simactive

TRAINING MATERIAL

HOW TO OPTIMIZE ACCURACY WITH CORRELATOR3D
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1. UNDERSTANDING INPUT DATA REQUIREMENTS

1.1 What is Aerial Triangulation?

The objective of aerial triangulation (AT) is to refine the camera positions / orientations and calibrate the sensor, when required. It consists of a very important step that has critical influence on all subsequent results. As such, AT is usually the first step after creating a project in Correlator3D. It can be done with or without the use of ground control points (GCP).

The AT process involves the following steps:

1. Tie Point Extraction
2. GCP Creation (if required)
3. Tie Point Editing (if required)
4. Bundle Adjustment
5. Quality Assessment

1.2 Recommended Flight Configuration

To achieve successful AT, the recommended flight configuration should be as follows:

1. Large / medium format cameras mounted on aircrafts: 60 % overlap and 30 % sidelong
2. Small format cameras mounted on drones: 70 % overlap and 50 % sidelong
For difficult scenes (e.g. dense forest or terrain with significant topographic variations), these recommended values should be further increased.

Overlap / sidelap values are key for tie point extraction during automatic feature matching. In the case of small format cameras, the overlap / sidelap values must be higher since these sensors are non-metric, uncalibrated and present severe lens distortion. The camera geometry is generally only recovered during bundle adjustment and therefore, a proper flight configuration is critical.

Although some applications (e.g. urban areas with tall buildings) require a gridded flight configuration, it is recommended to use parallel flight lines for processing in Correlator3D. As an added benefit, processing time will be reduced.

1.3 Data Requirements for Processing in Correlator3D

The required data for processing in Correlator3D include the geotags of each image (i.e. exterior orientation), either in an ASCII file or as an EXIF header. The sensor focal length / pixel size are also mandatory, and for common cameras, will automatically be retrieved from Correlator3D’s database. As an option, camera lens distortion information can also be imported in the form of calibration parameters or lookup table.
Sample project in Correlator3D.
2. PREPARING DATASETS

2.1 Organizing Data

It is good practice to specify an input image folder located in the same location as the Correlator3D project. Note that during processing, Correlator3D will access the image folder, so it is important not to move the input images. Should both the project folder and the image folder moved to a new location, Correlator3D will be able to locate images in the new location, as long as it has the same path relative to the project.

It might be necessary to have the image folder on another drive or on a server. While this can be convenient for managing disk space or centralizing data, this can make it more difficult to recover a Correlator3D project from a backup. In that case, the relative path between the project and the image folder may not be the same once the data are restored later. If the software cannot automatically rebuild the project tree, the .c3d project file can be manually edited to modify the path name as the new location of the image folder.

2.2 Creating a New Project

Project creation is a simple procedure involving three steps:

1. Importing images and selecting the projection
2. Defining the camera parameters
3. Specifying the project folder location

While importing images, elevation units should be correctly specified. As an example, while the desired processing may be in state plane coordinates and feet, the input units generated by UAVs are in general in meters. In such a case, the elevation units must be defined in meters when the software will request to input exterior orientation parameters. Next, when the project projection is defined, the project units will need to be selected. The input geotag system and unit (e.g. lat / long, meters) will be converted into the project projection (e.g. state plane, feet).

For the camera parameters, the appropriate camera model should be selected. For UAV, the "Digital Polynomial" model should be chosen. For medium / large format sensors, the "Digital" model will be desired. For more information on the different camera models, please refer to the Appendix A of the User Manual.
2.3 File Structure of a Correlator3D Project

Once the project is created, new subfolders will be automatically created by the software in the folder "Correlator3D". These include the following:

- **AT**: relevant information on AT, including tie points and GCP coordinates
- **IEO**: different bundle steps with calibrated camera parameters, EO and quality reports
- **DEM**: elevation models produced
- **Ortho**: individual orthorectified images.
- **Mosaic**: files associated with the mosaic creation process and editing, as well as the mosaic itself

This file structure should be preserved. Note that it is possible to create different ortho and mosaic folders within the project tree to generate different versions of these outputs.
3. IMPORTING GCPs AND CHECKPOINTS

3.1 Ground Control Point vs Check Points

Ground control points (GCP) can be used to identify visible features on the images and to associate their corresponding 3D coordinates. The GCPs will be used during the AT process for refining EO and camera calibration. The objective of using GCPs is to obtain a higher absolute accuracy.

A ground control point will contribute and influence the bundle adjustment calculations, while a check point is used independently against the resulting solution without affecting it. Check points are ultimately used to assess the accuracy of the AT result. Because they are independent from the solution, check points provide an objective assessment of accuracy.

3.2 Importing and Adding GCPs or Checkpoints

To import GCPs, the GCP import tool of the AT module should be used to select an input file (ASCII format). The correct variables should be assigned during the import process based on how the file content is formatted. The 'Type' option can be used to determine if points are check points or ground control points. The point's projection can also be specified to be identical to the project, or to be in a geographic system.

Once imported, the point will be displayed in the left menu and can be modified using the 'Edit' icon from the GCP editing tool. All points must be measured, and these should be saved. The software will automatically perform a preliminary bundle adjustment to facilitate the manual measurement of points. Consequently, measuring GCPs in Correlator3D is highly efficient and intuitive. As soon as the cursor is moved to the point location for two images, the software will automatically move to this location on every other image.
3.3 Number of GCPs and Configuration

Five GCPs are recommended as a minimum for good results. Ideally, the points should be uniformly distributed and should be visible from multiple images. Points located along the project boundaries should be avoided, as they will be visible on only one or two images. The exact number of required points and their distribution will depend on multiple factors, and is often dictated by the terrain accessibility. Ideally, a certain number of points would also be used as check points to assess the accuracy.
4. **ASSESSING AND EDITING TIE POINTS**

4.1 Validating Tie Point Extraction Results

The tie point extraction process is highly automated to minimize human interaction. Upon completion of tie point extraction, the user should validate that all images are tied to one another. If an image is untied, the AT schema will display it as a blue dot. Individual point reviews or mismatches should not be required; the software uses different iterations and a high number of points to establish redundancy in the solution, automatically deleting the bad points by finding them statistically.

4.2 Managing Images Without Tie Points

For challenging project areas (dense forest, large body of water), there could remain some untied images (blue dots) after the automatic tie point extraction. In such cases, the first step would be to run the tie point extraction again using the exhaustive option. This should help to extract more tie points. In cases where there are still untied images remaining, Correlator3D offers tools to manually add tie points between those images.

4.3 Manual Addition of Tie Points

To manually add a tie point, a link must be created between two images. If a link already exists, a right-click on the yellow line linking the two images will allow accessing the Tie Point Editing window. Using the mouse, a click on one image followed by a drag to the
same location on a different image will add a tie point. The zooming option can be used to refine the position of the point and specify its final location. Tie points, when manually measured, must be identified on each image with the best possible accuracy (at the pixel level).

Links between all images are unnecessary if neighbouring images are linked. Generally, all images should be at least tied together inside a given flight line, and flight lines should be tied together at the beginning and end of each line. Optionally, a block can be reinforced adding links between flight lines at five image intervals. Note that four to five well-distributed points per image link should be sufficient. When possible, points should be measured on more than two images (three and more) to create more robust links.

Automatically detected tie points.
5. SELECTING BUNDLE ADJUSTMENT PARAMETERS

5.1 Using Parameter Constraints

The AT module enables full control of the parameters used for bundle adjustment. For a typical UAV project, the parameters' adjustment should be set to “Unconstrained” for both the EO and the sensor. This will allow to converge to the best solution which minimizes the overall residual errors.

If a calibrated camera is being used, the sensor option should be set to “None”. In rare situations, constraining some of the EO parameters may help for bundle adjustment. As an example, if the input EOs are inaccurate, it could be difficult for the software to adjust the XYZ position without affecting rotation angles. In such cases, there is the option to turn off the attitude parameters (omega, phi, kappa), forcing a translation on the XYZ. An additional bundle adjustment iteration could then be performed to finetune the solution by selecting all parameters.

If highly accurate positions and attitudes are available, the Direct-Georeferencing option can be used, or a simple Boresight calibration can be performed.

![Bundle Adjustment dialog in Correlator3D.]

5.2 Working with GCP Uncertainty

Uncertainties can be used for each ground control point. The value entered should correspond to the accuracy of the measured location according to the source, equipment
and technique used when they were surveyed. For example, if the GCPs are coming from a highly accurate survey, values of 0.02 m in XY and 0.04 m in vertical could be used. If a point is being extracted from Google Earth, values in the range 2m in XY and 5m in vertical should be used instead.

According to the values specified for the point uncertainties, the software will allow itself to refine the point location to reach a better solution. The higher the uncertainties, the more the point location may be adjusted. If uncertainties of 5m are entered, the software is being informed that the real location of this point can be anywhere in a 5m radius from the input coordinates. When looking at the final residuals of the adjustment, the adjustment that was performed on the points' original locations should be considered, in addition to the error (information that is available on the left column of the GCP residuals report).

In general, values specified for the GCP uncertainties should make sense from a practical point of view. Note that if the uncertainty is set to 0, the software will take the GCP location as an absolute truth.

![Bundle Adjustment Parameters](image.png)

**GCP uncertainty values in Correlator3D.**

There is also an option for specifying the Pixel Radius. This value corresponds to the accuracy when visually identifying the point in the images (in pixel). In general, a value between 0 and 2 should be used. A value of 0 means the sampled image coordinates will be used without any further adjustment where a higher value will be used to refine the image location to converge to a better solution.
5.3 Impact of Different Constraint Settings on the Bundle Adjustment

Using different set of values and constraints for bundle adjustment will affect the final residuals, the calculated EO and the sensor calibration. If EO values are inaccurate and the solution is being heavily constrained, high residuals may result from a lack of flexibility in the adjustment. Alternatively, if high uncertainties are included on the GCP, the residuals will be very small, but the calculated point locations may end up far from the original coordinates of the GCPs. In such situations, if more realistic error residuals of the original coordinates are desired, the uncertainty values should be lowered.
6. CALIBRATING SENSORS

6.1 Sensor Calibration

The sensor used for image acquisition introduces geometric deformations into the imagery. To correct such deformations, a camera geometry needs to be used for modeling the physical characteristics of the sensor. Traditionally, large format metric cameras would be calibrated with controlled data and reports would be produced providing the physical parameters of the sensors (focal length, principal point, pixel size, distortion, etc.). Ultimately, the internal geometry of the camera is modeled into a set of parameters (known as interior orientation) used by the bundle adjustment equations.

In the case of UAV cameras, the smaller sensors used have a more unstable geometry and showing greater lens distortion. For this reason, they are considered non-metric cameras. Because of the instability of these small systems, the traditional process of calibration is less relevant. Correlator3D solves this problem by performing a self-calibration on a per-project basis.

6.2 Metric vs. Non-metric Cameras

In Correlator3D, a calibrated metric camera should be processed using the "Digital" distortion model, while a non-metric typical UAV camera must use the "Digital Polynomial" model. These model types are selected during step two of project creation. Both have different approaches of modeling the sensor geometry. Additional distortion coefficients are present in the case of the "Digital Polynomial" model. Appendix A of the user manual includes a complete description of the supported camera models.

Large format camera.
6.3 Self-calibration in Correlator3D

Correlator3D can solve the camera geometry during bundle adjustment using a process of self-calibration. To successfully solve the parameters of the distortion model, it is recommended to have at least two or three consecutive flight lines going in opposite directions.

Because some parameters of the interior orientation can correlate with other parameters of the exterior orientation, the resulting calibration will be highly dependent of a given project solution. As such, the calibration parameters should not be used as a permanent camera calibration. Self-calibration is recommended each time the bundle adjustment is run for a new project. In the case of a metric calibrated camera, the self-calibration does not require being re-run.
7. PERFORMING DIRECT GEOREFERENCING

7.1 What is Direct-georeferencing?

Direct-georeferencing is a method of photogrammetry to convert aerial imagery into precise ground coordinates without the use of ground control points. In the UAV market, it typically involves using an integrated GNSS-inertial system or RTK positioning during the acquisition. Correlator3D has an option during the bundle adjustment that will use a set of constraints assuming the input exterior orientation parameters are highly accurate. This option can be used to perform bundle adjustment on data coming from a direct-georeferencing system, or to do the self-calibration of the sensor if the internal geometry of the camera is not known in this context. A bundle adjustment with check points for QC / QA of the direct-georeferencing input can also be chosen. Note that if this option is used with inaccurate EO (or incorrectly post-processed EO data), the bundle adjustment may lead to bad results and high residuals.
8. MANAGING MULTIPLE BUNDLE ITERATIONS

8.1 Bundle Iterations

Correlator3D allows successive iterations (steps) of bundle adjustments to be performed. Each iteration uses the previous one as a starting point. These steps appear in the project tree on the left menu in the AT module. At any time, a step can be displayed by opening / closing the steps using the project tree. It is also possible to delete a step and come back to the previous solution. Each time the bundle adjustment is run, a new step will be automatically created after the previous one.

Multiple bundle iterations in Correlator3D.

8.2 Risks of Performing Multiple Iterations

When running a new iteration of bundle adjustment, the initial parameters used for the calculations are the ones from the previous step, not the original parameters provided at the project creation. In situations where the bundle adjustment is problematic, running successive iterations may cause the solution to drift and never to converge to a good solution. For this reason, it is recommended to always delete a problematic iteration of the bundle adjustment (by deleting the corresponding step) and starting the adjustment from the initial set of parameters (initial step). Running multiple steps should only be done intentionally in specific circumstances. For example, running a first bundle adjustment without the GCPs for easier tagging, and then performing another iteration including them.
8.3 Data and File Structure to Validate Parameters

Each time a step of the bundle adjustment is run, a new folder is created in the IEO folder of the Correlator3D project. This folder will be named identically to the associated step (Step_1, Step_2, Step_x, etc.) and will contain the different AT reports of said iteration. The folder will also contain a file named Step_x.ieo. This file contains all the calculated EO and camera parameters from the bundle adjustment. It is an XML file that can be opened with a simple text editor, and it can be useful to verify its content. For example, if the wrong focal length is specified at the project creation, it is possible to open and edit the initial.ieo file to change the focal length value directly in this file, without creating a new project.
9. UNDERSTANDING AT RESULTS AND REPORTS

9.1 Interpreting Quality Reports

Correlator3D provides all the necessary reports to evaluate and assess the accuracy of the aerial triangulation. These reports are located in the folder /Step_x/Reports. It is essential to review these reports after the bundle adjustment, and before proceeding with the next steps of the processing. This ensures that the resulting AT meets the accuracy requirements of the project before generating the output mapping products.

9.2 Assessing Accuracy

Correlator3D generates different detailed reports in text format. Most have a self-descriptive file name to assist in understanding their content. Below is a review of the most important reports.

**ATSummary.txt** provides information on the general statistics of the AT result. It can be quickly consulted to find information on the tie point pixel error, the number of images without tie points, or min / max error of ground control points.

**ImageAdjustments.txt** details the extent of exterior orientation adjustment. It can be useful to detect any unusually high adjustments.

**CheckPointResiduals.txt** or **GCPResiduals.txt** details the residual error of ground control points or check points. It allows assessment of the absolute accuracy of adjustments, and the quality of the position of an object on the image compared to ground truth.

**TiePointResiduals.txt** details the pixel residual error of tie points. It allows the assessment of relative accuracy of the adjustment, and quality of the image bonding in the block.
10. EXPORTING ADJUSTED EO AND CAMERA INFORMATION

10.1 Exporting Parameters

When results of the bundle adjustment are satisfactory, the EO and camera parameters can be exported by using the export EO option from the File menu. A text file will be exported for each set of parameters (EO and camera separately). The function will always export the parameters corresponding to the last step of bundle adjustment.

10.2 Using the EO and Camera Information in Third-party Software

The exported EO can be used in third-party software as an input (e.g. stereo model georeferencing). However, it is important to use the same camera model that will be compatible with the parameters exported by Correlator3D. If the camera parameters are interpreted differently (or worse, not considered), this could create an offset in the resulting stereo models. It is recommended to use a third-party software that can directly import the Correlator3D project files without any ambiguity.

Evaluating the accuracy of Correlator3D in a third-party software is not necessarily a valid option if the importation and interpretation of parameters is not certain. Some software packages can read the C3D project files directly and have proven to be using these files properly. For a proper evaluation of Correlator3D accuracy, check points are recommended to be used against the output products generated in Correlator3D (i.e. DSM and mosaic).

Sample project in Correlator3D.
11. TROUBLESHOOTING CHALLENGING PROJECTS

11.1 Gross Error Detection

The concept of gross error detection is old in the photogrammetry field, but remains valid today. One common source of error in aerial triangulation often comes from gross errors in the input parameters used for bundle adjustment. When the aerial triangulation for a project completely fails or results in very high residuals, it is good practice to review and validate systematically potential sources of error. Problems in the AT are rarely due to the software itself.

Below are examples of common sources of error that should be considered when weak bundle adjustment solution occurs:

1. **Errors in the geotags which are not associated with the right images, or are simply wrong.**
   Once the project is created in C3D, two adjacent images can be opened on two different lines. If there is a problem with the geotags of the images, the overlap area of these images will not match. This can also be associated with a camera mount rotation incorrectly specified during project creation.

2. **Errors in the GPS coordinates of the GCPs.**
   Usually, GCPs should be loaded in a source of validation like Google Earth to validate their location.

3. **Mismatch in the ID of the GCPs and the identification of the point on the images (i.e. the point identified on the images is incorrect).**
   Typically, this will yield to very high residuals, yet the error can also be localised (cluster of red points on the resulting AT schema). One way to validate is to perform bundle adjustment without the GCPs. If the result is good, there may be an issue with the GCPs. Two or three GCPs should be added at a time until the outliers or mismatched points are identified. It is good practice to look at the GCP text file itself to see if it matches with what was tagged in the software.
4. **Error in the projection system or units selected.**
   When GCPs are imported, they will appear completely off with the project.

5. **Error in the camera parameters specified.**
   This issue can be harder to detect. Focal length and pixel size error will usually translate into vertical error and problem of scale.

### 11.2 Troubleshooting Large Projects

A large project can be difficult to troubleshoot because of longer processing times. In such situations, processing should be performed on smaller sections of the entire dataset in a new Correlator3D project. This will enable a quick run-through of the different steps and can also shed some light on the actual source of the problem. For example, if the small project succeeds, then the problem may be localised elsewhere. If the small project fails, it can be a sign that the issue is more global and could be, for example, related to the camera parameters, or a mistake in the elevation units selected. It is more efficient to quickly find the source of error with a subset, before applying the solution to the overall project.

*High residual errors.*