration of the camera. Let´s use the measured GCP to refine the geometric camera model. With this new camera model, a new position and orientation of the photos will be done. We´ll get new residuals and errors.

To Refine the camera model, we are going to **Optimize camera parameters and point coordinates**.



Referencia

Cámaras	Este (m)	Norte (m)	Altitud (m)	Precisión (m)	Error (m)	Yaw (deg)	Pitch (deg)
IMG_34...	684177.061623	4721840.724535	644.980048	10.000000	27.670374		
IMG_33...	684151.695312	4721787.327449	635.040048	10.000000	30.245531		
IMG_33...	684145.580370	4721797.845552	637.160048	10.000000	30.430388		
IMG_34...	684182.272646	4721843.641113	642.580048	10.000000	30.784749		
IMG_33...	684197.874079	4721731.725075	0.000048	10.000000	636.530024		
IMG_33...	684194.600212	4721723.674040	0.000048	10.000000	642.323379		
IMG_33...	684193.671986	4721723.433305	0.000048	10.000000	645.087932		
IMG_33...	684184.060981	4721721.387646	0.000048	10.000000	648.935307		
IMG_33...	684174.040329	4721734.765364	0.000048	10.000000	651.332029		
IMG_33...	684168.596887	4721743.171360	0.000048	10.000000	651.619371		
IMG_33...	684156.586740	4721776.529908	0.000048	10.000000	653.635547		
IMG_33...	684165.076827	4721764.130179	0.000048	10.000000	653.810279		
Error total					**14.280470**		

Marcadores	Este (m)	Norte (m)	Altitud (m)	Precisión (m)	Error (m)	Proyecciones	Error (pix)
d1	684166.557000	4721711.744000	604.923000	0.005000	0.028341	59	0.637
d2	684167.865000	4721715.084000	604.541000	0.005000	0.011729	1	0.000
d3	684174.040000	4721735.248000	603.045000	0.005000	0.018259	66	0.574
d4	684177.115000	4721749.414000	601.964000	0.005000	0.032696	63	0.585
d5	684188.904000	4721788.675000	599.243000	0.005000	0.028470	50	0.664
d6	684206.594000	4721830.625000	598.199000	0.005000	0.023356	35	0.701
d7	684208.204000	4721850.661000	597.948000	0.005000	0.019257	35	0.581
d8	684109.037000	4721852.397000	615.750000	0.005000	0.013397	23	0.862
d9	684125.928000	4721832.392000	612.022000	0.005000	0.005802	33	0.626
d10	684125.917000	4721807.529000	611.494000	0.005000	0.015737	41	0.397
d11	684125.792000	4721791.803000	611.186000	0.005000	0.011271	36	0.652
d12	684128.550000	4721752.024000	610.561000	0.005000	0.019903	28	0.447
d13	684127.880000	4721735.244000	610.598000	0.005000	0.035948	37	0.999
suelo1	684159.908000	4721752.115000	604.538000	0.005000		0	0.000
suelo2	684142.986000	4721752.744000	607.576000	0.005000		0	0.000
suelo3	684144.111000	4721766.448000	607.716000	0.005000		0	0.000
suelo4	684160.013000	4721765.939000	604.436000	0.005000		0	0.000
suelo5	684167.155000	4721794.424000	603.228000	0.005000		0	0.000
suelo6	684151.436000	4721793.941000	605.883000	0.005000		0	0.000
suelo7	684148.715000	4721809.156000	607.369000	0.005000		0	0.000
suelo8	684165.719000	4721807.469000	604.393000	0.005000		0	0.000
suelo9	684146.918000	4721837.234000	608.163000	0.005000		0	0.000
suelo10	684163.845000	4721836.924000	605.354000	0.005000		0	0.000
suelo11	684148.867000	4721851.060000	607.569000	0.005000		0	0.000
suelo12	684163.664000	4721850.794000	605.102000	0.005000		0	0.000
Error total					**0.022095**		**0.647**

Precise Georeferencing X

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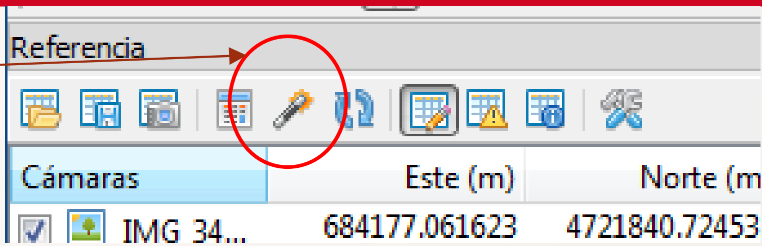
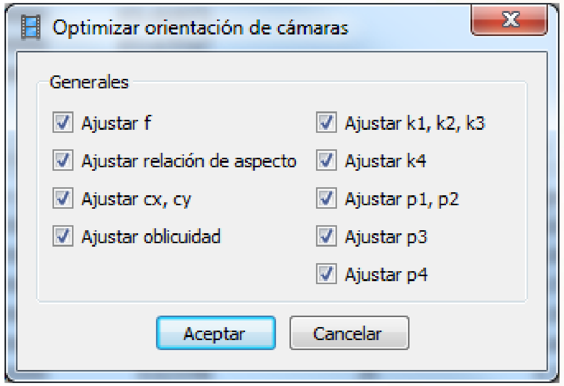
35. Click the command 35, at the reference panel.





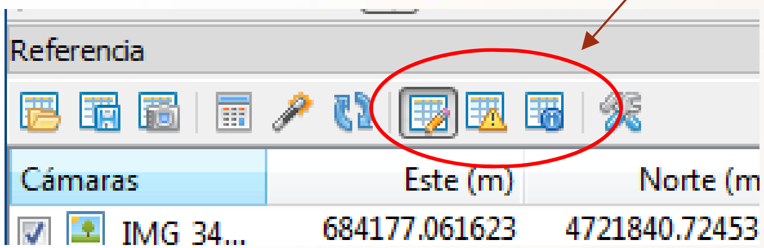
36. In the dialog box check all the boxes. With this we will give camera modeling all possible flexibility. This can only be done if the coordinates of the control points are very reliable. Otherwise we worsen the 3D model.

00		0	0.000
00		0	0.000
00	0.007581	1	0.000
00	0.009330	33	0.244
00	0.011523	23	0.235
00	0.013074	36	0.279
00	0.015790	41	0.226
00	0.019298	50	0.220
00	0.019695	28	0.284
00	0.020558	35	0.165
00	0.020629	66	0.315
00	0.022591	35	0.215
00	0.025181	59	0.241
00	0.027351	37	0.341
00	0.029469	63	0.270
	0.019743		**0.260**

37. Once the camera is refined accuracy project improve to 1,97cm. Write your results.

- New RMS error on photos: _______________
- New RMS Error in GCPs: _______________
- New Worst GCP: _______________

38. **Source values, error values and estimated values**. In the Reference Pane it is possible to display the original coordinates (measured on the ground with the topographic GPS or measured by the camera GPS), the coordinates calculated by the 3D model and the difference between them, which is the accuracy.



39. **Projections.** One of the columns in the Reference Pane (marker zone) is Projections. Projections are the number of measured photos in a GCP. The higher the number of projections the greater reliability of that GCP.

Marcadores	Precisión (m)	Proyecciones	Error (pix)
d3	0.005000	66	0.313
d4	0.005000	63	0.270
d1	0.005000	59	0.240
d5	0.005000	50	0.219
d10	0.005000	41	0.226
d13	0.005000	37	0.339

Precise Georeferencing XI

IMPROVEMENT AND REVIEW OF GCPs MEASURES IN THE PHOTOS. **THIS IS AN OPTIONAL TASK**

When the photos are "measured“, we may have made a mistake. Even without having committed any gross error, it is possible that some photomarks be "improvabled". To try to locate the worst marks, it is necessary to have a look at the Error column (pix) on the Reference Pane. In this column we have the RMS values of all marks for every GCP, and the RMS for all of the GCP.

Write your results:

RMS Global Error (pix): _________

Worst Error (pix): ___________

Marcadores	Precisión (m)	Proyecciones	Error (pix)
d3	0.005000	66	0.313
d4	0.005000	63	0.270
d1	0.005000	59	0.240
d5	0.005000	50	0.219
d10	0.005000	41	0.226
d13	0.005000	37	0.339
d11	0.005000	36	0.276

Let´s try to improve the photomarks.

40. Short the column from highest to lowest. On the worst GCP error Click with Right Button→ Show Info. A new table with alL photos containing this GCP will appear. Order the column value from highest to lowest. Write in a paper or memorize the 3-4 worst photos and their GCP.

- Go to the photo list at the Workspace Pane. Open the photos and review or try to improve the marks.

- Repeat the process with the other GCPs.

Quality Control

41. The 3D model accuracy is the difference between the calculated 3D coordinates (from the intersection of the rays) and the true coordinates (measured with the surveying grade GNSS receptor). However; GCPs have been used to refine the calibration of the camera and therefore to recalculate the model too. As a consequence, measuring accuracy at these points is not entirely independent.
To get an objective measure of accuracy it´s necessary to introduce the use of **Check Points**. These points are points which coordinates are known but not used in the recalculation of the model or the refinement of the camera.

Let´s use Check Points:

- To use the target d1 as checkpoint, in the Reference Pane uncheck d1 marker, then, recalculate the model according with paragraph 35.
- Write the resulting d1 error in the first row of the table.
- Repeat the procedure with every marker, enabling d1. Complete all the rows.
- **The accuracy of the project will be the worst value in this table.**

Check Point ID	Error (m)
d1	
d2	
d3	
d4	
d5	
d6	
d7	
d8	
d9	
d10	
d11	
d12	
d13	