

CORRELATOR3D™

User Manual

Software Version 6.4

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1. Important Notes



This symbol indicates an important notice. Failing to follow the notice could lead to unexpected or incorrect results.



This symbol indicates a tip or helpful information. Following this advice will lead to better results and performance.

This manual uses the following abbreviations as summarized in Table 1:

DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
GSD	Ground Sampling Distance
LUT	Look-Up Table
EO	Exterior Orientation
GCP	Ground Control Points
RPC	Rational Polynomial Coefficient

Table 1: Abbreviations.

2. Overview

Correlator3D™ software is a patented end-to-end photogrammetry solution for the generation of high-quality geospatial data from satellite and aerial imagery, including UAVs. It builds on unique computer vision algorithms that significantly differ from traditional photogrammetry techniques. Powered by GPU technology and multi-core CPUs, Correlator3D™ ensures matchless processing power to support rapid production of large datasets.

Correlator3D™ consists of the following modules:

- **Aerial Triangulation:** exterior orientation correction and camera calibration
- **DSM Generation:** generation of digital surface models and point clouds
- **DTM Extraction:** extraction of digital terrain models
- **DEM Editing:** manual editing of DEMs
- **Orthorectification:** creation of orthophotos and true orthos
- **Mosaic Creation:** stitching orthophotos together creating a mosaic
- **Mosaic Editing:** manual editing of mosaic seamlines
- **Feature Extraction:** semi-automated collection of 3D features

The software also provides other tools including:

- **Automated Workflow:** automatic execution of Correlator3D™ workflow
- **GCP File Creation:** semi-automatic tool for creating and editing GCPs
- **NDVI Map Creation:** compute the normalized difference vegetation index
- **Change Detection:** identification of 3D changes
- **DEM Merging:** stitching of DEM patches
- **DEM Inspection:** generation of statistics about DEM quality
- **Point Cloud Colorization:** colorization of a point cloud using a mosaic

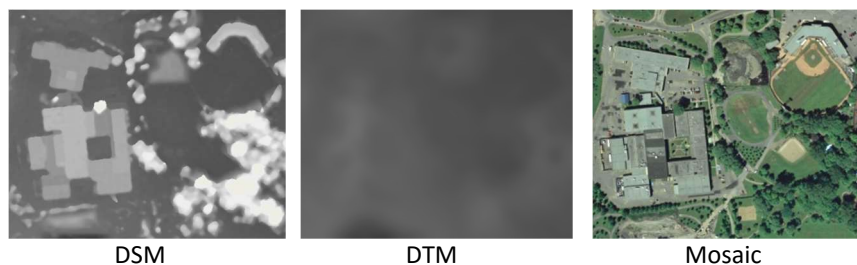


Figure 1: Sample geospatial data.

The following sections describe, in detail, the different functionalities, uses, and guidelines of the software, to ensure optimal results.

3. System Requirements

Correlator3D™ has been designed to operate on standard PCs. However, it consists of state-of-the-art software and as such, requires a recent computer. A great portion of the processing is performed directly on the graphics card, which is part of what allows Correlator3D™ to generate geospatial data so rapidly. The supported cards must feature an NVIDIA® GeForce graphics processor.

It is therefore recommended to use Correlator3D™ on a PC that meets or exceeds the specifications in Table 2:

Component	Description
CPU	Intel® Core™2 Duo processor or higher
GPU	Graphics card with an NVIDIA® GeForce 9 GPU (G92) or higher, with 512MB RAM or higher. Note that some Quadro cards also feature a GeForce GPU.
RAM	4GB or higher
OS	Windows 7, 8 and 10. Correlator3D™ is a 64-bit application.

Table 2: Recommended specifications for running Correlator3D™.

4. Data Requirements

Correlator3D™ requires different types of data to be able to perform its processing and can produce several kinds of outputs. As a result, it expects and generates data using specific data types. Table 3 summarizes the supported file formats.

Data Type	Supported Formats	File Extensions
DEM	SimActive Model Format (SAMF) GeoTIFF Arc/Info ASCII Grid	.smf .tif .asc
3D Constraint	ESRI Shapefile Microstation DGN	.shp .dgn
Image Types	Tagged Image File Format (TIFF) GeoTIFF JPEG Compliant JPEG2000 Windows Bitmap NITF	.tif .tif .jpg .jp2 .bmp .ntf
Mosaic Definition File	SimActive Format	.sbd
Tile Definition	SimActive Format	.tdf
Ground Control Points	SimActive Format	.gcp
Orthorectified Images	GeoTIFF TIFF World Format	.tif, .tif, .tfw
Support File for ADS	SOCET SET support file	.sup
RPC for Satellite	RPC Model file	.rpc, .rpb, .xml, .txt
Image Tiles for Satellite	Tile Model file	.til
SimActive Script	SimActive Script Format	.spt, .txt
Geoid	GTX Format	.gtx
Project File	SimActive Format	.c3d
3D Features	ESRI Shapefile	.shp
Interior/Exterior Orientation File	SimActive Format	.ieo

Table 3: Supported file formats.

4.1 Sensor Types

Correlator3D™ supports the following types of sensors:

- UAV / Medium / Large format camera systems
- Satellite sensors using the RPC model
- Leica's ADS pushbroom sensors
- VisionMap A3 camera systems

These four sensor types function in a similar manner, but require different parameters when creating a project. The following flowchart describes the workflow of Correlator3D™. Note that the workflow is sensor-dependent.

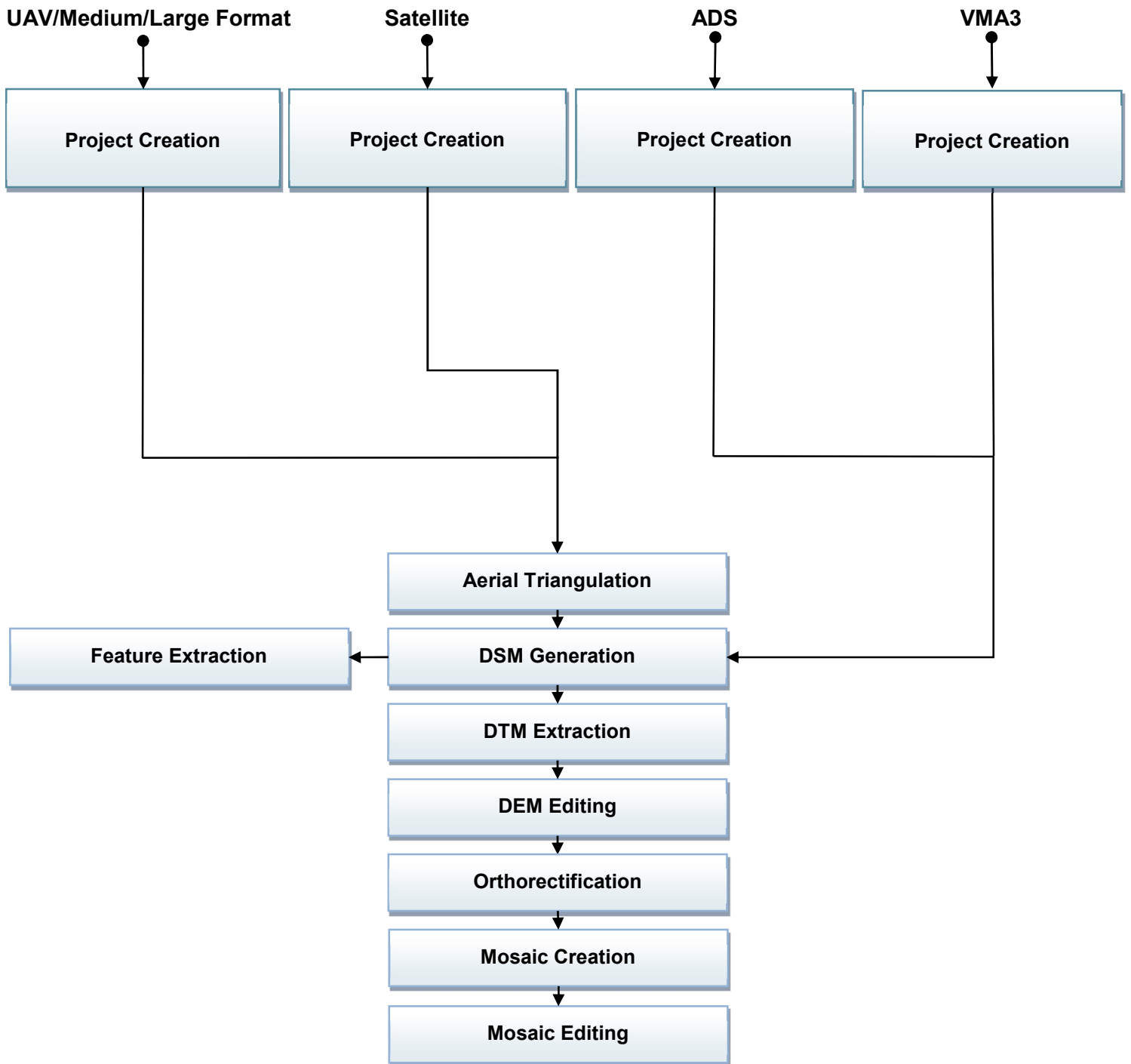


Figure 2: Correlator3D™ workflow.

4.2 Input Image Formats

Supported formats are summarized in Table 4.

Image Type	Data Format
TIFF and GeoTIFF	8 or 16 bits per channel 1, 3 or 4 channels
JPEG in TIFF	8 or 12 bits per channel 1, 3 or 4 channels
LZW in TIFF	8 or 16 bits per channel 1, 3 or 4 channels
JPEG	8 bits per channel 1 or 3 channels
JPEG2000	8 or 16 bits per channel 1, 3 or 4 channels
NITF	8 or 16 bits per channel 1, 3 or 4 channels
Windows Bitmap	8 bits per channel 1, 3 or 4 channels

Table 4: Supported input image formats



TIFF and GeoTIFF images are supported in both interleaved (RGBRGB) and pixel ordered (RRGGBB) formats.

4.3 DEM Format

The DEM should have square cells for both the GeoTIFF and Arc/Info ASCII Grid formats. This means that cell dimensions in X and Y should always be the same. Also, elevation values in GeoTIFF files should be expressed as 32-bit floating point numbers.

4.4 Orthophoto Format

Orthophotos can be generated in the Tiled TIFF format with overviews to maximize system performance during their subsequent exploitation using GIS software. However, the user should keep in mind that in general, more basic image viewing software do not support images in the Tiled TIFF format with overviews. Orthophotos are produced in one of the following formats:

- 1 channel 8-bit or 16-bit (panchromatic)
- 3 channels 24-bit or 48-bit
- 4 channels 32-bit or 64-bit

4.5 3D Constraints

A 3D constraint can be supplied to the DSM generation and DTM extraction modules to force specific elevation values in the output DEM. Such a 3D constraint must be provided in the form of a vector file (ESRI Shapefile or Microstation DGN), which may contain points, lines or regions.



Elements in the constraint file must contain elevation (3D) data.

4.6 3D Features

Existing 3D features can be supplied to the software. These must be in an ESRI Shapefile (.shp) and must support storage of elevation data, i.e. features must have a z-component.

4.7 Coordinate Systems

Correlator3D™ requires the projection to be specified when creating a project. The user specifies the projection details as shown in Figure 3.

Figure 3: Projection dialog.

Four options are presented to the user. A predefined list of the most common projections is available. Otherwise, the user may specify a custom projection, specify an EPSG code or use a Proj.4 projection definition. If using the EPSG or Proj.4 options, please refer to the official website for specific values: <http://spatialreference.org/>

Although mandatory for satellite, ADS and A3 sensors, the projection is optional for UAV/medium/large format sensors, and can be ignored by pressing the “Ignore” button as shown in Figure 3. Note that the rotation system supported by Correlator3D™ is photogrammetric (omega, phi and kappa) and that the geographic coordinate system (i.e. latitude/longitude) and navigational angles (i.e. roll, pitch and yaw) are converted when importing EO data during project

creation. If the user chooses to ignore the projection, then no projection information will be saved in the GeoTIFF files.



For a given project, the DEM and exterior orientation parameters used should thus be expressed in the same coordinate system (including the same projection, datum, geoid and units).



EPSG or Proj.4 values representing a geographic coordinate system (latitude/longitude) are not supported.



Units are specified along with other projection information. It is very important that the units are specified correctly.

5. Visual Interface

Correlator3D™ is designed for ease of use, featuring a simple visual interface. The main window serves to load, save, and display DEMs, mosaics, orthos, images, GCPs, and AT results. Additionally, it provides access to the different software functionalities and tools. At the core enabling this user experience is the project tree, further described in the corresponding section.

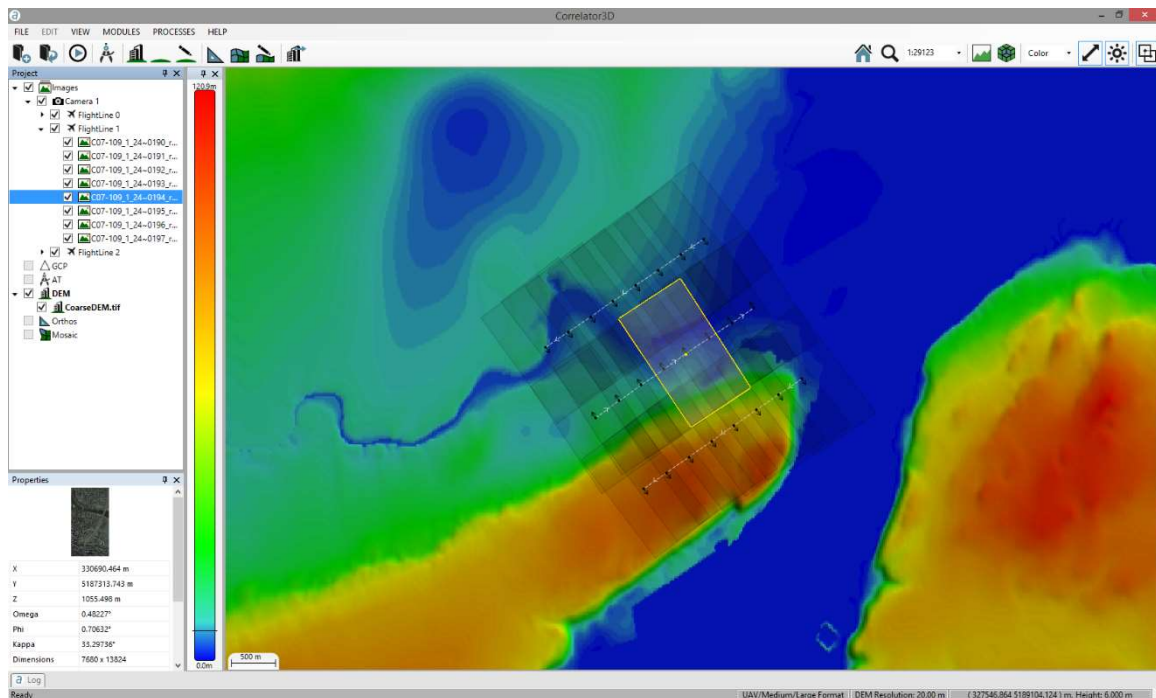


Figure 4: Correlator3D™ main window.

5.1 Multilingual User Interface

Correlator3D™ can be operated in different languages, including English, French, Japanese, and Chinese. The user can select the language at any time by accessing the corresponding option in the General Settings dialog from the File menu. Note that the language change is only applied once the software is restarted.

5.2 Project Tree

The project tree displays the project information as a hierarchical structure on the user window. The tree is used to perform multiple functions: modify the visibility of an overlay using a checkbox, save results, add data to the project, etc. It allows the user to seamlessly transition between data within each project. When the cursor is placed above an item listed in the project tree, contextual buttons appear. The following subsections describe each aspect of the project tree.

5.2.1 Images

At the top of the project tree are the “Images”. This item is filled with parameters given during the project creation. When selecting the “Images”, the camera(s) used in the project appear with their corresponding image footprints if a DEM is loaded. It is possible to have more than one camera within each project, and consequently, within the project tree.

Double-clicking on a camera will allow the user to see its associated flight line(s). The user has the option to select which flight lines or images are to be processed in corresponding steps using the contextual buttons. With this, flight line and images can be disabled; they will not be considered while generating a DSM or orthos. Moreover, the checkboxes are used to toggle visibility in the main window of the corresponding item (image, flight lines, or complete image set).



In the AT module, all images included in the project are considered; enable/disable have no impact and cannot be changed in this mode.



When a DEM is loaded, the image footprints on the ground are displayed. This function can be turned on and off at the user's preference.

When images are selected using the tree, the image positions are displayed as arrows overlaid on the DEM. This is very useful when ensuring that both the imagery and 3D data span the same region. Note that each arrow indicates the top of the image. Flight lines and their direction are also displayed as dashed lines with arrows.



When the cursor is placed over an arrow, a tooltip shows the name of the corresponding image. The user can also right-click on the image position to display the image in a separate window. The image will be rotated following its kappa-angle value. Panning is performed by clicking and dragging with the middle (wheel) mouse button while zooming can be performed using the mouse wheel. Note that several images can be displayed simultaneously.



Within the aerial triangulation module, the arrows may be replaced by color disks to allow a quick assessment of the quality of the bundle adjustment process. Please refer to section 7.1.5 for details.



Figure 5: Image window.

5.2.2 GCP

An existing GCP file can be added to the project directly using the project tree. There is also the option to remove the GCP file from a project. In order to create a GCP file, the user can go into the AT module. Similar to the aforementioned option, the project tree can be used to toggle the GCP visibility using the checkboxes.

Correlator3D also allows the user to specify check points. GCPs and check points are stored in the same GCP file, but the project tree displays them in two distinct subcategories of GCPs. GCPs and check points are only considered when performing bundle adjustment, but can be used to visually assess quality of the DSM, DTM, and mosaic. Please refer to sections 7.1.2 and 10.4 for further details.

5.2.3 AT

Please refer to section 7.1 for details.

5.2.4 DEM



The project tree simplifies working with DEMs as a DEM can be loaded directly onto it. Select “Add a DEM to project”, by placing the cursor over the “DEM” item in the project tree. More than one

DEM can be a part of the project. However, at any given time, only one DEM can be displayed. The ability to toggle between multiple DEMs is possible through the project tree using the checkbox for each DEM. It is also possible to remove a DEM by clicking on the “X” when placing your mouse over the respective DEM.

Once the data is read, it will be displayed in the window. Two display styles are available for viewing elevation data: color and grayscale.

If the color display style is selected, elevation values are mapped from blue to red (through green and yellow) according to the minimum and maximum values found in the data: low elevation values will be displayed in blue or green, middle values in yellow and high values in red.

If the grayscale display style is selected, elevation values are linearly mapped from black to white according to the minimum and maximum values found in the data: low elevation values will be displayed in dark colors while high values will appear in light colors.

The display style can be changed by selecting “Display Style->Color” or “Display Style->Grayscale” in the “View” menu.



Colors can be mapped from the minimum and maximum elevation values visible on the screen. The latter case is called “stretch” mode and can be enabled or disabled by selecting “Display Style->Stretch” in the “View” menu.



Subtle variations in elevation values can be highlighted by selecting the “Shade DEM variations” feature, which simulates lighting and shadows. This feature can be enabled or disabled by selecting “Display Style->Shade” in the “View” menu.

When a DEM file is loaded, a legend is visible at the left of the main window. This legend shows the color mapping currently used for displaying the elevation data. Minimum and maximum values are displayed with a line indicating the “0” value, if relevant. When the cursor is moved over the DEM, a horizontal bar moves up and down over the legend providing a visual cue for the elevation under the cursor. Precise elevation and coordinates of the location under the cursor are available in the right part of the status bar. The legend can be shown or hidden by selecting “Legend” in the “View” menu.



DEMs can be saved by clicking the contextual button in the tree.

5.2.5 Orthos

With the project tree, the user can toggle the visibility of each generated ortho with its checkbox. It is possible to directly delete all the orthos from the project by hovering over the “Orthos” item on the project tree and clicking on the “X”. The user can also specify a new or existing folder for orthos. In order to do this, place the mouse over the “Orthos” and select the “+” icon to open or set a new ortho folder. Note that generating orthos without specifying a new folder will delete the previously stored orthos from the folder.

The user has the option to select which orthos are to be processed in mosaic creation using the contextual buttons. With this option, orthos can be disabled; they will not be considered while generating a mosaic.

5.2.6 Mosaic

The user can toggle the visibility of the mosaic using the project tree by using the checkbox. It is possible to directly delete the mosaic from the project by hovering over the “Mosaic” on the project tree and clicking on the “X”. The user can also specify a new or existing folder for the mosaic. In order to do this, place the mouse over the “Mosaic” item and select the “+” icon to open or set a new mosaic folder. Note that generating the mosaic without specifying a new folder will delete the previously stored mosaic from the folder.

5.2.7 Reference

Reference orthos are orthos that were created outside of a project and are used for quality assessment. The AT module can also use the reference orthos along with a DEM as horizontal and vertical reference data when GCPs are not available.

The functionality of the tree view with respect to the reference orthos is the same as the one described in section 5.2.5. Note that disabled reference orthos will not be considered while performing a bundle adjustment with reference imagery.

5.3 Properties

The project tree includes a window that displays the properties of a selected object (e.g. GCP, camera, images, DEM, orthophotos). The tool is beneficial as it assists in the assessment of metadata, such as the camera calibration, image position, GCP type, etc. The information the property window displays is dependent on the type of object selected.

5.4 Zooming and panning

The main window of Correlator3D™ supports advanced zooming and panning capabilities. Data caching and automatically triggered refreshes are performed to offer both rapid and fluid response, while displaying the most accurate information available. Fast results are obtained even for huge projects at low memory costs. When working with large files, hard disk performance can limit the speed at which information can be displayed. In such situations, Correlator3D™ will temporarily display a less accurate version of the data while it is being loaded. The accurate version will be displayed shortly afterward, as soon as available.



This allows the user to continue panning and zooming while data loading is performed and ensures a fast response at any given moment.

Panning is performed by clicking and dragging with the left or middle (wheel) mouse buttons.



Note that during DEM editing, only the middle (wheel) button is supported for panning.

Zooming can be performed in multiple ways. The simplest and most intuitive way is to use the mouse wheel. If the mouse does not include a wheel, the options “Zoom->Zoom In” and “Zoom->Zoom Out” in the “View” menu will provide the same results.



The “Zoom to region” feature lets the user specify a rectangular area. Zoom and pan operations are then computed to show the selected area as large as possible and centered onscreen. The “Zoom to region” feature is available by selecting “Zoom->Zoom to region” in the “View” menu.



At any time, the user can return to the default view by selecting “Zoom->Home” in the “View” menu. The default view displays the entire project centered onscreen.

5.5 Scale

The user can also zoom the current view to a specified scale. For example, to make 1 centimeter on the screen to be equivalent to 1 kilometer of ground truth, one would enter a scale of 100,000 (this is the number of centimeters in a kilometer).

A scale indicator is located near the bottom of the legend. The indicator can be shown or hidden by selecting “Scale” in the “View” menu. The scale is dynamically adjusted during a zoom operation.

5.6 Status Bar

The status bar provides various types of information, including the sensor type, the DEM horizontal resolution, the coordinates of the cursor and the elevation at the cursor’s location. The sensor type is either “UAV/Medium/Large Format”, “Satellite”, “ADS” or “VMA3” and indicates the current project type. The DEM resolution displays the resolution of the DEM written in the file. Unlike the scale, it is invariant to zooming operations. Coordinates are refreshed while the cursor is moved over the DEM and the elevation under the cursor is displayed only when available. The status bar can be shown or hidden by selecting “Status Bar” in the “View” menu.

5.7 Profile



The Profile tool generates a vertical profile of the DEM over a user-specified path. The path consists of a series of connected linear segments. Once a path is specified, Correlator3D™ opens a new window containing the vertical profile. The profile is generated by sampling the DEM and contains two different representations simultaneously.

The first representation is an area chart shown in light blue. It shows the real elevation value for each sample based on a nearest neighbor approach for samples falling between two values of the DEM. It provides a discrete representation that is well-suited for visualizing surfaces that are highly non-continuous (e.g. urban areas).

The second representation is a smooth dark blue line super-imposed over the previous representation. This time, a bilinear interpolation technique is used to obtain the sample values.

The representation is better suited for visualizing areas where the terrain is continuous (e.g. rural areas).

In the profile windows, vertical blue lines show the delimitation of each linear segment of the path.

When the mouse is moved over the profile, a blue circle located on the interpolated profile follows the mouse motion. XY coordinates and elevation values associated with this blue circle are automatically updated and shown in the lower right corner of the profile window. A similar circle appears and moves synchronously in Correlator3D™'s main window over the user-specified path to show the exact location corresponding to the mouse position in the profile view.

A “stretch” button located in the status bar enables or disables the stretch mode. When enabled (default), the profile is stretched to take the entire size of the window, but the aspect ratio is not respected. When disabled, square aspect ratio is used, ensuring that the same number of pixels in the x or y dimensions correspond to the same physical dimension in DEM units.

By right-clicking on the profile, the user can save an image of the profile in a file or to the clipboard.

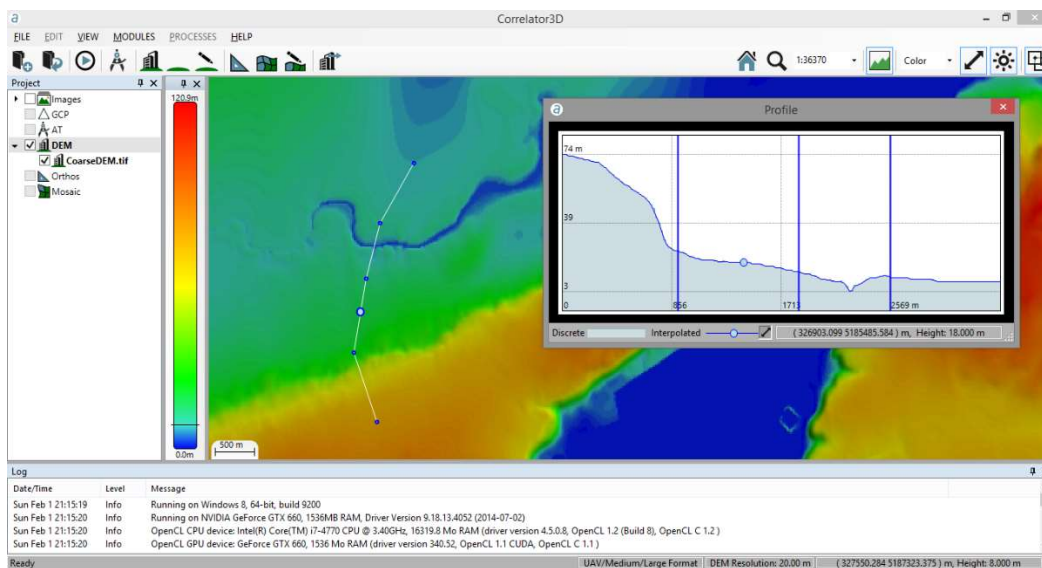


Figure 6: Profile window.

5.8 Volume



The Volume tool measures a volume over a user-specified selection and a reference elevation. The user begins by selecting the area in which the volume is to be calculated. Once a path is specified, Correlator3D™ opens a window for the user to select a reference elevation for the volume to be computed. There are five types of reference elevations:

- Interpolate DEM at selected boundary: obtain volume by interpolating DEM values present at the chosen boundary

- Use fixed elevation: obtain volume from a specified height
- Remove constant offset (dig): obtain volume by removing an offset value
- Add constant offset (fill): obtain volume by adding an offset value
- Use reference DEM: obtain volume by selecting a reference DEM

These options give the user flexibility in the volume type they can calculate.

The following statistics appear in the properties windows on the left once the process is complete:

- Volume (Cut): the volume measured between the reference elevation, and the terrain above
- Volume (Fill): the volume measured between the reference elevation, and the terrain below
- Terrain area: the area covered by the selection, considering the terrain morphology. This can be visualized as the size of the sheet you would require to drape the terrain
- Orthogonal area: the area covered by the selection, not considering the terrain elevation
- Volume coverage: percentage representing the coverage of the selection used to measure the volume, with no consideration for the undefined elevation values. The user should ensure that this value is always close to 100%. The value may indicate that the reference DEM being used does not overlap completely with the current DEM, or that the software was not able to completely interpolate at selected boundary (because too many vertices were falling outside the model).

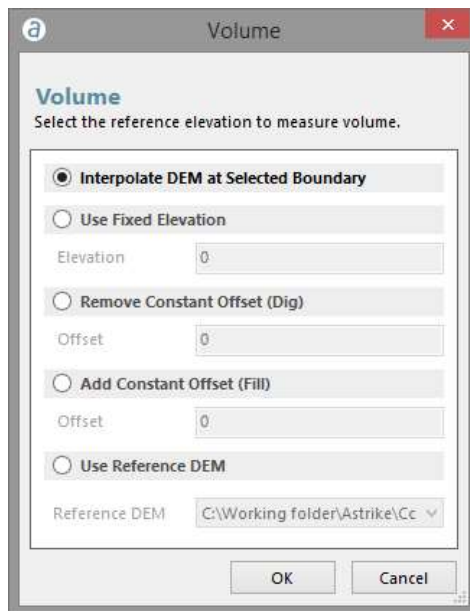


Figure 7: Volume window.

6. Project Creation

The simplistic design and interactive user interface is made possible through the creation, and use, of projects. A project within Correlator3D™ consists of a file with information about the location of all the input and output data: EO data, camera calibration, AT data, projection, images, DEMs, GCP, orthos, mosaic and reference orthos. The purpose of the project is to centralize information for ease of use. Part of this information must be specified during project creation.

The project creation wizard is used to create a project in Correlator3D™. As the wizard incorporates all supported sensor types, the user does not have to be concerned with the specific sensor type for the full photogrammetry workflow. A project type must be simply selected from one of five options, and proceed with the required steps.

Once a project has been created, it can be closed and accessed at a later time. A project can be moved from one location to another, as long as the file hierarchy is preserved on disk (e.g. one folder with the project file and all images, orthos).

To save the main file of a project, the user can select “Save Project As” within the File menu. This will not change or move the other files, only the main one.

There are five types of projects differentiated by the sensor type and image size. These include: UAV, Medium/Large Format, Satellite, ADS, and A3. The following sections describe the steps to create a project for each of the listed project types. As the UAV and Medium/Large Format project types only differ in image size, they are grouped together.

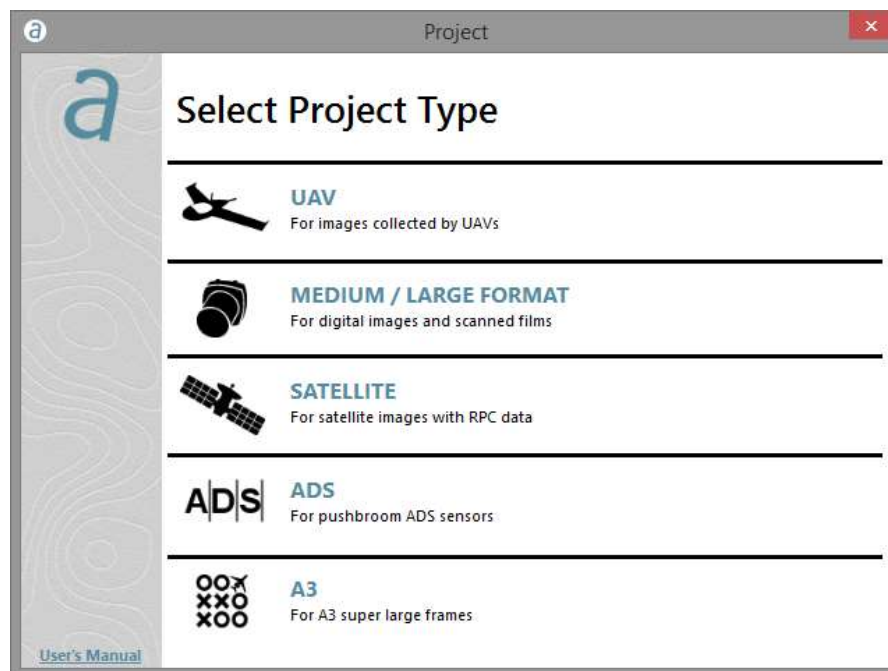


Figure 8: Project type.

6.1 UAV / Medium / Large Format

The UAV/medium/large format imagery refers to digital images and scanned films. The difference with each is based on the image size. The UAV format is used for digital images smaller than or equal to 40MP. The medium/large format is used for images greater than 40MP, and for scanned films.

UAV/medium/large sensor the user should ensure that the overlap between adjacent images is appropriate to ensure optimal results. The endlap (i.e. the overlap between successive images) should be at least 60% of the image size, but also should be as close as possible to that value. In terms of the sidelap requirements (i.e. the overlap between images from adjacent flight lines), it is recommended to use a value between 20% and 30%. Note that for low-altitude flights, the endlap should be approximately 80% and the sidelap 50% to minimize occlusion effects from one image to the other.



If images were collected with an endlap greater than 75%, half of the images can be disabled (i.e. one out of every two images) from the image list. This will not only reduce the processing time, but will also lead to more accurate results. Note that for image orthorectification, the overlap of the resulting orthorectified images can be specified.

6.1.1 Step 1 - Image Selection

The user selects the images to be processed in the project. This is done by adding the images and their corresponding EO data in the wizard. Images can be added individually, or through a complete folder using the appropriate button. Once they are added, the software automatically requests EO data (please refer to section 10.1 for further details). If EXIF information is present, the software can use it to generate the EO data, though it is not mandatory. The user has the option to import a text file, or a legacy SimActive EO file. Projection information will be asked for after this dialog (please refer to section 4.7 for further details).

More than one camera can be added to a project. If there is more than one camera, those cameras can either belong to the same group (e.g. a multi-head camera systems), or to different groups (e.g. an area was flown by two different cameras that are not attached together). This can be performed through the drop-down menu under “Camera” and “<Add a new camera>”. The camera name must be inputted and the group selected based on the aforementioned description.

The user has the ability to remove all selected images using the “Clear” button, choosing a new set of images instead. Specific images can be removed from the dataset using the “X” button on the right of the list of selected images.

6.1.2 Step 2 – Camera Parameters

Camera parameters for all cameras of the project must be specified. The user can import a legacy SimActive camera file. Alternatively, the software can detect the values automatically, including the focal length and pixel size. “Digital – Polynomial” is the suggested type for non-metric cameras

similar to those normally used on UAVs. More information on different camera calibration types can be found in section 13.1.1.1. If the user is working with scanned films, the fiducial detection tool will be shown (please refer to section 10.3 for further details).



Although parameters can vary from one camera to the other, only one calibration type is supported for a given project. For scanned films, if the dimensions of images in pixels vary, then the smallest width and height values observed should be specified. Note that these minimum width and height values may come from two different images.

6.1.3 Step 3 – Project Parameters

In this step, the user defines the project location by clicking on the “...” button. There is the option to specify a projection, however, it cannot be different than the one selected for the images in Step 1.

The other project parameters are optional. The “Seed DEM” option allows the user to create (please refer to section 10.2 for further details) or specify (e.g. SRTM) a seed DEM.

With the “GCP File” option, the user can specify a file containing GCP and check point information. The file can be an existing one or it can be created by importing data from a text file (please refer to section 10.4 for further details).

The “Reference Orthos” option lets the user browse and select a folder containing the reference orthos.



Both GCPs and reference orthos can be specified during project creation. However, when performing bundle adjustment, the user will need to select a single ground reference.

6.2 Satellite

6.2.1 Step 1 - Image Selection

The metadata of a satellite image is stored in its corresponding RPC file. This file comes in several formats, all of which are supported by Correlator3D™. When creating a project, the user must specify the input RPC files of the images to be processed. Correlator3D™ automatically parses these files to recover the satellite parameters. For large satellite images, the images may be tiled and referenced by a TIL file. This TIL file will be required as an input. Only one (1) RPC file is needed per TIL file. The project creation wizard will automatically suggest an image file when an RPC file is selected first.

The user has the ability to remove all selected images using the “Clear” button, choosing a new set of images instead. Specific images can be removed from the dataset using the “X” button on the right of the list of selected images.

6.2.2 Step 2 - Image Pairing

In order to generate a DSM using overlapping satellite images, the user must specify image pairs. Each pair will be used to generate a corresponding DSM, with the results merged at the end of the process.

To construct a pair, select each of the images to be paired using the drop-down menu, and click on “Add”. A star (*) before the name of the image in the drop-down menu indicates that the image has not been used in any pair thus far.

This step can be skipped if no DSM is required.

6.2.3 Step 3 – Project Parameters

In this step, the user defines the project location by clicking on the “...” button. It is mandatory to specify a projection. The projection can be specified by selecting a Seed DEM with a valid projection in it.

The other project parameters are optional. The “Seed DEM” option allows the user to create (please refer to section 10.2 for further details) or specify (e.g. SRTM) a seed DEM.

With the “GCP File” option, the user can specify a file containing GCP and check point information. The file can be an existing one or it can be created by importing data from a text file (please refer to section 10.4 for further details).

The “Reference Orthos” option lets the user browse and select a folder containing the reference orthos.



Both GCPs and reference orthos can be specified during project creation. When performing bundle adjustment, the user will need to choose which ground reference to use as they cannot be used simultaneously.

6.3 ADS

6.3.1 Step 1 - Image Selection

The metadata of an ADS image is stored in a standard SOCET SET support file. This support file is an ASCII file that uses keywords. When creating a project, the user must specify the support files of the images to be processed. Correlator3D™ automatically parses these files to recover the names of the images, the camera calibration files, and the exterior orientation data. Therefore, the user must make sure that all file names and paths specified in the support file are valid.



In the ADS support files, paths containing spaces are not valid.



Correlator3D™ only processes level 1 (L1) imagery for ADS sensors.

6.3.2 Image Pairing

In order to generate a DSM using ADS imagery, the user must specify image pairs. Each pair will be used to generate a corresponding DSM, with the results merged at the end of the process.

To construct a pair, select each of the images to be paired using the drop-down menu, and click on “Add”. A star (*) before the name of the image in the drop-down menu indicates that the image has not been used in any pair thus far. This step can be skipped if no DSM is required.



Better results in ADS mode will be achieved if the angle between the sensors is small (i.e. forward-nadir or nadir-backward). Using the pair forward-backward is likely to generate noisy or erroneous results due to occlusions (objects visible in one image might not be visible in the other).

6.3.3 Project Parameters

In this step, the user defines the project location by clicking on the “...” button. It is mandatory to specify a projection for an ADS project. The projection can be specified by selecting a Seed DEM with a valid projection; it must correspond to the one specified in the support files. The Seed DEM (like SRTM) is optional, but highly recommended. The user can create a flat Seed DEM (refer to section 10.2 for further details).

6.4 A3

6.4.1 Step 1 - Image Selection

Each VMA3 frame is stored in its own folder along with files containing metadata. When creating a project, the user must specify a VMA3 frame folder containing all frames to be processed.



Correlator3D™ only processes Super Large Frame (SLF) imagery for VMA3 sensors.

6.4.2 Project Parameters

In this step, the user defines the project location by clicking on the “...” button. It is mandatory to specify a projection for an ADS project. The projection can be specified by selecting a Seed DEM with a valid projection in it. The Seed DEM (like SRTM) is optional, but highly recommended. The user can create a flat Seed DEM (refer to section 10.2 for further details).

7. Data Generation

7.1 Aerial Triangulation

Correlator3D™ includes an aerial triangulation (AT) module for UAV/medium/large format sensors and satellite sensors, which automatically improves exterior orientation values and camera calibration parameters from the image data. It is therefore recommended to perform this process on every project to ensure the quality of the geospatial products generated from the imagery. The software requires as a minimum overlapping aerial images, coarse GPS measurements, and basic camera parameters.

It is worthwhile to spend time on the AT step, as it will help save significant processing time on subsequent steps.

To enter this mode, the user must select “Aerial Triangulation” in the “Module” menu. Aerial triangulation should be performed in the following order:

1. Tie Point Extraction
2. GCP Creation (if required)
3. Tie Point Editing (if required)
4. Bundle Adjustment
5. Quality Assessment
6. Image List Filtering (if required)
7. Coarse DEM Extraction (if required)

7.1.1 Tie Point Extraction



The first step is to extract tie points, which is performed automatically. A tie point is an image feature that is visible in two or more images.

Correlator3D offers two types of tie point extraction: standard and exhaustive. The standard extraction type is suitable for most projects, while the exhaustive type is better fitted for challenging datasets with suboptimal inputs.



Exhaustive tie point extraction is usually slower than standard tie point extraction. It is suggested to use the exhaustive type only when the standard one does not generate optimal results (e.g. several images that are not connected to others).

If reference orthos are present, the tie point extraction process will also extract points in those images, even if their ground sampling distance is different. Note that these observations will be used during bundle adjustment only if the Ground Reference option is set to “Reference Orthos”.



Compared to bundle adjustment, the tie point extraction process is the most time consuming. If the user needs to perform numerous bundle adjustments on the same project, then tie points do not need to be recalculated each time.



For best performance, the user should ensure to have both a GPU and CPU OpenCL enabled devices. Most graphics card drivers include OpenCL support. However, special drivers may need to be installed to enable OpenCL on the CPU. The CPU manufacturer can be consulted for more details.

7.1.2 GCP Creation

Next, the user must decide whether to use ground control points (GCP). Although not required for relative accuracy, ground control points are necessary for absolute accuracy. The quality of the ground control points will have a strong impact on the results. Ground control points have two benefits. First, they ensure that there is no global spatial offset (i.e. xyz translation) in the refined values. Second, they provide another means to validate the residual error of the refined values.

The user can also create check points. These are special GCPs that will not be considered during bundle adjustment, but for which statistics and reports will be generated. Check points are used to assess the quality of the bundle adjustment using an independent data set.

The GCP Editing tool helps the user locate GCPs in the images by selecting the best image candidates, and estimating where the GCPs should fall in those images. Correlator3D™ relies on the exterior orientation parameters and camera calibration data located in the IEO file. Upon entering the GCP Editing tool, the software will verify the average residual error and suggest the user to perform an estimation of IEO parameters if this error is too large. This will add an “Estimate” AT step to the project tree. When GCP creation is completed and bundle adjustment is performed, the “Estimate” step will be automatically removed. Therefore, the “Estimate” step has no impact on the bundle adjustment process. The GCP Editing tool is described in Section 10.4.

7.1.3 Tie Point Editing

After the initial automatic tie point extraction step has been performed, the software will display links created between images. Hovering the mouse over any link displays the number of tie points present between those images.

The user can right-click on any link to visually inspect or edit the tie points between two images, ensuring features match in both images. They can also right-click on the image position to display the image itself, with all its feature points displayed as an overlay.



Under some circumstances, it may not be possible to automatically extract tie points between some images. This is more likely to occur when the overlap is too low or the quality of images is not sufficient. The user can then manually add tie points to the project. A link can be added between two images by clicking on the corresponding button, by clicking and holding the left

button on the first image and by dragging the link to the second image. The tie point editing dialog will appear with the two corresponding images. The user can zoom in using the mouse wheel, and pan by clicking and dragging with the center button (wheel).

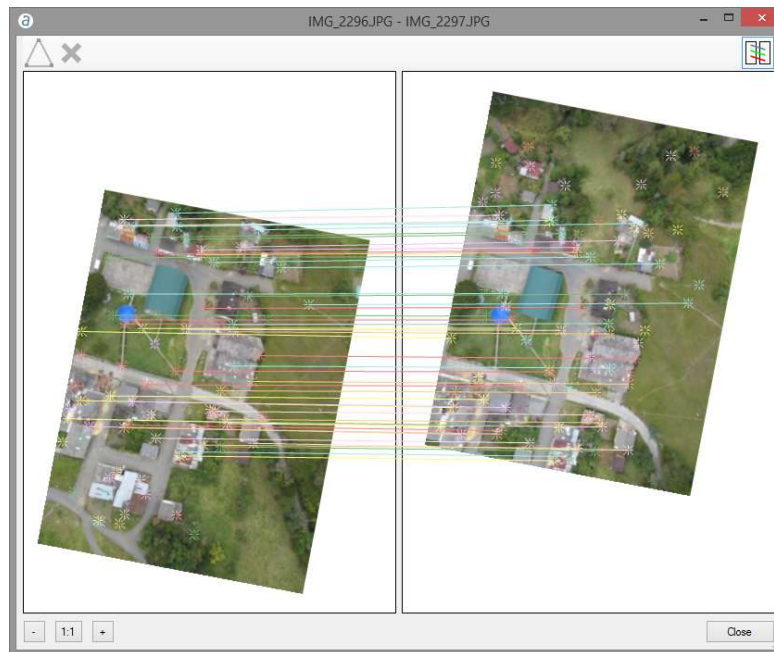


Figure 9: Tie points between two images.

At this point, the objective is to add as many tie points as possible. To do so, the user must right-click on one feature in one image, and drag it to the corresponding feature in the second image. The software will then automatically try to refine the match, and will display the Tie Point Editing window. In the window, the user can either validate or refine the position of the feature in each image.

A tie point is more beneficial when the feature is identified in multiple images. Due to this, user should always consider using such features, distinguished as colored stars in the images. If the user clicks on one of these stars, then drags to the corresponding feature in the other image, the software will display the Tie Point Editing window. Multiple images containing the feature will be displayed. The new observation for the tie point will be identified with its name in blue.

As the user enters more tie points, the software will adjust the relative orientation of the two images to facilitate the task. Also, when moving the cursor in one of the two images, the software will provide a predictor (shown as a multicolored circle) in the other image to give a hint of where the feature should approximately appear. This helps facilitate the process.



At all times, the user can select a tie point to edit by either right-clicking on it, or using the corresponding button.



The user can also select a tie point to delete it using the corresponding button.

There is no specific rule on how many tie points should be added between two images, although 5 or 6 is a good approximate.

Note also that the goal is not necessarily insuring that there is a link between every corresponding image. For example, adding a link between a pair of images can tie two flight lines together, but it is not necessary to link each adjacent images in the flight lines. Instead, the links can be added on image pairs that are well dispersed (e.g. one image pair in the beginning, middle, and end of the flight lines). This can save the user time, while ensuring that the overall project is connected.

7.1.4 Bundle Adjustment

Bundle adjustment derives adjusted exterior orientation and camera data. Correlator3D™ can be used to perform a boresight calibration or a full AT adjustment. In the boresight calibration process, the software computes the error component that is common to all exterior orientation estimates. This corresponds to the relative position/orientation of the camera to the GPS/IMU unit. If a full AT adjustment is selected, then the software still automatically performs a boresight calibration beforehand but also computes a unique correction for each individual image.

The software can also be used to perform a camera calibration in parallel to the EO adjustment. The software adjusts camera parameters based on the camera type used. These values may include focal length, principal point, LUT values, as well as radial and decentering distortion parameters. Various camera models are supported and described in Appendix A.

When available, the user can use either ground control points or reference orthos to ensure that there is no global spatial offset (i.e. XYZ translation) in the refined values.

When using ground control points, Correlator3D™ takes into account user error when identifying the GCP location in the images and also accounts for possible error in the XYZ coordinates. In the bundle adjustment settings, the user may specify uncertainty values for the GCP. The "Pixel Radius" is the presumed error when defining the GCP locations in the image using the GCP Editing tool. For example, a value of 0.5 means that the user predicts having introduced an error of half a pixel when defining the GCP location in the image.

The bundle adjustment settings let the user specify a general uncertainty for the "XY" and "Z" components of the GCPs. For example, an uncertainty value of 1m for the "XY" field will allow a 1m fluctuation to the XY values of the GCPs, whereas a value of 0m implies the user has absolute confidence in the GCPs. This will force the software to comply with the GCPs exactly when performing an EO adjustment. This setting only applies to GCPs that do not have per-point uncertainty values.



Per-point uncertainty values are specified using the GCP Editing tool. Different XYZ uncertainties can be specified for each GCP. When available, these values override the aforementioned general uncertainty values.

When GCPs are used, final residual analysis and statistics will also be computed for the check points.

If reference orthos are used, tie points detected in these images will provide horizontal (XY) anchoring to the project. If a DEM is currently loaded in the user interface, it will provide vertical (Z) anchoring. While optional, the use of a reference DEM is recommended.



Bundle adjustment can be run in two (2) modes. These are called "Constrained" and "Unconstrained" and apply to the camera calibration and EO adjustment settings. The EO adjustment setting allows for either a boresight adjustment or a full AT adjustment. The unconstrained mode performs all necessary parameter allocations for the user. It is designed to provide the fastest AT solution. The constrained mode requires specification of the bundle block settings, providing more control over the project.

In the constrained mode, the user can lock one or more parameters for bundle adjustment. These locked parameters can come either from the EO values and/or the camera values. For example, if the GPS and camera data are known to be accurate, the user may choose to lock them and only process the IMU portion for bundle adjustment. This would force the software to perform bundle adjustment only on the IMU portion of the EO values.

In the constrained mode, the user is also required to define a search space for the easting (x), northing (y), elevation (z), omega, phi and kappa values. The search space defines the assumed uncertainty regarding the accuracy of the input data. For example, specifying an uncertainty of 5m for easting and an uncertainty of 2° for omega, restricts the software to adjust the easting and omega parameters from their current positions as defined by the input to a maximum of 5m and 2° off respectively, in the output.

Note, in a full AT adjustment, the uncertainty value bounds only the full AT portion of the adjustment, meaning only the unique correction for each image will be bound by the uncertainty value. The boresight portion of the adjustment, which is automatically performed during any full AT adjustment, will not be bound at all. For example, if a 5m value in X was chosen as the uncertainty for a full AT adjustment, then as a first step, a common boresight correction of any appropriate magnitude (as determined by the software) will be applied to all images followed by a unique correction to each individual image of up to 5m in X. The user may change this behavior by unchecking the "Perform Boresight Calibration" option. With this option unchecked, the software will skip the boresight calibration process, making sure the uncertainty range is respected during the adjustment.



The search space must be appropriately large to compensate for the EO errors. Large average residuals may imply that the search space was too small and that results are not optimal.

In the case of satellite sensors, the AT process will calculate corrections on RPC values to improve the accuracy of the georeference. The software requires overlapping satellite images and RPC data. GCPs may also be used to ensure absolute accuracy. The EO refinement process will automatically adjust the RPC values and output the RMS pixel error.

7.1.5 Quality Assessment

Once the bundle adjustment has been performed, the user is presented with the overall tie point residual error expressed as colored circles centered on each image. There are four different colors:

- Green: when the residual error is less than 0.75 pixel
- Yellow: when the residual error is between 0.75 and 1.5 pixel
- Red: when the residual error is larger than 1.5 pixel
- Blue: when it was not possible to correct the position/orientation of the image (e.g. no tie point)

Note that it is normal for the residual errors to be red in the initial step. It simply means that bundle adjustment is necessary to bring the values down to the green range. Tie points, ground control points and check points, when available, are also displayed using the same color coding. By hovering the mouse over a point or an image, the user can see the associated residual error in the right hand side of the status bar.

At any time during AT, the user can switch between the color-coded circles and the kappa arrows by selecting the corresponding option in the “View” menu. The “IEO Display Style” option applies to images while the “GCP Display Style” option applies to GCPs. For GCPs, a third display style is also available: Spatial Residuals.

The spatial residual is the difference between the specified coordinates of the GCP and the theoretical coordinates that are triangulated using the current IEO data. When the “Spatial Residuals” display style is selected, each GCP and check point is represented as a set of two arrows. The red arrow shows the vertical residual error. A red arrow pointing up indicates that the specified GCP altitude is higher than what is triangulated from the IEO data. The blue arrow shows the planar residual error. A blue arrow pointing north-east indicates that the specified GCP coordinates are north-east of what is triangulated from the IEO data.

In the software interface, an AT List is displayed on the left hand side detailing the AT steps that have been performed. As more bundle adjustments are performed, the list grows displaying all iterations. This allows flexibility to back track in case of an undesirable iteration. Specifically, the last bundle adjustment operation may be undone or the user may choose to come back to results of a specific iteration.

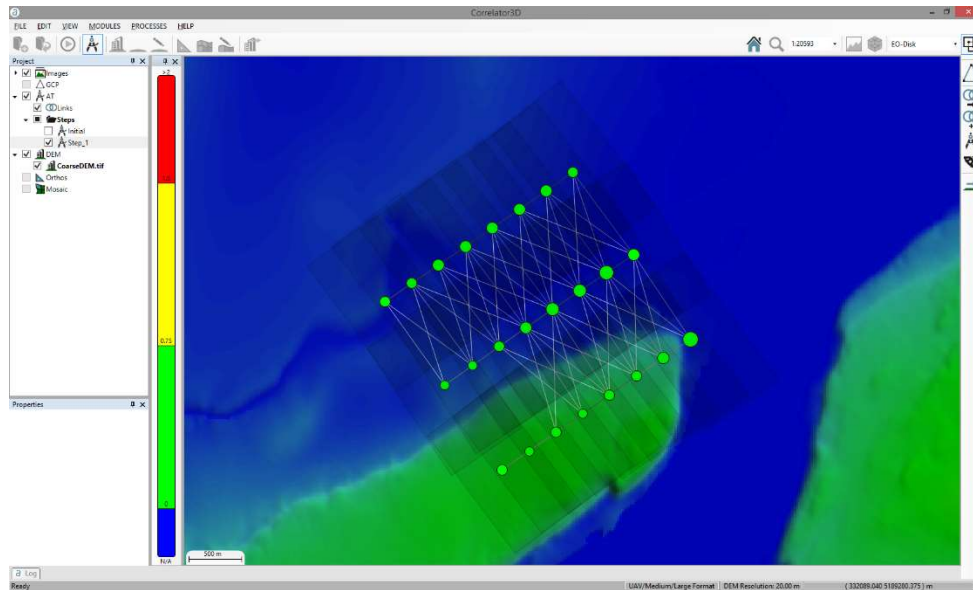


Figure 10: Bundle adjustment results.

To provide the user with feedback, detailed aerial triangulation reports are generated outlining the statistics on all operations performed. The user has access to a general summary, or more detailed reports, such as boresight corrections, image and camera calibration adjustments and tie point, image and GCP residuals. At the end of any AT process, the software automatically displays a report summarizing the adjustment performed. For convenience, a link to the folder containing more detailed AT reports is also provided at the bottom left corner.

7.1.6 Image List Filtering

Before continuing with the rest of the photogrammetric workflow, the user should ensure that incorrect images are removed from the project. This will avoid having noise or other artifacts in their results. Therefore, the option to select the “Image List Filtering” on the right-hand side is available. This tool creates a new AT step in which images having a tie point residual error higher than the specified threshold will be removed. The user can see the images being filtered in real-time as the threshold value is modified.

7.1.7 Coarse DEM Extraction

Once all iterations have been performed and the user is satisfied with the results, the updated project can be saved. At this point, the user can create a coarse DEM with the corresponding button, and then use that coarse DEM to start DSM generation. For satellite, VM, ADS and large frame sensors, and if the terrain is mountainous, it is better to use data such as SRTM.

7.2 DSM Generation

One of Correlator3D™'s main capabilities is the generation of digital surface models (DSM) from imagery. The software requires overlapping aerial images and GPS/IMU data. To determine the approximate terrain elevation, a seed DEM covering the project area is required. Although this DEM can be coarse, the use of at least DTED Level 2 elevation data or equivalent is suggested. However, note that the software can process data even if there is a large difference between the input and output DEM horizontal resolution. The coarse DEM can be generated using the AT module, or a flat seed can be created using the File menu.

The user must specify the desired output horizontal resolution, or simply request the software to calculate an optimal value given the input dataset. This feature takes into account the project parameters (i.e. image resolution, altitude, focal length, etc.) as well as the required processing time and then determines the best compromise. The user can also request the software to calculate the maximal value given the input dataset.

Once a horizontal resolution is specified, the user must select a vertical accuracy from the corresponding drop-down menu. By default, the lowest accuracy value is selected, leading to better processing times.

The user can generate a point cloud by selecting the corresponding option. It will be generated in parallel with the DSM, with virtually no added processing time. Once the process is completed, the point cloud will appear as a sub-item to the DSM in the project tree. Saving the DSM will result in having a LAS file created with the same name on disk. Note that since Correlator3D™ uses LAS files as an export format only, the user will not be able to visualize the point cloud in the interface. Therefore, once the point cloud is saved, it will disappear from the project tree. Once the point cloud is created, it can be colorized using the Point Cloud Colorizing tool. Please refer to section 10.12 for details.

The maximum height variation parameters must also be set. They represent the level of elevation value inconsistency between the original DEM and the one that will be produced from the DSM generation process. One describes the above ground variation while the other describes the below ground elevation. The user should not only consider the errors in the original DEM, but also the size of objects in the scene. As an example, urban areas with tall buildings will require the above ground variation parameter value to be high. Note however, that the higher the values are, the longer the processing time is going to be. While the maximum height variation parameters can be set in the DSM generation dialog, it can also be calculated automatically by using the corresponding checkbox.

Images are processed pair-by-pair in the order that they appear in each flight line. The required time is thus directly proportional to the number of images. Processing can be performed on multiple machines by taking the exact same project and disabling images through flight lines based on the respective divisions. DSM results can then be merged using the DEM Merging Tool (see Section 10.5).

An optional 3D constraint file can be provided to Correlator3D™. This file can contain points, lines or polygons with elevation (3D) data. Using data values located in the constraint file may result in two benefits. First, it may help the DSM generation process to resolve potential ambiguities, such as occluded regions. Second, it will force the output DSM to have the provided elevation values at the location of the constraining elements.



If a 3D constraint is provided, Correlator3D™ will force the output values in the DSM to be consistent with the provided constraint. However, if the constraint is not consistent with the rest of the dataset, it may lead to visual artifacts in the DSM. If such a situation appears, the user should make sure that the input DEM and 3D constraint are in the same coordinate system (e.g. same datum) and that all input data are valid (e.g. camera calibration or exterior orientation parameters).

The software generates a DSM representing all objects in the scene (terrain, vegetation and man-made structures). No manual post-processing is necessary to remove pits or spikes: once generated, the DSM is ready to use. Correlator3D™ will generate high quality DSMs across most types of surfaces. However, because of their inconsistent appearance from one image to another, water bodies will generally lead to noisy DSM regions. Note that the overall vertical accuracy of the DSM will be displayed once the processing is done.

The following steps must be followed to perform DSM generation:



1. Select the seed DEM you wish to use from the project tree.
2. Select “DSM generation...” in the “Processes” menu.
3. If a 3D constraint is used:
 - a. Check “3D Constraint”.
 - b. Specify the file containing the 3D constraint using the corresponding drop-down menu. The constraint will be displayed in the main window overlaid on the DEM.
4. Specify the desired resolution. Press the “Optimal” or the “Maximal” button to let the program calculate the optimal or maximal value. Once a resolution is specified, select a vertical accuracy from the corresponding drop-down menu.
5. If a point cloud is required, check “Generate Point Cloud”.
6. Specify the maximum height variation parameters. The values should reflect the expected discrepancy between the original DEM and the resulting DSM.
7. Click on the “Processes” button. Real-time feedback will be provided on the overall progress of processing.
8. Save the generated DSM by selecting “Save DEM As...” using the contextual button in the project tree. If a point cloud was generated, it will be automatically saved as a LAS file with the same name.



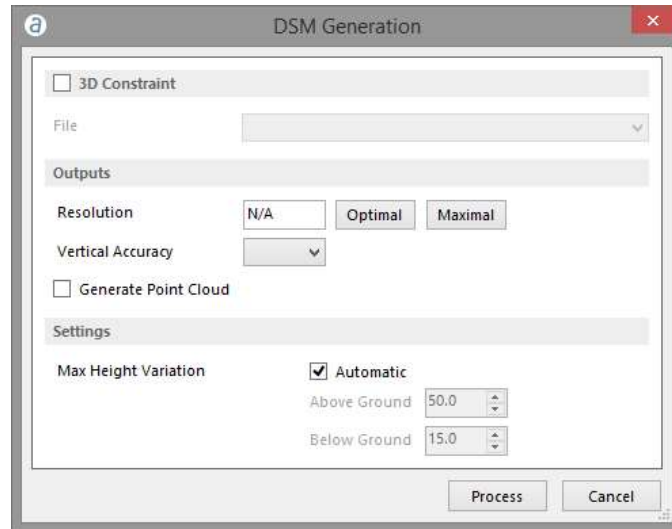


Figure 11: DSM generation dialog.

7.3 DTM Extraction

Correlator3D™ features a module to extract a digital terrain model (DTM) from a digital surface model (DSM). Such models are particularly useful for generating orthophotos, as they avoid visual artifacts (e.g. along building edges) caused by using DSMs. The software analyses the DSM and automatically removes structures lying on the ground.

In addition to the input DSM, an optional constraint file can be provided to Correlator3D™. This file can contain points, lines or polygons with elevation (3D) data. It will force the output DTM to have the provided elevation values at the location of the constraining elements. Alternatively, the user has the option to provide an exclusion zone. In such a case, the software will extract the DTM for all areas minus that of the exclusion zone.

If a constraint is provided, Correlator3D™ will force the output values in the DTM to be consistent with the provided constraint. However, if the constraint is not consistent with the rest of the dataset, it may lead to visual artifacts in the DTM. If such a situation appears, the user should make sure that the input DEM and 3D constraint are in the same coordinate system (e.g. same datum) and that all input data are valid (e.g. camera calibration or exterior orientation parameters).

The user can also output into a DEM the features that were removed from the DSM. Note that only the DSM features will appear in that DEM. All other elevation values will be set as undefined.

To create a DTM, follow these steps:

1. Select the DSM you wish to use for DTM extraction from the project tree.
2. Select "DTM extraction..." in the "Processes" menu.
3. If a constraint is used:
 - a. Check "Constraint".
 - b. Specify the type. Either "Elevation" or "Exclusion Zone".

- c. Choose the file containing the constraint using the corresponding drop-down menu. The constraint will be displayed in the main window overlaid on the DEM.
4. If the DSM features are required:
 - a. Check “Output DSM Features”.
 - b. Specify the output DEM file using the corresponding drop-down menu.
5. Click on the “Process” button. Real-time feedback will be provided on the overall progress of processing. Once the process is done, the DTM will appear in the main window.
6. Save the generated DTM by selecting “Save DEM As...” using the contextual button in the project tree.

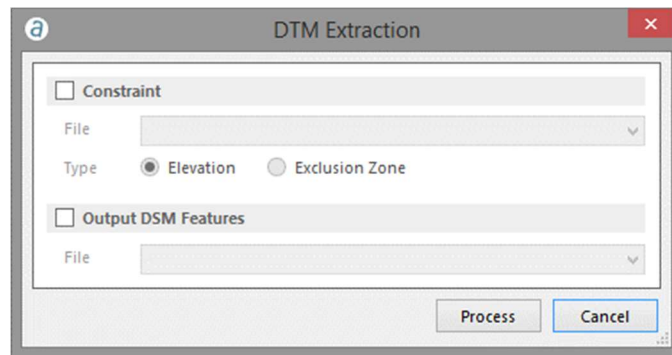


Figure 12: DTM extraction dialog.

7.4 DEM Editing

While the DSM/DTM generation modules produce highly accurate results, the user may still desire to alter results according to their specific requirements. The Correlator3D™ DEM Editing module features nine (9) easy to use, yet powerful editing tools:

- Crop an area
- Delete an area
- Force the elevation to a user-specified value
- Offset the elevation by a user-specified value
- Apply a median or mean filter of user-specified size
- “Delete and fill” i.e. delete an area and analyze neighboring areas to fill the deleted region.
- DTM Extraction for a user specified area
- Touch Up small areas
- Paste an external DEM onto the existing DEM

The aforementioned tools process a user-specified polygonal selection. The time required to perform the operations depends on the operation type and the size / complexity of the selection. The user can also display orthorectified images or a mosaic as an overlay to the DEM using the project tree. This can facilitate the selection of features like water bodies.

To edit a DEM with a user-defined selection the following steps must be performed:



1. Enter the DEM editing module, by selecting “DEM Editing...” in the “Edit” menu. The editing toolbar will appear at the right of the window.
2. Create a selection.
3. Select an operation to perform in the Edit menu or the DEM Editing toolbar.
4. Repeat step 2 and 3, as required
5. Save the edited DEM by selecting “Save DEM As...” using the contextual button in the project tree.



7.4.1 Polygonal Selection



The first step of DEM editing is to make a selection. When the DEM editing mode is enabled and the Touch Up tool is not used, a selection can be entered at any time by clicking on the left mouse button. Doing so automatically deselects the previous selection and starts a new one. Additional left-clicks are necessary to make the selection. To close the selection, the user must click in the vicinity of the initial point or simply right-click.



Correlator3D™ supports single non-self-intersecting polygonal selections. Correlator3D™ will refuse to add a point to or close the selection if it makes the polygon to self-intersect.

When the selection is finalized, the user has the option to edit the selection by moving existing points or creating new ones. Correlator3D™ computes which DEM cells are considered inside the selection. These cells are shaded in gray over the polygonal selection.

A selection can be cleared by pressing the “Escape”.



During a selection, pan operations are supported using the middle (wheel) mouse button. Placing the cursor at the edge of the display area automatically pans the DEM.



Note that zoom operations are not permitted during a selection

7.4.2 Magic Wand



If instead of a polygonal selection, the user wishes to select features, the magic wand option should be used. This option works in a similar manner as the polygonal selection with the only difference being that the selection is squeezed automatically to follow the boundary of a feature. The user has then the option to edit the selection by moving existing points or creating new ones.

7.4.3 Loading a Selection



The user can load a selection from a vector file. This file can contain one or several polygons (selections) that will be considered when using one the tools.

7.4.4 Saving a Selection



The user can save a selection to a vector file. Note that when saving to an existing file, the new selection will be appended. This file can contain one or several selections.

7.4.5 Editing a Selection

The user can modify the path of a selection using two different tools. These tools can be accessed by clicking on their corresponding buttons in the DEM editing toolbar or from the edit menu.



The first one, the hand tool, is used to move, add, or delete selection points. A point can be moved by clicking on its vicinity with the left button of the mouse and dragging it at a new location. Conversely, it can be removed by clicking on the right button. New points can be added by clicking on the right button of the mouse anywhere on the selection.



Depending on the scale factor, Correlator3D™ will adjust automatically the level of details of the selection. Therefore, if the user zooms in the selection, additional selection points will be shown.



The second tool, the scissors tool, is used to remove a series of selection points and replacing them with new ones. A first point must be selected with clicking on the left button of the mouse, and then a second one to determine the series of points to be removed. New points can then be added to follow a new path, starting from the last point to the first one.



The last operation on a selection can always be undone by pressing the corresponding button in the mosaic editing toolbar or using the keyboard shortcut “Ctrl-Z.”

7.4.6 Crop

Correlator3D™ features a polygonal crop tool. Once a polygonal selection is made, the Crop tool will discard any elevation values outside the selection. The DEM will also be resized to fit the size of the bounding box of the selection.



To use the Crop tool, select “Crop” from the “Edit” menu.

7.4.7 Delete

The Delete tool discards all elevation values inside the selection, leaving any other value intact.



To use the Delete tool, select “Delete” from the “Edit” menu.

7.4.8 Set Elevation

The Set and Offset Elevation tools are accessible from the same dialog.

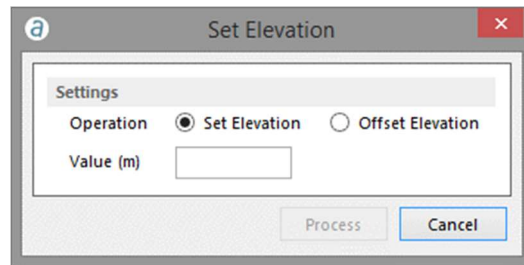


Figure 13: Set and offset elevation dialog.

The following is a description of the required settings:

Operation: Decides between a Set Elevation or Offset Elevation function.

Value: New elevation value for the Set Elevation tool or offset value for the Offset Elevation tool.

The Set Elevation operation sets the selected DEM cells to the specified elevation, while the Offset Elevation operation offsets the selected DEM cells by the specified elevation. The elevation can be a positive or negative fractional value and is specified in the DEM units (meters or feet).



To use the Set Elevation or the Offset Elevation tool, select “Set Elevation...” in the “Edit” menu.

7.4.9 Filter

The filter tool applies a mean or a median filter to the selected DEM cells. Cells outside the selection and cells located on the border will be used to compute filtered elevation values. However, these cells will remain unaffected by the process. Settings can be adjusted using a dialog.

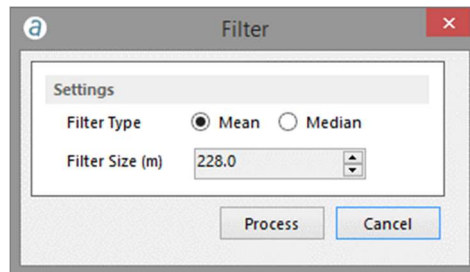


Figure 14: Filter dialog.

The following is a description of the required settings:

Filter Type: Decides between mean and median filters.

Filter Size: Diameter of the filter, specified in DEM units (meters or feet). The specified value must be an odd multiple of the DEM resolution.



To use the Filter tool, select “Filter...” in the “Edit” menu.

7.4.10 Delete and Fill

Delete and Fill is probably the most useful and powerful editing tool provided by Correlator3D™. With a single click, all the selected DEM cells are deleted and replaced by new elevation values obtained from an analysis and interpolation of the area surrounding the selection. It requires no parameters to be specified and provides excellent results in most situations.



To use the Delete and Fill tool, select “Delete and Fill” from the “Edit” menu.

7.4.11 DTM Extraction

The DTM Extraction tool extracts the DTM for the selected DEM cells. It uses the same algorithms than the DTM extraction process and settings can be adjusted using a similar dialog. Please refer to Section 7.3 for further details.

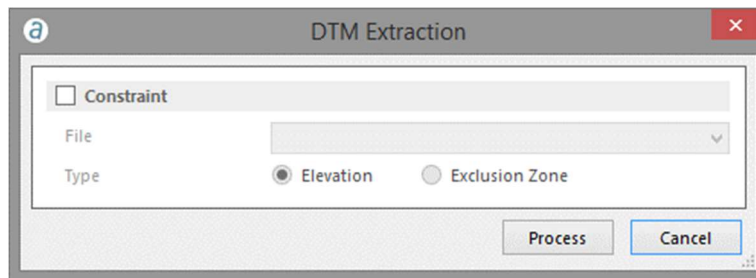


Figure 15: DTM extraction dialog.



To use the DTM Extraction tool, select “DTM Extraction” from the “Edit” menu.

7.4.12 Touch Up

The Touch Up tool works in a similar manner than the Delete and Fill tool. Instead of requiring a manual polygonal selection, a small fixed-size square selection is automatically performed around the location clicked by the user. The tool requires less user interaction and the internal processing is optimized for higher performances. Thus, it is a very fast tool to correct small areas.

To edit a DEM with the Touch Up tool, the following steps must be performed:



1. First enter the DEM editing mode by selecting “DEM Editing...” in the “Edit” menu. The editing toolbar will appear at the right of the window.
2. Select “Touch Up” in the “Edit” menu.
3. Click the area to correct.
4. Repeat step 3, as required.
5. Exit the DEM editing mode by selecting “DEM Editing...” in the “Edit” menu. The editing toolbar will disappear.



6. Save the edited DEM by selecting “Save DEM As...” using the contextual button in the project tree.



The size of the square selection is automatically adjusted with the zoom factor used to visualize the DEM. If the size is inappropriate for a given situation, the Delete and Fill tool can be used instead.

7.4.13 Paste DEM

The Paste DEM tool replaces regions of the current DEM with a provided DEM. The user can adjust the height tolerance parameter that defines the difference in height between the two DEMs for which a smooth transition will be calculated. Hence, elevation values showing a difference smaller than this value will be averaged in the final DEM.

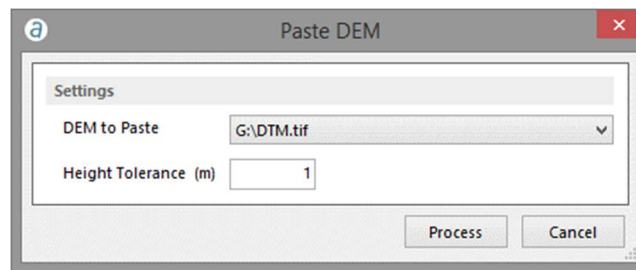


Figure 16: Paste DEM dialog.



The Paste DEM tool will not consider any current selection as the input DEM will be pasted entirely.



To use the Paste DEM tool, select “Paste DEM” from the “Edit” menu.

7.5 Orthorectification

Correlator3D™ can generate orthorectified images. In addition to input images, it requires a DEM and exterior orientation parameters. The user can specify the desired output resolution, or simply request the software to calculate the optimal value. This feature automatically determines the ground sampling distance (GSD) of the input imagery.

Correlator3D™ can generate true orthos if a DSM and/or a constraint file is used. In such a case, the orthorectification process will correct for the distortion of buildings and other 3D structures, resulting in a true ortho. Occluded areas which have no image content, e.g. building shadows, will be set to black in the final orthorectified image. Note that if a constraint file is inputted, it must contain polygons with elevation (3D) data defining the structures.

For frame-based sensors, the user can also specify the overlap of the resulting orthophotos. By default, the software will suggest the maximal overlap, i.e. the actual overlap between images. The user can also select the optimal overlap, which corresponds to 30%.



Choosing a smaller overlap will result in a faster orthorectification, smaller orthophotos on disk and ultimately faster mosaic creation. Note however that reducing the overlap between orthophotos will also reduce the area where a mosaic seamline can go through and may therefore impact results.

For UAV/medium/large format sensors, the user can crop the image width and height to any user-defined value. This allows for forward and sidelap control, which may be desirable as a strategy to extract the most nadir image portion from the orthophoto.



The better the quality of the inputs, the higher the quality of the resulting final orthophotos. Therefore, it is recommended first to perform an aerial triangulation¹, a DSM generation and a DTM extraction and then use the DTM for producing orthorectified images.



The output format of the orthorectified images is by default tiled with overviews. This should not be changed if the user prefers using the Mosaic Editing module afterward to obtain the highest performance.

A real-time overview of the orthophotos will be displayed during processing. Each time an orthorectified image is generated, it will appear as an overlay to the currently loaded DEM.

To create orthorectified images, the following operations should be performed:



1. Select the DEM you wish to use for orthorectification from the project tree.
2. Select "Orthorectification..." in the "Processes" menu.
3. If true orthorectification is required:
 - a. Check "DSM-based" if a DSM is being used for orthorectification.
 - b. If a 3D constraint file is used, check "Constraint File" and specify the file using the corresponding drop-down menu. The constraint will be displayed in the main window overlaid on the DEM.
4. Specify the desired output horizontal resolution or press the "Optimal" button to let the program calculate the optimal value.
5. In the "Settings", select "Overlap" to specify the desired output overlap percentage. Press the "Optimal" or the "Maximal" button to let the program calculate the optimal or maximal value. To crop the image width and height, select "Crop" and specify the desired percentages.
6. Specify the format for the orthorectified images.
7. Click on the "Process" button. Real-time feedback will be provided on the overall progress of processing.

¹ Not supported for ADS and VMA3 sensors.

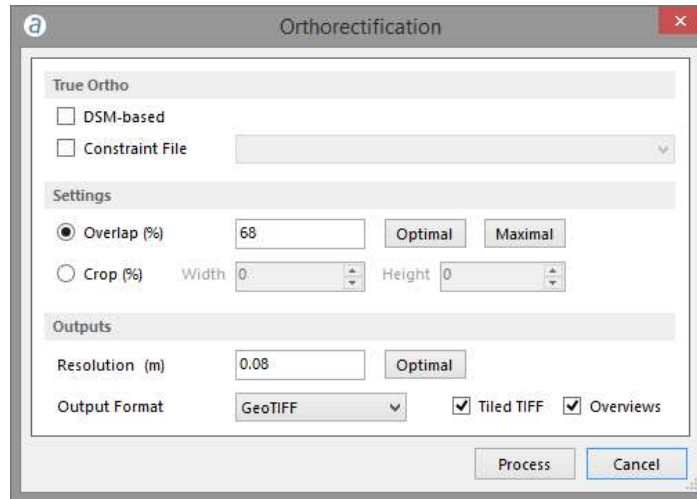


Figure 17: Orthorectification dialog.

7.6 Mosaic Creation

The mosaic creation module allows for the merging of individual orthorectified images to obtain a unique image covering the entire project area. The process is entirely automated. Correlator3D™ will select which portion of which image must be included in the final mosaic. Local intensity adjustments and seamline generation are performed to provide smooth and seamless transitions between adjacent images composing the mosaic.

Before starting the mosaic operation, the user can specify how many blocks to divide the mosaic into at minimum. A block is a smaller section or part of the overall mosaic. The purpose of this is to support the generation of large mosaics but also to allow multiple users to edit different blocks simultaneously after the mosaic has completed. The number of blocks is therefore dependent on the user's choice and project size. The software will create the blocks according to the user's selection, but may need to perform further block divisions as necessary.

Selecting the Bound Mosaic Area option allows to generate a mosaic for only a portion of the project, as defined by a user created polygons stored in a tile definition file or a Shapefile. The user can also specify the size of the feathering zone depending on project type. The feathering zone is the region along a seamline where blending will be applied to ensure a smooth transition from one image to the other. For urban areas, a smaller value is recommended in order to avoid ghosting effects along smaller objects like cars. In other areas like open fields, the value should be larger since the content is very similar from one image to the other. The size of the feathering zone is specified in pixels. Note that when editing a mosaic, a different value can be specified for each seamline.

Fully automated color balancing can be applied during the mosaic creation process. This balancing includes:

- Brightness and contrast adjustments of each image
- Inter-image equalization

- Independent channel analysis for hue equalization
- Photometric constraints to maintain global information of brightness, contrast and hue

Some projects may include regions where colors are very different from one image to the other (e.g. water bodies). In order to avoid these regions to have too much effect on the color balancing results, the user can specify an exclusion zone. This file can contain several polygons depicting the regions to be ignored.

The output of the mosaicing process consists of a single image divided in multiple blocks, themselves divided into multiple tiles. Files required to manually edit the mosaic seamlines and colors are automatically generated during mosaicing and are stored in subfolders to the mosaic folder. The software has therefore its own structure to store the files. Users who desire to specify their own mosaic tiling and format have to export the mosaic, either during the mosaic creation process, or during mosaic editing. This functionality is described in section 7.7.2.

To create a mosaic, follow these steps:



1. Make sure the project includes orthos.
2. Select "Mosaic Creation..." in the "Process" menu.
3. If only some portions of the orthos need to be mosaiced, check "Bound Mosaic Area" and specify the file using the corresponding drop-down menu.
4. Specify the size of the feathering zone in pixels.
5. Specify the minimum number of blocks
6. If color balancing is required, check "Color Balancing".
7. If an exclusion zone is specified, check "Exclusion Zone File" and specify the file using the corresponding drop-down menu.
8. If the mosaic needs to be exported after the process, check "Export Mosaic after Completion". A dialog will be displayed before the process to specify export options.
9. Click on the "Process" button. Real-time feedback will be provided on the overall progress of processing.

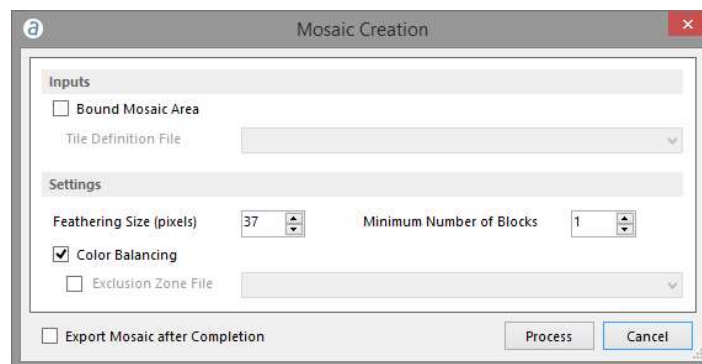


Figure 18: Mosaic creation dialog.

7.7 Mosaic Editing

The mosaic editing module allows the auto-generated mosaic to be interactively adjusted according to specific user requirements. It provides a smooth interaction with the data and allows real-time updating during modifications, without having to regenerate the entire mosaic completely. This design reduces the number of manual operations required, significantly increasing the overall productivity.

Correlator3D™ also allows for limitless users to simultaneously edit a mosaic without conflicts or duplication of any data. Therefore, multiple users can access the same mosaic location, reducing significantly storage requirements and leading to fast and efficient operation suited to production environments.

To edit a mosaic, please follow these steps:



1. Make sure the project includes a mosaic and the orthos used to generate this mosaic.
2. Select “Mosaic Editing...” in the “Processes” menu. The mosaic and the corresponding blocks will then appear in the main window.

Upon entering mosaic editing mode, users are presented with a view of the entire mosaic and a block overlay. The block overlay reveals how the mosaic is split up. This view enables users to apply global operations to the entire mosaic area including exporting seamlines, exporting the mosaic and manually adjusting the colors.

Users can also edit the auto-generated seamlines by selecting which block(s) to work on. Blocks are selected by clicking on them. While each mosaic block can be edited by a single user, different mosaic blocks can be edited simultaneously by multiple users. In order to provide multiple users seamline editing capability, Correlator3D™ provides an automatic locking system. Blocks already in use cannot be selected and will be shaded in red to indicate they are locked by another user. Otherwise, if no blocks are in use, then they will all be shaded in green to indicate they are available.



Please note, while users do not need to manually select them, all blocks must be available (i.e. not locked) to export seamlines, export the mosaic or manually adjust colors.

7.7.1 Export Seamlines



Users can export the seamlines to an ESRI Shape file by pressing the corresponding button in the toolbar.

7.7.2 Export Mosaic



Users can export the final mosaic using a tile definition file and selecting the type of mosaic they want to create. Either a standard mosaic or a NDVI (Normalized Difference Vegetation Index) map can be created. If the latter is selected, red and infrared bands must be available in the original mosaic. Users can specify different settings for the resulting NDVI map by clicking on the

corresponding button, including the type of color map to be used, the number of classes (colors), as well as the bounds of the index.

Users can either specify a fixed size for the tiles, or specify individual tile size and coordinates through a tile definition file. If a fixed tile size is specified in the dialog, each tile will have that size, except for tiles located on the border of the mosaic. In such cases, the size of the tile is simply reduced to remove unnecessary undefined areas. The tiles are created to be juxtaposed one after the other with no overlap between two adjacent tiles. The naming of the tiles describes the spatial relation between each other. The name convention is as follows: Name_LineNumber_ColumnNumber.tif.



The position and orientation of the input orthorectified images can lead to situations where some tiles only contain undefined data (completely black areas). When specifying a fixed tile size in the Export Mosaic dialog, if such a situation occurs, the corresponding tiles are not created by Correlator3D™. This behavior is part of an optimization effort to reduce memory and disk requirements while improving overall performance.

If a tile definition file is used, then the tile size specified will be respected, even if the resulting area contains unnecessary undefined areas. Moreover, each tile will be created even if they do not contain any data at all.

Users can also export only a portion of the mosaic using the "Crop Area" option, as defined by a user created polygon stored in a DGN file or a Shapefile.

To export a mosaic, the following steps must be performed:

1. If a Crop Area is used, specify the constraint file using the corresponding drop-down menu.
2. If a Tile Definition File is used, specify the Tile Definition File using the corresponding drop-down menu.
3. Specify the Mosaic Folder that will contain the mosaic using the corresponding drop-down menu.
4. If no tile definition file is used:
 - a. Specify the name for the mosaic.
 - b. Specify the tile size.
5. Specify the format for the mosaic tiles.
6. Click on the "Process" button. The mosaic will then be exported using the parameters specified.

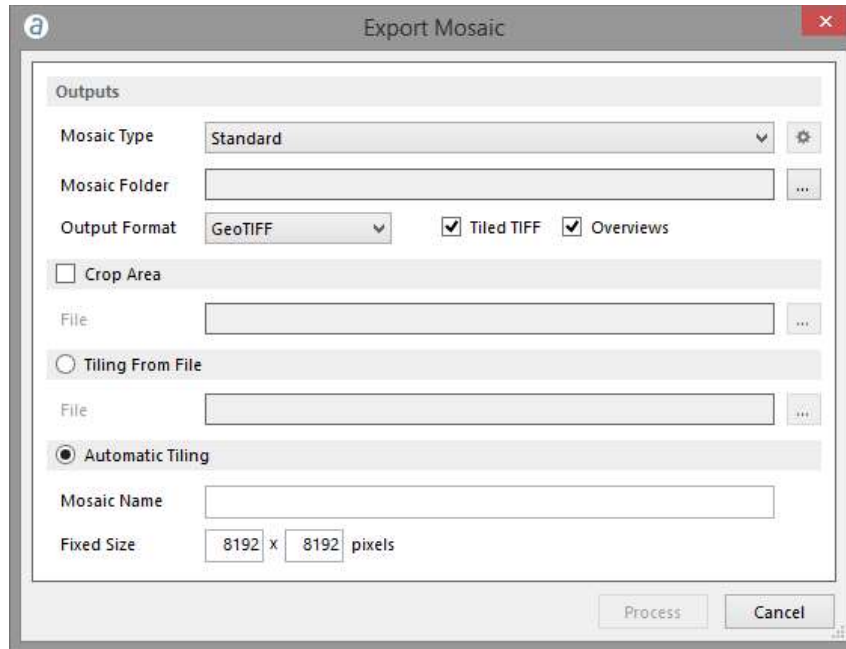


Figure 19: Export mosaic dialog.

7.7.3 Adjusting the Colors



Users can adjust the global colors of the mosaic using the Color Adjustment tool to enhance its visual appearance. This tool allows modifying the levels of the mosaic, i.e. making adjustments to the brightness, contrast, and gamma for each individual channel or for all channels together.

In the Channel drop-down list, users can select a color channel to edit. Depending on the number of channels of the imagery, users can choose the "Master" channel to edit the red, green, blue and alpha channels all together, or choose "Red", "Green", "Blue" or "Alpha" to edit the channels individually. Note that selecting the "Alpha" channel will also allow users to display this channel in the main window. For grayscale mosaics, only one channel can be selected.

The original histogram of the mosaic for the selected channel is displayed in blue in the dialog, while the new histogram to be applied is overlapping in red. A preview of the adjusted mosaic is displayed on the mosaic in the main window. This option can be toggled at all times in the color adjustment dialog.

To increase the contrast of the image, users must drag the input levels sliders, which show the image's brightness values. To darken the darkest values, the left slider must be dragged to the right; all values below this value become zero (black). To lighten the lightest values, the right slider must be dragged to the left; all values above this value become 255 (white) or 65,535 for 16-bit imagery. To change the value of medium grey, the gamma slider must be dragged left or right; the range for of the gamma value is 0.1 to 10.0, with 1 being in the middle.

To decrease the contrast, users must drag the output levels sliders. To lighten the darkest pixels, the left slider must be dragged to the right. To darken the lightest pixels, the right slider must be dragged to the left.



For 16-bit imagery, users can activate the "Stretch" mode of the main window. Doing so when the Color Adjustment dialog is displayed will automatically stretch the histogram of the Master channel and therefore provide a quick way of adjusting the colors over the 16-bit range.

Adjustments to the mosaic on disk will not be applied until the "Process" button is clicked. Note that once the process is started, it cannot be stopped since all mosaic tiles on disk must be adjusted with the same parameters.

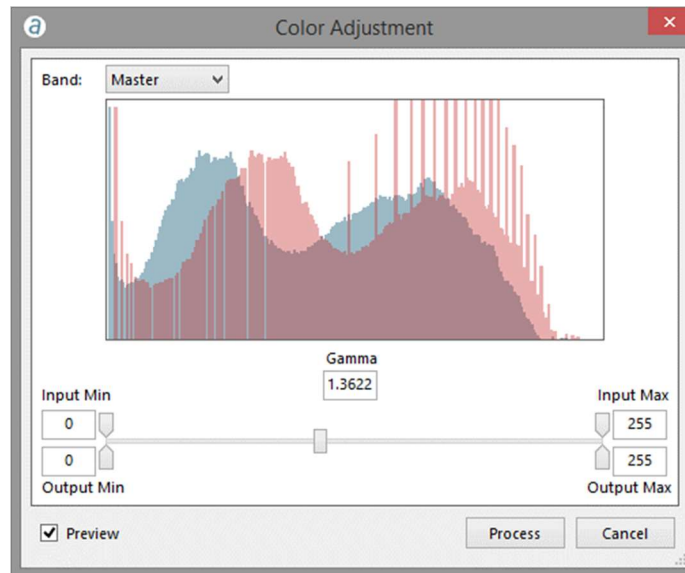


Figure 20: Color adjustment dialog.

7.7.4 Seamline Editing Mode



After the blocks to be edited have been selected, press the "Seamline Editing" button to enter Seamline Editing Mode.

Note that users can toggle back to the mosaic overview to select different blocks by pressing the "Block Section" button.



To ensure smooth operation and to minimize memory requirements, it is recommended to select the fewest blocks possible when entering into seamline editing mode.

There are two viewing modes in which users can interact with the project. In both modes, users can zoom in, zoom out or pan the images the same way they interact with a DEM. The first mode displays the chosen blocks and the corresponding seamlines and is used to visually inspect this mosaic section and locate seamlines to be edited.

The second mode is used to edit a particular seamline. Users can access this mode by clicking on the seamline to be edited. Correlator3D™ will then load the images corresponding to each side of the seamline. One side is displayed as a bright image and corresponds to the mosaic region that was generated prior the addition of the new orthorectified image. The other side is displayed as

a dark image and corresponds to the new orthorectified image that is being added to the mosaic. The overlap region between both images is displayed with the original color.



In order to accelerate the loading time, only orthorectified images corresponding to the current view region are displayed. Therefore, when editing a seamline, some images may be missing if users pan outside the region.

Correlator3D™ displays seamlines according to a particular color scheme. A color is assigned to each segment of a seamline depending on its quality, i.e. as determined automatically during the mosaic creation. If the software is confident that the seamline follows a path that minimizes the artifacts in the final mosaic, it will be green. If not, its color will be red and if the confidence level is in between, the seamline will be yellow. Note seamlines that have been previously edited will be blue. Users can therefore rely on the color scheme to have a first appreciation of the mosaic and determine which seamlines should be edited first.



For 16-bit imagery, users can also stretch the histogram to improve brightness and contrast during mosaic editing. It can be enabled or disabled by selecting “Display Style->Stretch” in the “View” menu. Note that enabling this mode will not modify the colors of the mosaic on disk.



Users can also display the mosaic tile definition by toggling the corresponding button. The name of each tile as well as its boundaries will be displayed as an overlay to the mosaic. If a tile overlay was not provided by the user, then this option will instead display the software's own internal tile definition for the blocks.

7.7.4.1 Interacting with Seamlines

Once a seamline has been selected, users can modify its path using two different tools. These tools can be accessed by clicking on their corresponding buttons in the mosaic editing tool bar or from the edit menu. Users can also switch from one tool to the other by pressing the “Tab” key on the keyboard.



The first one, the hand tool, is used to move, add, or delete seamline points. A point can be moved by clicking on its vicinity with the left button of the mouse and dragging it at a new location. Conversely, it can be removed by clicking on the right button. New points can be added by clicking on the right button of the mouse anywhere on the seamline.



Depending on the scale factor, Correlator3D™ will adjust automatically the level of details of the seamlines. Therefore, if users zoom in the seamlines, additional seamlines points will be shown.



The second tool, the scissors tool, is used to remove a series of seamlines points and replacing them with new ones. A first point must be selected with clicking on the left button of the mouse, and then a second one to determine the series of points to be removed. New points can then be added to follow a new path, starting from the last point to the first one.



When moving points of a seamline, a red region is displayed around the seamline. This region corresponds to the feathering zone, i.e. the region where a progressive transition is made between an image and another. Users should take into account this region when defining the path of a

seamline since it may result into blurry results in the final mosaic. For example, the feathering zone should not pass nearby an object if this object does not appear in both images.



When modifying the path of a seamline, Correlator3D™ will automatically update the image to represent what the mosaic should look like, without feathering and color balancing being applied.



If there is a seamline traversing multiple blocks, then only the section of the seamline in the currently loaded blocks will be available for editing. Furthermore, modifying the point at the boundary of the block will not be possible. Likewise, changing the feathering size will not be possible unless all the blocks containing the seamline are loaded.



The last operation on a seamline can always be undone by pressing the corresponding button in the mosaic editing toolbar or using the keyboard shortcut “Ctrl-Z.”



Users can also modify the size of the feathering zone for a specific seamline. Once the new size has been set, it will first modify the size of the red region that is displayed around a seamline when moving its points. Note that modifying the size of the feathering will have a great impact on the processing time when updating the mosaic since it has to be applied on its full length. Also note that the new size only affects the currently selected seamline, and that a different size can be specified on every seamline.



Note, the feathering size can only be changed for an entire seamline. Hence, if a block contains only part of that seamline, then the feathering size cannot be adjusted. Users will need to load all blocks containing a seamline in order to change its feathering size.

7.7.4.2 Updating the Mosaic



Once users are satisfied with a seamline, modifications must be saved by pressing the corresponding button in the mosaic editing toolbar or the keyboard shortcut “Enter”. The display will then automatically switch back to the mosaic viewing mode. Each modified segment of the seamline will be displayed in blue, and the region of the mosaic that will be affected by the modifications will be highlighted in cyan.



Users can then update the mosaic by pressing the corresponding button in the mosaic editing toolbar. Correlator3D™ will only process the new region, with feathering and color balancing being applied. This functionality removes the necessity of regenerating the whole mosaic and allows users to get the final result in a matter of seconds.



Modifications of a seamline can also be discarded by pressing the corresponding button in the toolbar or the keyboard shortcut “Esc”. The display will then automatically switch back to the mosaic viewing mode with the original seamline being displayed.

Table 5 summarizes the keyboard shortcuts that can be used when editing seamlines.

Action	Keyboard Shortcut
Undo the last operation on a seamline	Ctrl-Z
Change current editing tool	Tab
Save modifications to a seamline	Enter
Discard modifications to a seamline	Esc

Table 5: Keyboard shortcuts for mosaic editing.

8. Automated Workflow

The automated workflow is an automatic solution to the traditional Correlator3D™ data production process. This tool is used to perform the complete Correlator3D™ workflow:

- Aerial Triangulation
- DSM Generation
- DTM Extraction
- Orthorectification
- Mosaic Creation

It is important to note that each step is optional; the user selects which processes to automate. As seen in the following figure, by simply selecting or de-selecting a checkbox, the user can perform desired actions. For example, the user can start the automated workflow from DTM up to mosaic only by using the checkboxes.

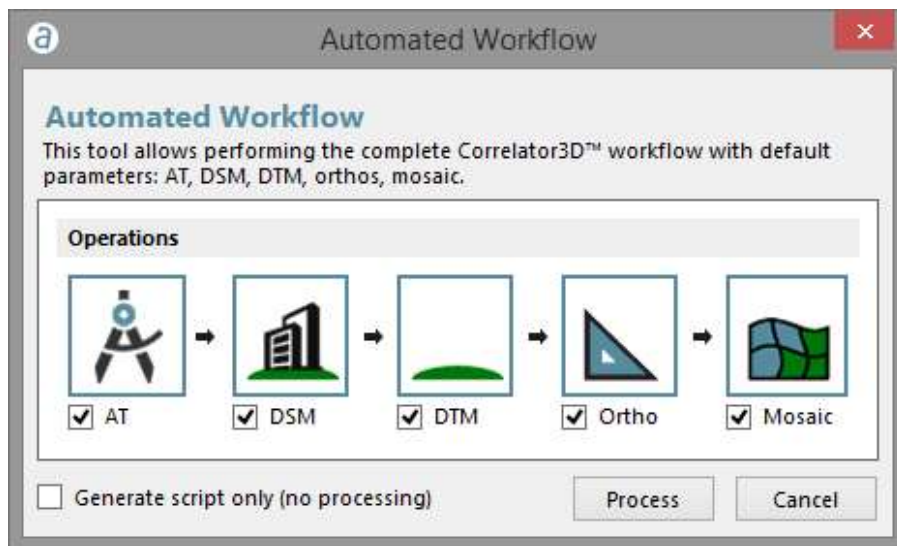


Figure 21: Automated workflow dialog.

The automated workflow creates:

- Adjusted EO and camera calibration parameters
- DSM
- DTM
- One individual orthophoto for each input image
- Orthomosaic

Selecting the “Generate script only” option seen at the bottom of the dialog, the user can create a script with the chosen actions. The script can be adapted to specific requirements, where variables and parameters can be changed from the default settings. The user can then execute the script from the file menu.

A script file (Project.spt) is also created in the output project folder and used by Correlator3D™ during the automated workflow. It is possible to manually modify and run the script file. Further details can be found in section 11.

9. Feature Extraction

The feature extraction module enables the user to extract 3D features from a DSM by creating 3D polygons. Automatic contour detection of buildings and other features enable fast footprint collection. Intelligent analysis aids the user while editing features, using the 3D information in the DSM to automatically calculate how well planes fit the segmented polygon and providing visual feedback. Feedback can also be provided through real-time true orthorectification to achieve pixel accuracy. This semi-automatic design saves time over traditional vector extraction methods.

To extract features, the following operations should be performed:



1. Select the DEM you wish to use for feature extraction from the project tree.
2. Select “Feature Extraction...” in the “Mode” menu.
3. Check the Edit/Append box to edit an existing vector file. Specify the vector file using the corresponding drop-down menu. The vector file must be an existing ESRI shapefile containing 3D information.
4. Check the "Real-time True Ortho" box to enable this feature. Specify the DTM file using the corresponding drop-down menu.
5. Click on the “Process” button to start extracting 3D features. The resulting vector information will be saved in a new vector file once the user chooses the save option in the feature extraction menu.

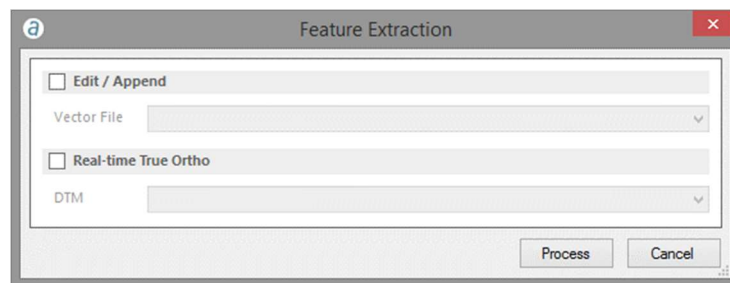


Figure 22: Feature extraction dialog.



If loading an existing vector file containing building footprints, the user will need to select/edit each building to assign a 3D polygon.

9.1 Extraction Modes

There are four modes in which the user can interact with the DSM. These four modes are based on feature type which includes buildings, roads, water bodies and forests. The default mode is buildings. The user can switch modes by clicking on the Process menu and selecting the mode of choice.

9.1.1 Building Extraction Mode



Should the user wish to extract buildings must first ensure they are in the building extraction mode. A building is selected in 2 steps. First, pan and zoom to the area of interest. Second, make a rough selection around the building by clicking around the building perimeter. The software will automatically squeeze the selection around the contour of the building as shown in Figure 23.



The user can go back to the original selection by selecting "Undo" in the "Edit" menu.

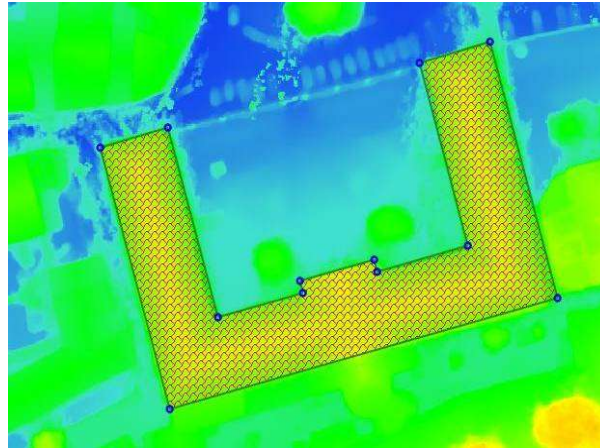


Figure 23: Contour around a building.



The user then has the option to modify the contour according to their requirements using the hand tool. The hand tool is used to move, add, or delete points. A point can be moved by left-clicking and dragging it to a new location. Conversely, it can be removed by right-clicking with the mouse. New points can be added by right-clicking anywhere on the contour.



Holding the control (Ctrl) button while moving a line segment will restrict the movement of that segment in such a way that the line segment moves either in a direction parallel to itself or in a direction along itself (collinear with itself). A special case occurs when moving an interior line segment contained within the building footprint. In this case, the line segment will also resize itself to fit within the building footprint. Note, however, the line segment may not resize itself if the building footprint is irregular.



The edge merging option is enabled by default. When enabled, edges will be merged together as long as they are collinear and represent the same line.



When using the hand tool to add a point, that point may "disappear" if it was added to a straight line. This is because the edge merging tool is enabled. The edge merging tool "sees" this point as splitting a line segment into two collinear line segments and consequently merges them. Hence, the edge merging tool should be disabled to split a straight line into two parts.



All angles of a selected building contour that approach ninety (90) degrees can be rectified. The rectify operation changes these angles to be as close to ninety (90) degrees as possible.

The software automatically extracts 3D information from the DSM and determines the z-value of each vertex of the polygon bounded by the contour. The polygon starts off as a plane representing the building. In most cases a building's roof is more complex than a plane. For these situations, the "Add a surface" tool can be used to add further details to the building polygon. The 'Add a surface' tool is used to segment the building polygon into more planes to better represent the roof geometry. To segment the plane, left click and hold on any contour line of a building and drag the mouse to see a dotted line indicating the plane segmentation as shown in Figure 24.

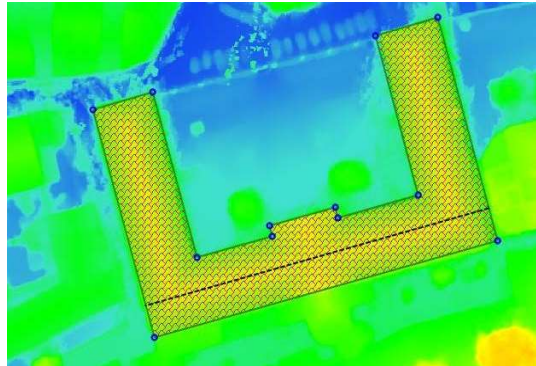


Figure 24: Plane segmentation indicated by the dotted line.

The newly created dotted line indicates the building polygon is divided into two sections. The software automatically recalculates the new plane to be applied to each section and determines the z-value of each vertex. It uses the 3D information in the DSM for this calculation. The fact that the line is dotted indicates that the two new planes touch at their boundaries (e.g. two planes that create a roof slope). If the line was solid it would indicate that the boundary of one plane meets the other plane in an area other than the boundary, creating a discontinuity in elevation (e.g. when a small building is connected to a taller building). In other words, the software automatically uses the building contour (the outer most border of the building) and the dotted/solid lines to fit planes within those boundaries. The user should segment the building polygon to create as many planes as necessary to represent all the various slopes in the roof geometry of a particular building.

In addition to segmenting planes by clicking on the edges, points can likewise be dragged to divide the polygon into different slopes. New points can also be added by right-clicking on the feature lines.

If the surface merging option is turned on, planes that are coplanar and that represent the same surface will be automatically merged together as the user is modifying the building.

Visual feedback is provided based on how well planes fit within their surfaces. In particular, as the user is segmenting the polygon to better define roof geometry, the software automatically calculates how well a particular surface can be represented by a single plane. If a plane poorly represents a surface, then that plane is shaded red. Likewise, if a plane represents a surface only marginally well, then it is shaded yellow. Otherwise, the plane fits a surface well and is shaded green.



The best fit function uses the information in the DSM to improve the position of the planes. The criterion for moving vertices is based on which configuration will result in the best fit for the planes. Note this might not necessarily correspond to the best visual positioning of the contour. If the position of the points is already optimal, then the best fit function will not perform any further changes.



Note that elevation values for each vertex can also be manually set. Use this function to select any vertex and change the elevation value.

9.1.2 Road Extraction Mode



This mode allows the user to extract road features. The user traces out the road using the mouse. For each vertex of the polygon, the median elevation within a fixed boundary inside the polygon is taken as the road height. This accounts for any banking or slopes the road may traverse.

9.1.3 Waterbody Extraction Mode



This mode allows the user to extract water surfaces. The user traces out the water boundary using the mouse. For each vertex of the polygon, the median elevation within a fixed boundary outside the polygon is taken as the water height. This means that there must be some ground clearing around the waterbody in order for the polygon to take on appropriate values.

9.1.4 Forest Extraction Mode



This mode allows the user to extract forests. As in building extraction, this mode uses contour fitting. Hence, the user needs only to make a rough selection around the forest area and the software will automatically squeeze the selection to the forest boundary. The elevation applied will be a local average at each vertex.

Table 6 summarizes the keyboard shortcuts that can be used when extracting features.

Action	Keyboard Shortcut
Switch between Move a Point and Add a Surface	Tab
Surface Merging	Ctrl + U
Edge Merging	Ctrl + E

Table 6: Shortcuts for feature extraction tools

9.2 Attributes

Attributes may be applied to each feature. To apply an attribute to a feature, the user needs to first select that feature and enter corresponding information. New fields can also be created to suit the user's requirements. Moreover, an XML file can be provided containing a user's desired attribute list. The information in this XML file will be loaded automatically. To specify the XML file,

please select "Feature Attribute File" in "General Settings" which can be accessed from the "File" menu.

9.3 Real-time True Orthorectification



A true ortho can be created for a small region in real-time around a selected feature. To allow for true orthorectification, the necessary inputs need to be specified when entering feature extraction mode. The user then proceeds to the feature extraction process. At any time, the user can enable true ortho generation by toggling the "Display real-time true ortho" button. Note, as the user continues editing the selected feature, the true ortho will be automatically updated to reflect the changes. This enables the user to iteratively refine the polygon for the selected feature until the true ortho is a perfect fit.

10. Tools

10.1 Import EO Data

Correlator3D™ features a tool to import EO data. The tool allows to load EO data stored in a file (ASCII format) and to arrange it according to the SimActive format. In the original file, the EO data must be ordered by columns and the tool assigns specific columns to particular EO values (i.e. image name, easting, northing, elevation, omega, phi and kappa). The interface also allows some rows or columns to be ignored.

The user must specify in which units the angular values are represented (degrees, radians or gradians) and the tool will convert them, if necessary, to degrees. An angular offset can also be added to kappa values by using the "Camera Mount Rotation" option. In addition, if values in the "ImageName" column do not include a file extension (e.g. tif, jpg or bmp), then the tool can automatically add one using the "Add Extension to Image Name" option.

The user must select a position and orientation system. The software operates using the "Easting/Northing" position and the "Omega/Phi/Kappa" orientation systems. However, a "Lat/Long" position and/or "Roll/Pitch/Yaw" orientation system may be specified. The tool will then perform the necessary conversion. Note, the user must specify a projection to allow conversion between different position and orientation systems. The orientation system can also be set to "Automatic". This will set omega and phi angle values to zero, and the kappa will be derived from the image positions.

Note, that the interface also allows the user to edit a particular cell value and to remove undesired lines.

To create an EO file, the user should perform the following operations:

1. Specify an ASCII file by pressing the corresponding "..." button.
2. Specify the delimiter(s) to be used by the software to recognize the columns in which EO data are represented.
3. Specify the input angular units.
4. If required, specify a camera mount rotation to add an angular offset to the kappa values.
5. If required, specify an extension to be added to image names.
6. Select the appropriate position and orientation system.
7. If necessary, select the projection.
8. Assign EO data values to the appropriate columns by pressing on the buttons located at the top of the displayed ASCII file.
9. Remove any undesired rows by clicking on the corresponding check box located at the beginning of a line.

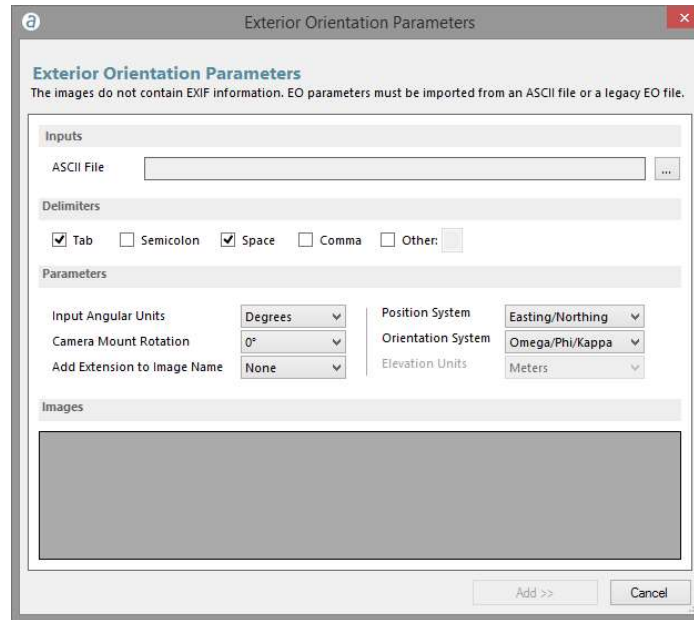


Figure 25: EO file creation dialog.

10.2 Seed DEM Creation

While it is strongly recommended to use a coarse DEM created using the AT module or at least DTED Level 2 elevation data or equivalent as a seed to DSM generation process, Correlator3D™ offers a tool to automatically create a seed DEM. The software creates a DEM with the boundaries computed from the provided project and with every elevation point set at the specified terrain height.

To create a seed DEM, the user should perform the following operations:

1. Select “Seed DEM Creation...” in the “Processes” menu.
2. Specify the average terrain height.
3. Click on the “Process” button. Real-time feedback on the overall progress of processing will be provided. Once the process is done, the seed DEM will appear in the main window.

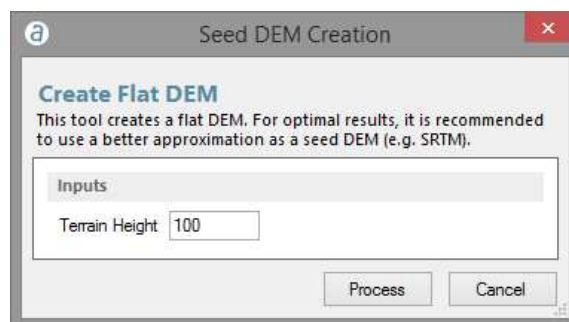


Figure 26: Seed DEM creation dialog.

10.3 Fiducial Detection

Correlator3D™ features a tool for automatically detecting fiducials. The tool is useful for extracting the position of marks (in pixels), which are necessary for using any processing module of the software with scanned films. The fiducial detection tool is shown to the user when creating a project with scanned films.

Correlator3D™ supports fiducial marks that consist of two lines intersected in a perpendicular manner. These two lines can be continuous or not and the corresponding cross mark can be oriented in any way. Also, note that fiducials are assumed to be bright on a black background.

Fiducial detection is performed in four steps:

1. The user enters the required information in the fiducial detection dialog.
2. The user manually selects the fiducial marks for the first image.
3. Correlator3D™ automatically detects the fiducial marks for the remaining images.
4. Correlator3D™ automatically validates the detection results and prompts the user to manually select the fiducial marks for faulty images.

Detection results can be verified visually using images that the software automatically generates (these can be found in the temporary folder as described in Section 12.3). The figure below shows an example of a successful fiducial detection. Note that the center of the green mark represents the location where the software located a fiducial mark.

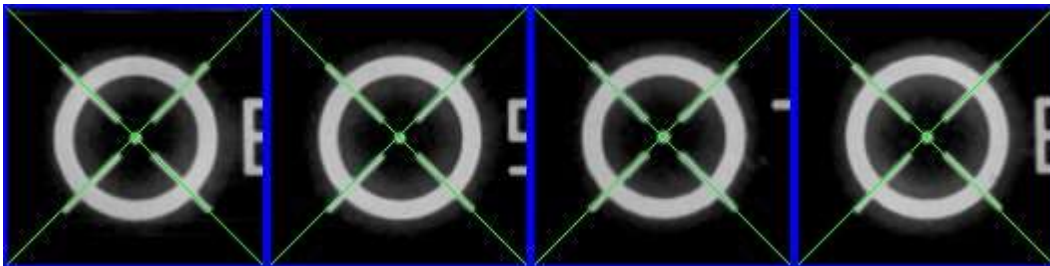


Figure 27: Sample fiducial detection results.

Fiducial marks that are incorrectly detected can be easily identified by looking at these images. The following figure presents such a situation. In that case, the user should manually correct the resulting exterior orientation file. Note that a warning will be reported in the log file (Section 12.1) when there was an error in the detection process.

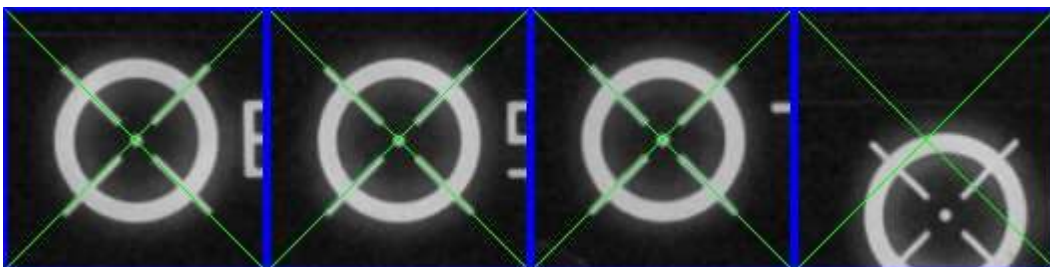


Figure 28: Sample fiducial detection results with one mark incorrectly identified.

The user can skip the automatic detection phase and manually select the fiducial marks.

To use the fiducial detection tool, the user should perform the following operations:

1. Drag each of the four images until a fiducial mark appears in the center of each frame under the green marks.
2. Check the "Skip automatic detection" if all fiducial marks need to be selected manually.
3. Click on the "OK" button when all fiducial marks are correctly selected.
4. Automatic detection is performed and real-time feedback on the overall progress of processing is provided.
5. Automatic detection of faulty images is performed. If necessary (or if the "Skip automatic detection" was checked), the fiducial detection dialog for manual selection appears and these steps must be performed:
 - a. Drag the faulty fiducial marks under the corresponding green marks.
 - b. Click the "Next" button.
 - c. Repeat steps a) and b) until process is completed.

When using the fiducial detection dialog for manual selection, the size of the fiducial marks can be adjusted by using the "+", "-" and "1:1" buttons. The fiducial marks are selected by dragging their image portion over the intersection of green lines, either by using the mouse or the arrow keys on the keyboard. If the arrow keys are used, "Shift" and "Ctrl" keys can serve for coarser, but faster positioning, while the arrow keys alone are better suited for fine-tuning purposes.

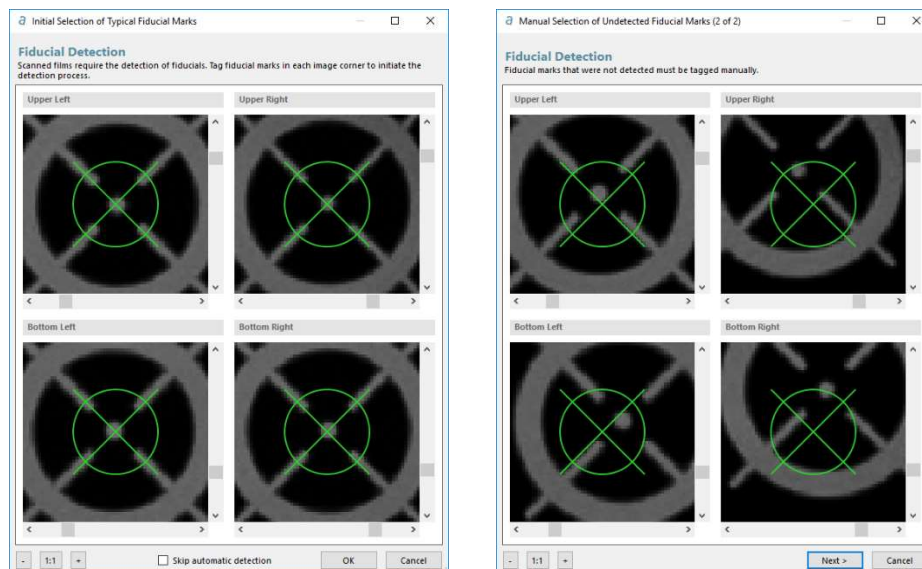


Figure 29: Fiducial detection dialogs for manual selection. On the left, all fiducial marks were correctly selected. On the right, a faulty detection must be corrected.

10.4 GCP Creation

Correlator3D™ features a tool to create GCPs for UAV/medium/large format and satellite sensors. The GCPs are used during the aerial triangulation process. The tool enables the user to specify pixel coordinates of ground control points in a visual environment. GCPs may be created by

specifying their positional coordinates. The software uses these inputs to automatically determine which images contain the specified GCP. These images are then displayed in the visual interface and the user is requested to pinpoint the locations of ground control points.



The GCP creation tool is only available in the AT module.

10.4.1 Creating and Importing GCPs

GCPs can be created using the project tree or imported from a text file. To create a GCP, the user must hover the cursor over the GCP portion of the project tree, and press the “Add a new point” contextual button. When GCPs are already specified in a text file (in ASCII format), they can be imported using the project creation wizard or directly in the AT module. The file should be organized in columns such that the tool can assign a specific column to a GCP field (i.e. GCP ID, X, Y, and Z). The interface also allows ignoring some rows or columns. Imported GCPs are then displayed in the project tree where they must be selected for editing in order to add observation data.

The following operations must be performed to import a GCP file:



1. In aerial triangulation mode, select “Import GCP File...” in the “Processes” menu.
2. Specify an ASCII file by pressing the corresponding “...” button.
3. Specify the delimiter(s) to be used by the software to recognize the columns in which GCP data are represented.
4. Specify the projection system of the coordinates to be imported.
5. Choose if the new GCPs should be added to the existing ones or should replace them.
6. Assign GCP data values to the appropriate columns by pressing on the buttons located at the top of the displayed ASCII file.
7. Remove any undesired rows by clicking on the corresponding check box located at the beginning of a line.
8. Click on the “Import” button.
9. Add observation data to each GCP by editing them using the corresponding button in the project tree.

10.4.2 GCP Editing Dialog

The GCP Editing dialog is used to edit GCP properties, such as its ID, description and coordinates, and to tag it in the images. The dialog is divided into four sections:

- Information: this section is located at the top of the window and contains the GCP properties. For convenience, it can be collapsed using the blue triangle button in the upper-right corner.
- Observations: this section occupies the largest part of the window. This is where the user can adjust the location of the GCP in the images.

- **Ribbon:** this section is located under the observation section. It contains an overview of all the observations of the GCP along with other images in which the GCP is likely to be found.
- **Zoom and Navigation:** this section can be found at the bottom of the dialog. It contains controls to help navigate the images.

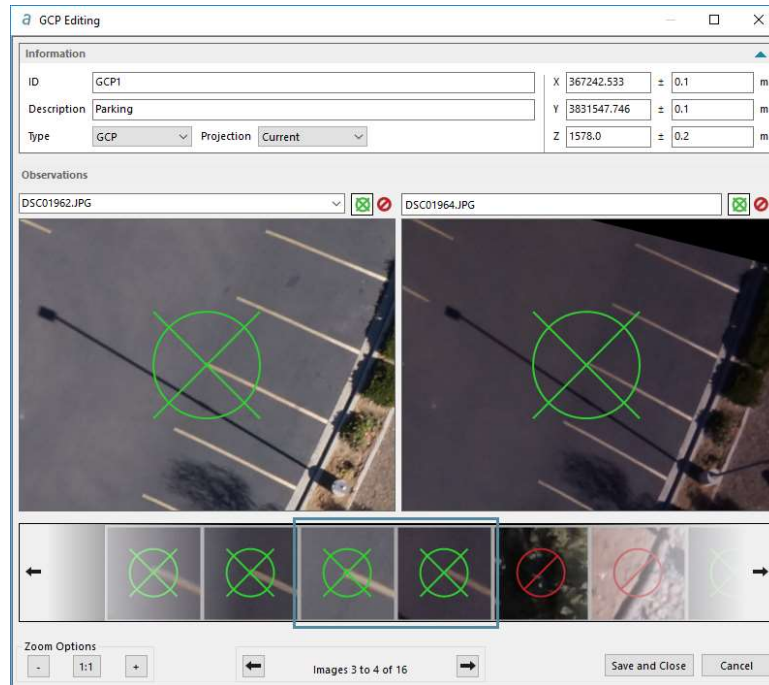


Figure 30: GCP Editing window.

There are four (4) GCP types which are "GCP", "GCP_XY", "GCP_Z" and "check point". The first three types are used to distinguish between varying forms of positional certainty. For example, the user may need to specify a GCP for which they are only certain about the Z component. In this case, GCP type "GCP_Z" will be used. Note, the user will still have to specify an approximate X and Y component. The effect of this is that the software will now treat this GCP accordingly in the aerial triangulation process, placing a high importance on the Z component, while allowing room for error in the X and Y components. Check points are GCPs that are not taken into consideration when performing bundle adjustment. They are generally used for quality assessment.

	Certain	Uncertain
GCP	XYZ	None
GCP_XY	XY	Z
GCP_Z	Z	XY

Table 7: GCP type description.

The user has the option to add uncertainty information. As described in in section 7.1.4, when the uncertainty values are left blank, the general uncertainty values will be applied during bundle adjustment. If an uncertainty value is specified in the GCP Editing dialog, it will overwrite the general uncertainty values for this specific point. This way, the user can specify a global

uncertainty for all points and redefine it on a point-by-point basis. If uncertainty is used, it must be specified for all three coordinates (X, Y, and Z).

Once coordinates are specified, Correlator3D™ will project the point in each image and populate the ribbon with the images that most likely contain the GCP. The software uses knowledge on already identified GCPs and current IEO parameters to select the best image candidates. Consequently, each time a new GCP is added to the project, Correlator3D™ becomes better at selecting candidate images.

The observation section of the dialog will display up to three images depending on the window size. These are used to adjust the GCP location in each image. Initially, an image candidate has an “unspecified” state. This state indicates that the user has not yet validated nor discarded the image. To validate an image, the user must adjust the GCP location in that image by clicking and dragging the image until the green aim is on top the GCP.



If the GCP is already at the proper location, the image can be validated by pressing the green aim button on the top-right corner of the image.



An image can also be discarded by checking the red discard button next to the green aim button.

Unchecking both the aim button and the discard button will revert the image back to the unspecified state. Images in the disabled or unspecified state will not be used during bundle adjustment as there is no functional difference between both. The disabled state exists to let the user differentiate images that have been rejected from those that require attention.

The ribbon is used to navigate around the image candidates. The blue rectangle indicates which images are currently displayed in the observation section of the window. To change the images being edited, the user can drag and drop the ribbon at the proper location. An alternate option is to use the arrows on the left and right side of the ribbon or those under the ribbon.



When the ribbon is dragged completely to the left (therefore showing the rightmost part of the ribbon) a special “+” button is visible. Clicking this button will add new image candidates to the ribbon.

At any time, the user can jump to a specific image by selecting it in the combo-box located above the left image in the observation section of the dialog. If necessary, the image will be added to the ribbon.

Each time the location of the GCP is adjusted in an image, the software recalculates the estimated location of the GCP in the images marked as “unspecified”. The ribbon is updated in real time to reflect these adjustments. This means that each new observation for the GCP improves the estimated location of the GCP in the other images.



Scrolling the ribbon is a fast and easy way to identify and validate the GCP observations.

The zoom options located in the lower-left of the window are used to adjust the zoom factor applied to the images displayed in the observation portion of the dialog. Cancel and save buttons

are located in the lower-right of the window. Clicking “Save and Close” will update the GCP. Clicking “Cancel” will discard the changes and close the window.

To edit a GCP, the user should perform the following operations:

1. Fill the required ID (name), type, projection and XYZ coordinates properties. If required, add a description and an uncertainty.
2. Mark which images are to be used with the GCP.
 - a. Use the ribbon to navigate between the images. Use the “+” button to add images if necessary.
 - b. Adjust each image to tag the exact GCP location. Use the zoom options to help find the exact location of the GCP.
3. After all the observations have been added click the “Save and Close” button to update the GCP file.

10.5 DEM Merging Tool

Correlator3D™ DEM merging tool allows combining DSM or DTM results that were created separately. It is useful to process a project in multiple parts (e.g. at different times or in parallel on multiple machines) and merge different tiles of DEMs together afterward. It can also help to recover intermediate results from individual pairs when, for some reason, the DSM process is interrupted. Correlator3D™ implements an intelligent data fusion approach that leads to consistent data sets, even when there are minor discrepancies along adjacent tile boundaries.

The DEM merging tool can be accessed from the Tools menu and does not require any DEM to be loaded in the main window. It can merge files stored in different formats and horizontal resolutions. Note that when merging DEM sets having different horizontal resolutions, the resulting data will automatically inherit the finest resolution. Also, if there is no overlap between adjacent data sets, Correlator3D™ will set the corresponding elevation values as undefined. An option to fill gaps in the resulting DEM is also available. This option allows the user to get a DEM in which small areas where elevation values were left undefined are filled with interpolated terrain data. The final merged data will be displayed in the main window and can then be saved by the user.

To merge DEMs, the user should perform the following operations:

1. Select “DEM Merging...” in the “Tools” menu.
2. Specify the files to be merged by clicking on the “Add Files...” button. A file browser will appear. Select the files to be added and click “Open”. The list will then be updated. Note that all files can be removed from the list (e.g. in case of an error) by pressing on the “Clear List” button.
3. Click on the “Merge” button. Real-time feedback will be provided on the overall progress of processing. Once the process is done, the resulting DEM will appear in the main window.
4. Save the merged DEM by selecting “Save DEM As...” in the “File” menu.

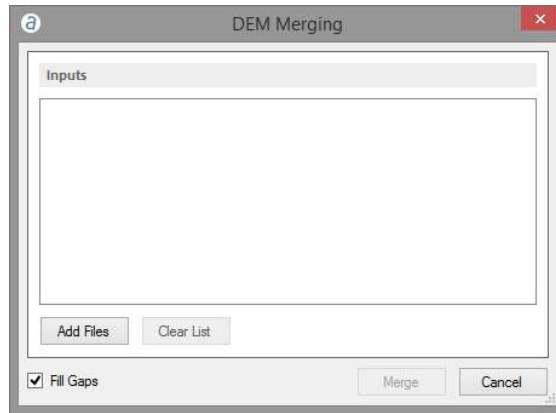


Figure 31: DEM merging dialog.

10.6 Export DEM Tiles

Correlator3D™ can divide a DEM in multiple tiles. The user can either specify a fixed size for the tiles or specify individual tile sizes and coordinates through a tile definition file. If a fixed tile size is specified in the dialog, each tile will have that size, except for tiles located on the border of the DEM. In such cases, the size of the tile is simply reduced to remove unnecessary undefined areas. The tiles are created to be juxtaposed one after the other with no overlap between two adjacent tiles. The naming of the tiles describes the spatial relation between each other. The name convention is as follows: Name_LineNumber_ColumnNumber.tif.



The shape of the input DEM can lead to situations where some tiles only contain undefined data (completely black areas). If such a situation occurs when specifying a fixed tile size in the Export DEM Tiles dialog, the corresponding tiles are not created by Correlator3D™. This behavior is part of an optimization effort to reduce memory and disk requirements while improving overall performance.

If a tile definition file is used, the tile size specified will be respected, even if the resulting area contains unnecessary undefined areas. Moreover, each tile will be created even if they do not contain any data at all.

The format of the output DEM tiles can be specified in the dialog. If a definition file is used, the format is specified through the extension of the DEM tiles.

The tool can be accessed from the File menu and requires a DEM to be loaded from the project tree.

To export DEM tiles, the following operations should be performed:

1. Select a DEM from the project tree. The DEM will be displayed in the main window.
2. Select "Export" -> "DEM" -> "DEM Tiles..." in the "File" menu.
3. If a tile definition file is used
 - a. Check "Tile Definition".
 - b. Specify the tile definition file by pressing on the corresponding "..." button. .
4. Specify the folder that will contain the tiles by pressing on the corresponding "..." button.

5. If no tile definition file is used
 - a. Specify the name for the mosaic.
 - b. Specify the tile size.
6. Specify the format for the DEM tiles.
7. Click on the “Process” button. Real-time feedback will be provided on the overall progress of processing.

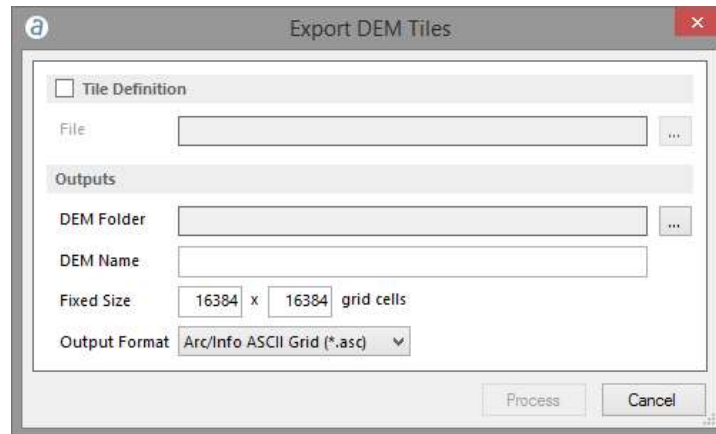


Figure 32: Export DEM tiles dialog.

10.7 Export LIDAR LAS and ESRI Shapefile

Correlator3D™ can export a DEM into a LIDAR LAS file or an ESRI Shapefile. Using these formats, elevation grids will be exported as a series of 3D points. The tools can be accessed from the File menu and requires a DEM to be loaded in the main window.

To export a DEM into the LIDAR LAS or ESRI Shapefile format, the user should perform the following operations:

1. Select a DEM from the project tree. The DEM will be displayed in the main window.
2. Select “Export DEM...” in the “File” menu.
3. Select “Export” -> “DEM” -> “LIDAR LAS File...” or “ESRI Shapefile” in the “File” menu.
4. Specify the name and the location of the file to be exported.

10.8 Export with Geoid

Correlator3D™ can export a DEM on which a geoid will be applied. The geoid file must be provided in the GTX file format.

The tool can be accessed from the File menu and requires a DEM to be loaded in the main window.

To export a DEM with a geoid, the user should perform the following operations:

1. Select a DEM from the project tree. The DEM will be displayed in the main window.

2. Select “Export” -> “DEM” -> “With Geoid...” in the “File” menu.
3. Specify the geoid file by pressing on the corresponding “...” button.
4. Specify the output DEM by pressing on the corresponding “...” button.
5. Click on the “Process” button. Real-time feedback will be provided on the overall progress of processing.

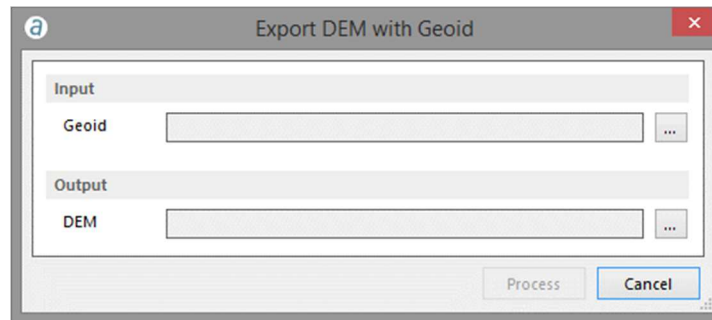


Figure 33: Export with geoid dialog.

10.9 Export EO and Camera Parameters

Correlator3D™ can export the EO information and camera parameters. In order to perform this, the user must specify a folder in which the information is saved. In the case of a frame-based project, one EO file and one calibration file per camera will be created. For satellite projects, one RPC file will be produced for each image. These files will be exported as simple text files, which can be used later on in the software.

10.10 DEM Inspection

Correlator3D™ DEM inspection tool is used to generate statistics about the quality of a DEM against reference data, i.e. elevation points provided in a ShapeFile. The software automatically computes the differences in elevation and provides statistics including bias error, standard deviation, RMS error and maximum error.



Statistics are displayed in a window at the end of the process. They can be saved as a text file.

To export DEM tiles, the following operations should be performed:

1. Select “DEM Inspection...” in the “Tools” menu.
2. Specify the DEM to be inspected using the corresponding drop-down menu.
3. Specify the reference data using the corresponding drop-down menu.
4. Click on the “Process” button. Real-time feedback will be provided on the overall progress of processing.

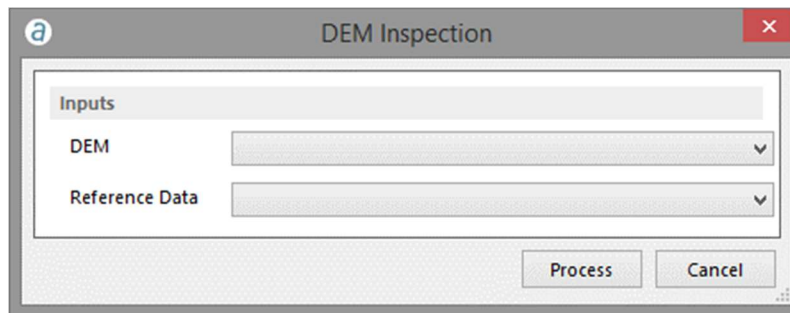


Figure 34: DEM inspection dialog.

10.11 Change Detection

Traditionally, change detection is performed by comparing two images. This approach is not robust in general since only changes in the appearance of the scene are detected and such changes do not necessarily imply structural changes. Correlator3D™ allows change detection by comparing DEMs instead of images. Such a comparison is possible since the software can quickly and automatically process 3D data.

Correlator3D™ requires two DEMs, which should be generated from two different image sets of the same area. It performs a comparative analysis and determines in 3D the importance of changes. The software outputs change detection results as a DEM with values corresponding to the differences in elevation between the two DEMs. The results can be optionally outputted as color information superimposed on a mosaic of orthophotos. This mosaic gets converted to grayscale and structural changes are highlighted using a specific color scheme: negative elevation changes (e.g. objects that have disappeared) are displayed in tones of yellow to red according to their importance (small to large changes respectively) while positive elevation changes (e.g. new objects) are shown in tones of dark to light blue (small to large changes respectively). A detection range in meters is used and only changes that are within the specified range (vertically) will appear.

To perform change detection, please follow these steps:

1. Select “Change detection...” in the “Tools” menu.
2. Specify the reference DEM (i.e. the DEM as it appears before changes) using the corresponding drop-down menu.
3. Specify the comparison DEM (i.e. the DEM as it appears after changes) using the corresponding drop-down menu.
4. If a change detection mosaic is required:
 - a. Check “Display Changes on Mosaic”.
 - b. Specify the “Input Mosaic File” of the input mosaic using the corresponding drop-down menu. This file can be either a mosaic definition file or a tile definition file. Change detection results will be overlaid on the mosaic after the processing is completed. This mosaic can correspond either to the images taken before or after the changes.
 - c. Specify the folder where the change detection mosaic will be generated using the corresponding drop-down menu.

If new 3D structures are mostly expected then the mosaic corresponding to the image data taken after changes should be used. If it is anticipated that structures have in general disappeared, then the input mosaic should consist of the image data collected before changes have occurred.

5. Specify the detection range. This implies that only changes within that range (vertically) will be detected.
6. Click on the “Process” button. Real-time feedback will be provided on the overall progress of processing. Once the process is done, the change detection DEM will appear in the main window.
7. Save the DEM by “Save DEM As...” in the “File” menu.

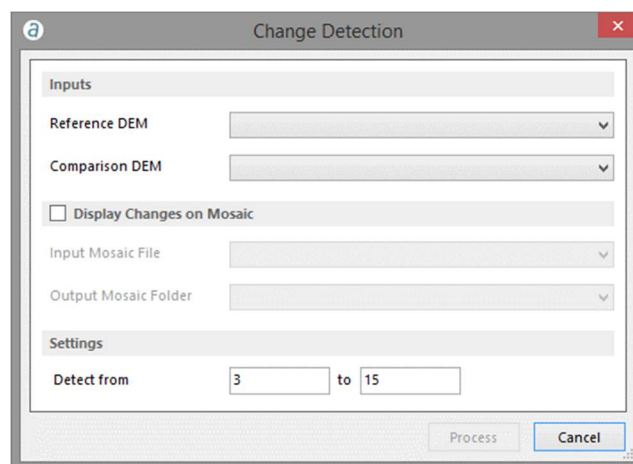


Figure 35: Change detection dialog.

10.12 Point Cloud Colorization

The Correlator3D™ point cloud colorization tool is used to colorize a point cloud using a mosaic. The software automatically determines correspondence between 3D points and pixels. The process requires as input a LAS file and a mosaic and generates a new LAS file with color information.

To perform point cloud colorization, the user can follow the listed steps:

1. Select “Point Cloud Colorization...” in the “Tools” menu.
2. Specify the input point cloud file using the corresponding drop-down menu.
3. Specify the input mosaic file using the corresponding drop-down menu.
4. Specify the output mosaic file using the corresponding drop-down menu.
5. Click on the “Process” button. Real-time feedback will be provided on the overall progress of processing.

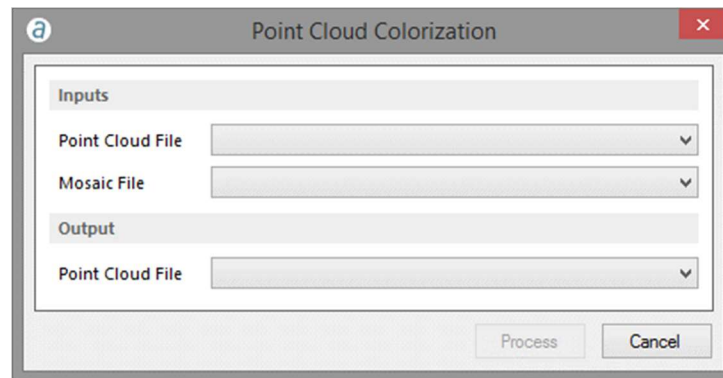


Figure 36: Point cloud colorization.

11. Script Mode

Correlator3D™ includes a scripting mode for advanced users who desire to fully automate their processing tasks. A script simply consists of a plain text file containing a series of instructions that the software will execute sequentially. The syntax is very simple: each operation starts with the process name and all necessary input/output parameters are then specified. Here is an example for a DSM generation process:

```
<DSMGeneration>
{
    InputDEM          C:\MyFrameBasedProject\DEM\InputDEM.asc
    InputEO           C:\MyFrameBasedProject\EO\IEO_AT.iew
    Resolution         Optimal
    AboveGroundVar     50
    BelowGroundVar 15
    OutputDEM          C:\MyFrameBasedProject\DEM\DSM.asc
}
```

Note that the order in which the process parameters are specified is not important. The user can perform as many operations as desired. Input files that do not exist can be specified as long as previous operations create them. For DSM generation and orthorectification, the optimal resolution or overlap can be set by entering "Optimal" (not case sensitive) in the corresponding field. Similarly, the user can set the maximal resolution by entering "Maximal" in the corresponding field. A description of the format of script files is included in Section 0.

Once a script file is created, it can be run by selecting "Run Script..." in the "File" menu. Real-time feedback on the overall progress of processing is provided during execution.

Please refer to Appendix A for the script format description.

11.1 Command Prompt

Instead of using the GUI to interact with Correlator3D™, the user may wish to use a command prompt to run individual scripts and batch files quickly. Navigate to the Correlator3D folder and type "C3D" to display the possible options. For example, the following command:

```
C:\Program Files\SimActive\Correlator3D\C3D
```

will display the possible options on the command prompt screen provided the software was installed in that directory.

To run a script:

```
C:\Program Files\SimActive\Correlator3D\C3D /f PathToMyScript
```

The "/f" must always precede the path to the script. The list of commands is summarized in Table 8:

Command	Action
/f	Operator preceding path to the script or batch file
/v	Outputs all messages
/m	Outputs only the main messages
/p	Outputs progress percentage to the screen
/r	Saves message content to a file

Table 8: Command line operations summary.

As another example, consider the following command:

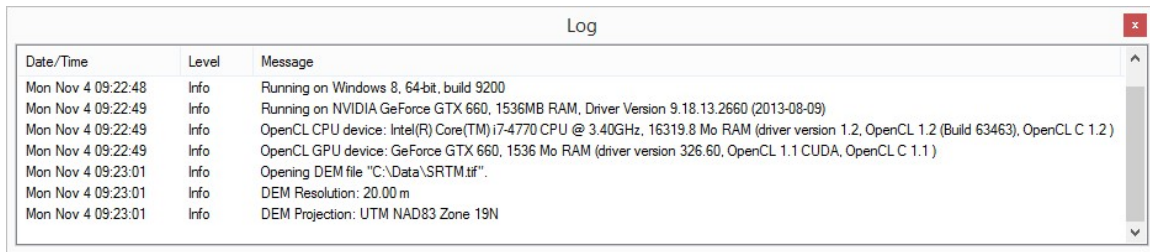
```
C3D.exe /f PathToMyScript.spt /v /p /r FileLog.txt 2>> Errors.log
```

This will make C3D.exe process the script file "PathToMyScript.spt". Since the "/v" command was used, all the levels of information will be outputted. Normally, this information would be displayed onscreen. However, the "/r" redirects this information to the file "FileLog.txt". The "/p" command outputs the progress of each operation in the script. This information is only displayed onscreen and will not be redirected by the "/r" command. Lastly, the "2>>" is a batch command that will append error messages if any to the file "Errors.log".

12. Troubleshooting

12.1 Log Window and Log File

Correlator3D™ includes detailed warning and error messages to facilitate troubleshooting. In addition, all major operations performed during processing are displayed in the log window. This window is fully dockable, allowing the user to customize their Correlator3D™ environment. Warning and error messages are color-coded in yellow and red respectively.



Date/Time	Level	Message
Mon Nov 4 09:22:48	Info	Running on Windows 8, 64-bit, build 9200
Mon Nov 4 09:22:49	Info	Running on NVIDIA GeForce GTX 660, 1536MB RAM, Driver Version 9.18.13.2660 (2013-08-09)
Mon Nov 4 09:22:49	Info	OpenCL CPU device: Intel(R) Core(TM) i7-4770 CPU @ 3.40GHz, 16319.8 Mo RAM (driver version 1.2, OpenCL 1.2 (Build 63463), OpenCL C 1.2)
Mon Nov 4 09:22:49	Info	OpenCL GPU device: GeForce GTX 660, 1536 Mo RAM (driver version 326.60, OpenCL 1.1 CUDA, OpenCL C 1.1)
Mon Nov 4 09:23:01	Info	Opening DEM file "C:\Data\SRM.tif".
Mon Nov 4 09:23:01	Info	DEM Resolution: 20.00 m
Mon Nov 4 09:23:01	Info	DEM Projection: UTM NAD83 Zone 19N

Figure 37: Log window.

The content of the log window is automatically saved in a log file. This can be particularly helpful if, for some reason, the processing is interrupted. The file is located in the folder "My Documents\SimActive\Correlator3D\" and named "Correlator3D_Log.xml". The file can also be accessed directly from the user interface by selecting "Log File" from the "Help" menu. A new log file is created each time the software is launched and logs information until the program is closed. Copies of the ten most recent log files are automatically stored in the folder "My Documents\SimActive\Correlator3D\History\".

12.2 Good Practice

As a first step, the user should perform a test on a few images before processing an entire project. This will ensure that there is no problem with the input data. It will also allow verifying that both the results and the required processing time meet expectations. Input parameters (depending on the module used) can be varied, and small scale tests can be repeated until satisfactory results are produced. Note that this recommendation does not hold for the aerial triangulation module, as it requires as much input data as possible.



If Correlator3D™ is provided with an input DEM that is smaller than the area covered by the image, only the portion of the image covered by the DEM will be processed. This can be helpful to make smaller and thus faster tests.

12.3 Temporary Files

Different temporary files are created during data processing. In the case of the DSM generation process, each individual file, which is stored in the SimActive model format (.smf files), contains DSM generated from a given pair. Temporary files are named according to the first image of the

pair processed. At the end of the DSM generation process, these individual files are automatically merged together to produce a single DSM.

If the DSM generation process is interrupted in the middle of a large batch process, then these files can be retrieved and merged manually using the DEM merging tool. The user can change the location of the temporary folder by selecting “General Settings” from the “Settings” menu and changing its location. For best software performance, this folder should be located on a separate local hard drive, different from the one where input/output data are stored.

In the case of the fiducial detection process, a visual representation of the results is also created. For each input photo, an image showing the four detected marks is stored for visual validation. These images are named according to input image.

12.4 Common Problems

The following is a list of problems that may occur as well as checklists to determine their causes:

1. The processing time required to generate results is too long.
 - Verify that the requested data resolution is not too small. When using the DSM generation module, it is recommended that the software calculates the optimal value (returning the best compromise between resolution and processing time).
 - When using the DSM generation module, verify that the “Max Height Variation” parameters are realistic and not too high. If the “Automatic” option was selected, verify the log to make sure that these values were not too high during the process.
 - Split the project in multiple parts and process them in parallel on several machines.
 - Always perform a small scale test on a few images to assess the required processing time before processing a larger image set.
 - Ensure that an appropriate graphics card is used.
 - Verify that the data are stored on local hard drives as opposed to network drives. Ideally, a different hard drive should be used for temporary files created during processing.

2. Buildings or other structures seem to be “chopped” or noisy in DSM model.
 - Ensure that the “Max Height Variation” parameters used for generating the DSM were appropriate. This number should reflect the expected variations in the height of objects. If the area contains large building or tall trees, then the above ground variation should be set to a higher value.
3. The 3D constraint creates “ditches” in forest areas.
 - Depending on the forest density, Correlator3D™ DSM generation module may return the elevation of the canopy of the forest. 3D constraint elements representing ground elevation values may thus force Correlator3D™ to create such “ditches” in dense areas. To get a more homogeneous DSM, the user can simply remove the constraint elements causing problems from the 3D constraint files.
4. Delete and Fill does not give the expected results.
 - The Delete and Fill tool analyses DEM cells that are adjacent to the selection. Make sure that the selection is large enough to include all DEM cells to be removed, but that it is small enough not to include other elements. For example, if a building is to be removed, the selection must include that building, but must not include another building.
5. Editing mode is activated but polygonal selections cannot be created.
 - Make sure the Touch Up mode is not activated.
6. There are visual artifacts along edges of structures (e.g. buildings) in the orthophotos.
 - Such artifacts are usually caused by using a DEM with a lower resolution than the desired orthorectified images. This can be avoided by using a DTM instead of a DSM.
7. Some tiles of the mosaic are not created.
 - The position and orientation of the input orthorectified images can lead to situations where some tiles contain only undefined data (completely black areas). When such a situation occurs, the corresponding tiles are not created by Correlator3D™. This behavior is part of an optimization effort to reduce memory and disk requirements while improving overall performance.

13. Appendix A

13.1.1.1 Camera Calibration Types

Correlator3D™ supports four types of camera calibrations.

1. Digital Sensors

The first calibration type, designed for metric cameras, simply consists of providing the following:

- Image width in pixels
- Image height in pixels
- Pixel size in microns
- Focal length in millimeters
- Principal point coordinates in millimeters

Note that the imagery is assumed to be already corrected for distortion.

2. Digital Sensors with Distortion Table

The second calibration type is meant to specifically support camera systems using a distortion table. The difference in the calibration file is that radial lens distortion is taken into account when processing imagery. The parameter values are thus defined as a look-up table (LUT) . These values specify radial distortion as a function of the pixel distance from the image center.

3. Scanned Films

The third calibration type, designed for scanned films, contains additional fields (compared to the digital sensor type) consisting of the coordinates in millimeters of the following:

- Bottom-left fiducial
- Top-right fiducial
- Top-left fiducial
- Bottom-right fiducial

Positions of fiducials and the principal point should be referenced to the principal point of autocollimation as the origin.

4. Polynomial

The fourth calibration type specifically supports camera systems with radial and decentering lens distortion. The parametric distortion model is defined by the following equations, where X and Y are measurements in mm referring to the principal point and $r = \sqrt{X^2 + Y^2}$:

$$\begin{aligned} dX &= dX_{\text{radial}} + dX_{\text{decentering}}, \\ dY &= dY_{\text{radial}} + dY_{\text{decentering}}, \end{aligned}$$

where,

$$\begin{aligned}dX_{\text{radial}} &= X (K_0 + K_1 * r^2 + K_2 * r^4 + K_3 * r^6 + \dots + K_7 * r^{14}), \\dY_{\text{radial}} &= Y (K_0 + K_1 * r^2 + K_2 * r^4 + K_3 * r^6 + \dots + K_7 * r^{14}), \\dX_{\text{decentering}} &= (1 + P_3 * r^2 + P_4 * r^4) * (P_1 * (r^2 + 2 * X^2) + 2 * P_2 * X * Y), \\dY_{\text{decentering}} &= (1 + P_3 * r^2 + P_4 * r^4) * (P_2 * (r^2 + 2 * Y^2) + 2 * P_1 * X * Y),\end{aligned}$$

and,

K_0 to K_7 are parameters associated with the radial distortion,
 P_1 to P_4 are parameters associated with the decentering distortion.

13.2 Tile Definition File

A tile definition file can be inputted in Correlator3D™ Mosaic Creation module to define the name, the coordinates and the size of each mosaic tile. A tile is defined by two corners located on the diagonal of its area. Each tile is specified on a separate line containing the following five (5) fields:

- Tile filename
- X coordinate of the first corner defining the tile area
- Y coordinate of the first corner defining the tile area
- X coordinate of the second corner defining the tile area
- Y coordinate of the second corner defining the tile area



Corners can be specified in any order, as long as they are located on a diagonal.

Sample:

```
*****
SimActive Tile Definition File
Copyright(c) 2009 SimActive Inc.
All rights reserved.
*****
# Tile Name      First Corner (x,y)      Second Corner (x,y)
TileName_01      446762.0 5032005.0      447170.0 5031653.0
TileName_02      447170.0 5032205.0      447643.0 5031415.0
TileName_03      446862.0 5031653.0      447170.0 5031415.0
TileName_04      447061.0 5031415.0      447351.0 5031120.0
TileName_05      446762.0 5030920.0      447351.0 5031120.0
```

13.3 Script Format Description

This section describes the operations and parameters available in a Correlator3D™ script.

Script syntax is the following:

```

<OperationName>
{
    ParameterName ParameterValue
    ParameterName ParameterValue
    ...
    ParameterName ParameterValue
}

```

The script file is case insensitive. This means that “DTMExtraction” and “dtmextraction” are both valid.

The name of the operations must appear between ‘<’ and ‘>’ marks. And the parameter lists is delimited by a pair of braces (‘{’ and ‘}’).

There is no limitation on the number of white spaces (spaces, tabs and new lines) as long as the *ParameterName* and its *ParameterValue* are on the same line.

Comments can be added in the file. Each line of comment must be preceded with ‘#’.

OperationName can be one of the following:

- AerialTriangulation
- DSMGeneration
- DTMExtraction
- Orthorectification
- MosaicCreation
- ExportMosaic
- ChangeDetection
- DEMMerging
- DEMTiling
- DEMInspection
- ExportGeoidDEM
- PointCloudColorization

The list of parameters and acceptable values varies according to the operation. For a given operation, the order of the parameters has no importance. The description of each available parameter follows.

Parameters for AerialTriangulation

Parameter name	Type	Description
TiePointExtraction	‘On’, ‘Off’	Indicates if tie point extraction must be performed.
CameraCalibration	‘None’, ‘Constrained’, ‘Unconstrained’	Indicates the type of camera calibration.
EOAdjustment	‘None’, ‘BoresightCalibration’,	Indicates the type of EO adjustment.

	'ConstrainedAT', 'UnconstrainedAT'	
PerformBoresight	'On', 'Off'	Bound boresight within total uncertainty. Only required if EOAdjustment is 'ConstrainedAT'
ExtractionType	'Standard', 'Exhaustive'	Type of tie point extraction to perform.
InputEO	String	Path to the input interior/exterior orientation file.
GCPFile	String	Optional. Path to the input ground control point file.
AdjustFocalLength	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment.
AdjustXmm	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment.
AdjustYmm	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment.
AdjustK0	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustK1	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustK2	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustK3	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustK4	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustK5	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustK6	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle

		adjustment for odd/even order polynomial distortion model.
AdjustK7	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustP1	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustP2	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustP3	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustP4	'On', 'Off'	Optional. Indicates if parameter will be adjusted during bundle adjustment for odd/even order polynomial distortion model.
AdjustLUT	'On', 'Off'	Optional. Indicates if parameters will be adjusted during bundle adjustment for LUT distortion model.
AdjustX	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
AdjustY	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
AdjustZ	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
AdjustOmega	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
AdjustPhi	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
AdjustKappa	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
AdjustGCPXY	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.

AdjustGCPZ	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
AdjustGCPObs	Float	Optional. Expected uncertainty in parameter to be adjusted during bundle adjustment.
ATFolder	String	Path to the AT folder.
OutputEO	String	Path to the output interior/exterior orientation file.
OutputDEM	String	Path to the output seed DEM file.

Parameters for DSMGeneration

Parameter name	Type	Description
InputDEM	String	Path to the input DEM file.
InputEO	String	Path to the input interior/exterior orientation file.
Resolution	Float, 'Optimal', 'Maximal'	Required resolution of the resulting DSM.
VertAccuracy	Float, 'Optimal', 'Maximal'	Required vertical accuracy of the resulting DSM.
GeneratePointCloud	'On', 'Off'	Optional. Indicates if a point cloud must be generated.
AboveGroundVar	'Automatic', Integer	Expected discrepancy between the original DEM and the resulting DSM (above ground).
BelowGroundVar	'Automatic', Integer	Expected discrepancy between the original DEM and the resulting DSM (below ground).
OutputDEM	String	Path to the output DSM file.
3DConstraintFile	String	Optional. Path to the 3D constraint file.

Parameters for DTMExtraction

Parameter name	Type	Description
InputDEM	String	Path to the input DEM file.
3DConstraintFile	String	Optional. Path to the 3D constraint file.
ConstraintType	'Exclusion', 'Elevation'	Optional. Type of constraint to be used.
DSMFeatures	String	Optional. Path to the output DEM.
OutputDEM	String	Path to the output DTM file.

Parameters for Orthorectification

Parameter name	Type	Description
InputDEM	String	Path to the DEM file.
InputEO	String	Path to the input interior/exterior orientation file.
DSMBased	'On', 'Off'	Parameter used to generate true orthos from a DSM.
3DConstraintFile	String	Optional. Parameter used to generate true orthos using a 3D constraint file.
OutputORIFolder	String	Path to the output folder.
Resolution	Float, 'Optimal'	Required resolution of the orthorectified images.
Overlap	Integer, 'Optimal', 'Maximal'	Required overlap between orthorectified images. Must be commented out if CropWidth and CropHeight are specified.
CropWidth	Float	Image crop width. Must be commented out if Overlap is specified.
CropHeight	Float	Image crop height. Must be commented out if Overlap is specified.
OutputFormat	'GeoTIFF', 'TFW'	Output format of the orthorectified images.
TiledTiff	'Tiled', 'Untiled'	Indicates if the orthorectified images must be tiled or untiled.
Overviews	'On', 'Off'	Indicates if the orthorectified images must be generated with overviews.

Parameters for MosaicCreation

Parameter name	Type	Description
InputORIList	String	The default file name is the name of the IEO file used to orthorectify the images.
MosaicArea	String	Optional. Path to the tile definition or vector file.
OutputFolder	String	Path to the output folder.
MosaicName	String	Name of the mosaic.
Feathering	Integer	Optional parameter. Default value is 37.
MinNumBlocks	Integer	Optional parameter. Default value is 1.
ColorBalancing	'On', 'Off'	Indicates if color balancing must be applied.
ExclusionZone	String	Optional. Path to the vector file. The exclusion zone file is only considered when color balancing is on.

Parameters for ExportMosaic

Parameter name	Type	Description
BlockDefFile	String	Path to the mosaic definition file.
MosaicType	'Standard', 'NDVI'	Type of the mosaic to be created.
OutputFolder	String	Path to the output folder.
TileDefFile	String	Optional* . Path to the tile definition file.
MosaicName	String	Optional* . Name of the output mosaic.
TileWidth	Integer	Optional* . Tile width in pixels
TileHeight	Integer	Optional* . Tile height in pixels
OutputFormat	'GeoTIFF', 'TFW'	Output format of the mosaic tiles.
TiledTiff	'Tiled', 'Untiled'	Indicates if the orthorectified images must be tiled or untiled.
Overviews	'On', 'Off'	Indicates if the orthorectified images must be generated with overviews.
ColorMap	'Beige to Dark Green', 'Dark Blue to Dark Green', 'DEM Color Style', 'Grayscale', 'Red to Blue'	Optional** . The color map to be used.
InvertColorMap	'On', 'Off'	Optional** . Invert the color map.
MinimumThreshold	Float, 'Optimal'	Optional** . Minimum bound of the NDVI index.
MaximumThreshold	Float, 'Optimal'	Optional** . Maximum bound of the NDVI index.
ClassCount	Integer	Optional** . Number of classes for the index. If omitted, the mapping is continuous.

*Either TileDefFile or MosaicName, TileWidth and TileHeight can be specified.

**Must be defined when mosaic type is set to NDVI.

Parameters for ChangeDetection

Parameter name	Type	Description
ReferenceDEM	String	Path to the DEM file before the changes.
ComparisonDEM	String	Path to the DEM file after the changes.
MinimumThreshold	Float	Minimum detection threshold (in model units).
MaximumThreshold	Float	Maximum detection threshold (in model units).
OutputDEM	String	Path to the output DEM file.
BlockDefFile	String	Optional . Path to the block definition file.
OutputFolder	String	Optional . Path to the mosaic output folder.

Parameters for DEMMerging

Parameter name	Type	Description
InputDEM	String	Path to the input DEM file.
InputDEM	String	Path to the input DEM file.
InputDEM	String	Path to the input DEM file.
FillGaps	'On', 'Off'	Indicates if the gaps in the resulting DEM must be filled.
OutputDEM	String	Path to the output DEM file.

Parameters for DEMTiling

Parameter name	Type	Description
InputDEM	String	Path to the input DEM file.
OutputFolder	String	Path to the mosaic output folder.
TileDefFile	String	Optional* . Path to the tile definition file.
DEMName	String	Optional* . Name of the output mosaic.
TileWidth	Integer	Optional* . Tile width in pixels
TileHeight	Integer	Optional* . Tile height in pixels
OutputFormat	'GeoTIFF', 'AsciiGrid', 'SMFFormat' 'Shapefile' 'LIDARLAS'	Format of the output DEM tiles.

*Either TileDefFile or DEMName, TileWidth and TileHeight can be specified.

Parameters for DEMInspection

Parameter name	Type	Description
InputDEM	String	Path to the input DEM file.
ReferenceData	String	Path to the reference data file.
OutputFile	String	Path to the output statistics file.

Parameters for ExportGeoidDEM

Parameter name	Type	Description
InputDEM	String	Path to the input DEM file.
GeoidFile	String	Path to the geoid file.
OutputDEM	String	Path to the output DEM file.

Parameters for PointCloudColorization

Parameter name	Type	Description
InputPointCloud	String	Path to the input point cloud file.
BlockDefFile	String	Path to the mosaic file.
OutputPointCloud	String	Path to the output point cloud file.