GreenValley International

LiMapper

Aerial Photogrammetry Software

www.greenvalleyintl.com

Introduction

LiMapper is an aerial photogrammetry software which can reconstruct 3D geometry structure from overlapping images and subsequently generate a series of standard products of surveying and mapping. The key advantages of the software include automated process, high efficiency, robust performance, and professional accuracy. All this stems from the state-of-the-art photogrammetry and computer vision algorithms implemented in LiMapper, which are accelerated by fully exploiting hardware resources such as multi-core CPU and high-performance GPU. Based on data-processing experience, the algorithms are further optimized to handle not only traditional aerial images of large frames, but also UAV-images with unstable orientations and unknown lens distortions. Considering user friendliness the well-designed software interface is kept simple and easy to use for both novice and expert users.

LiMapper has the scalability to process more than 10000 photos in a project. Supported source data types are nadir, oblique, and multispectral photos. The core functions/modules of the software include feature point extraction/matching, bundle block adjustment, camera self-calibration, dense reconstruction, DEM/DSM generation, smart ortho-mosaicking, true orthophoto generation, stitching line editing, data visualization and analysis.

Features

	Features and Advantages	
Inputs	Aerial Images	• Process photos of multi-camera, multi-flight, multiple platforms with various flight heights • Support data types of nadir, oblique, multispectral photos • Support image formats JPG, TIFF, BMP
	Camera Intrinsics	• Import LiMapper Params(XML), PhotoScan Params(XML), Australis Params(TXT) • Extract lens infos from image EXIF automatically • Group photos and edit parameters flexibly
	Positions and Orientations	• Extract positions from image EXIF automatically • Import and parse external file with the formats TXT, CSV • Support local coordinate system, geographic coordinate system, and projection coordinate system
	Control Point/Check Point/Tie Point	• Use ground control points to increase the accuracy of photos alignment • Use check points to evaluate the absolute accuracy • Use manual tie points to register photos of featureless area
	One-Stop Process	• Highly automated workflow • User-friendly interface for beginners
	Align Photos	• Automated images matching and bundle block adjustment without preconditions about camera intrinsics, positions and orientations • Integrated camera self-calibration • Editable measurement weights in bundle block adjustment • Robust performance for hard dataset such as forestry photos

Workflow	Build Dense Cloud	• Reconstruct object details through pixel-wise image matching • Generate 2.5D or 3D dense cloud
	Build DEM/DSM	• Extract ground points automatically to generate DEM which meets the requirements of surveying and mapping • Generate DSM that keeps object details • Import/convert external DEM/DSM
	Build Orthomosaic	• Generate true orthophoto based on DSM, and fill occlusion area using photos taken from other view directions • Generate smart stitching lines that elude significant objects, in order to mitigate distortions at edges • Blend images for better visual effect
	Acceleration	• Exploit multi-core CPU and high-performance GPU to accelerate processing
Orthomosaic Edit	Adjust Stitching Line	• Edit polygonal area and assign visible orthophotos • Update stitching line and orthomosaic in real time
Data Visualization & Analysis	2D	• Quick view of input photos, corresponding feature points and control points • Display huge orthomosaic utilizing adaptive LOD • Provide tools to measure position, length, and area of object
	2.5D	• Display huge DEM/DSM with hillshade effect utilizing adaptive LOD • Provide tools to measure position, length, area, and height of object
	3D	• Update tie points and camera positions in real time while aligning photos • Disply massive dense point cloud utilizing adaptive LOD • Use EDL to enhance the rendering of depth discontinuity
Tools	Haze Removal	• Enhance images in pre-processing step
	Image Undistortion	• Undistort images using calibration parameters
Products	Export Interior & Exterior Orientations	• Export interior & exterior orientations after photos alignment
	Export Point Cloud	• Export sparse tie points and dense point cloud as PLY, OBJ, LAS
	Export DEM/DSM	• Export DEM/DSM as TIFF, KML
	Export Orthomosaic	• Export Orthomosaic as TIFF, KML
	Export Stitching Line	• Export stitching line as Shape file

Get Started

Please refer to Installation and License to get the software. The usage is described in Tutorials and Workflow.

Workflow

Mandatory

- New Project
- One-stop Process

Exporting

- Generate Report
- Export Product

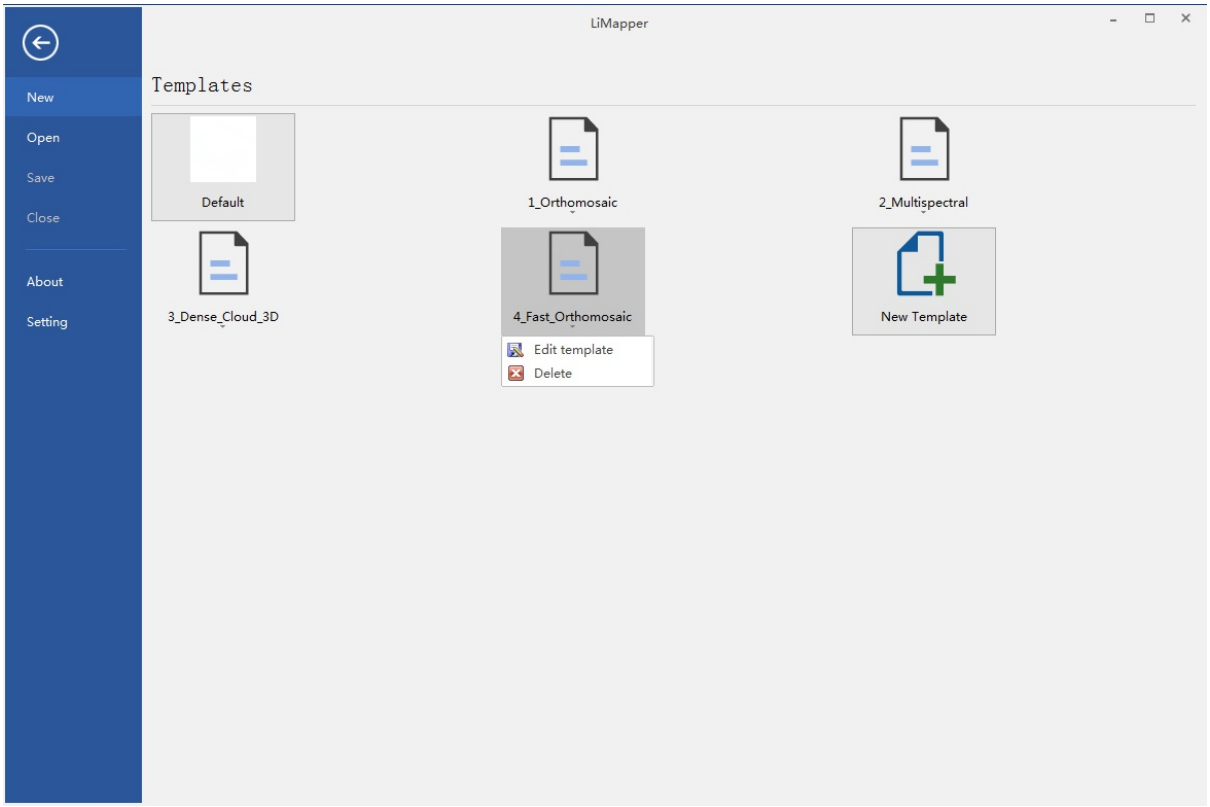
Optional

- Extra Input
  - Using POS
  - Using GCP/MTP
  - Using Camera Intrinsics
- Editing
  - Set Master Band
  - Remove Photos
  - Adjust ROI
  - Adjust Stitching Lines
- Other
  - Create Project Template

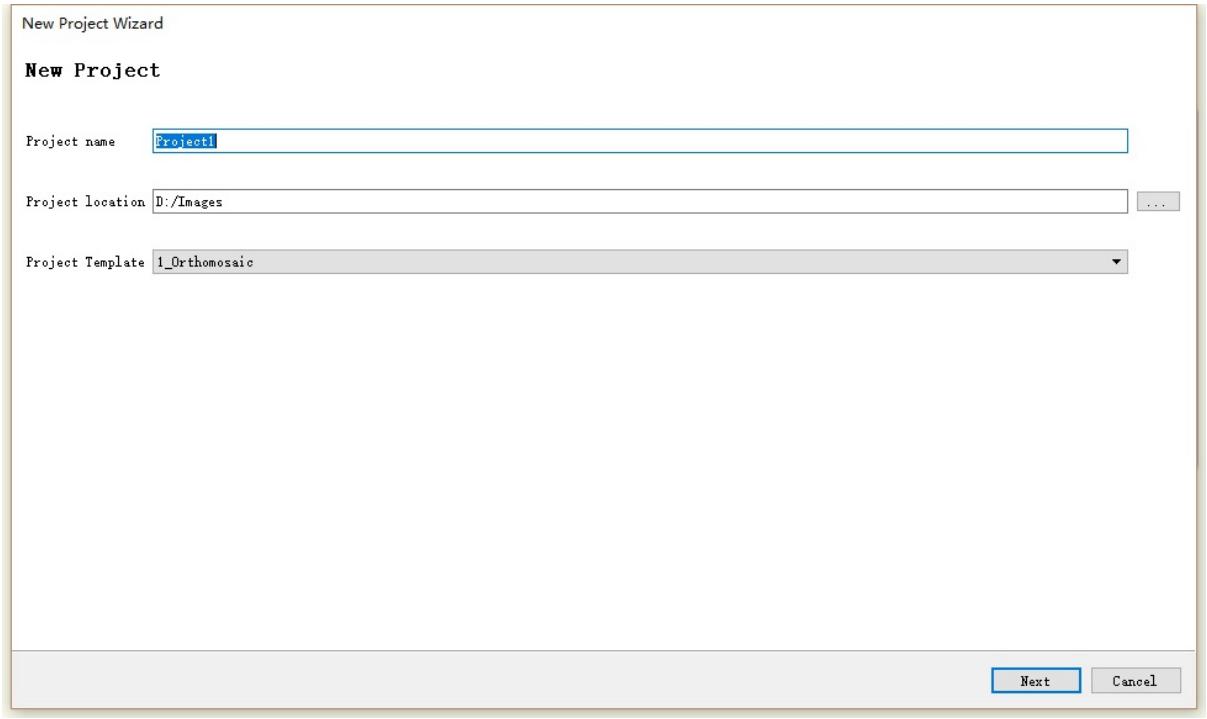
New Project

New Project Wizard

Click *[New]* in the side menu to enter the new project page, then click on a template to activate the *New Project Wizard*, and complete the project setup in the wizard's series pages.

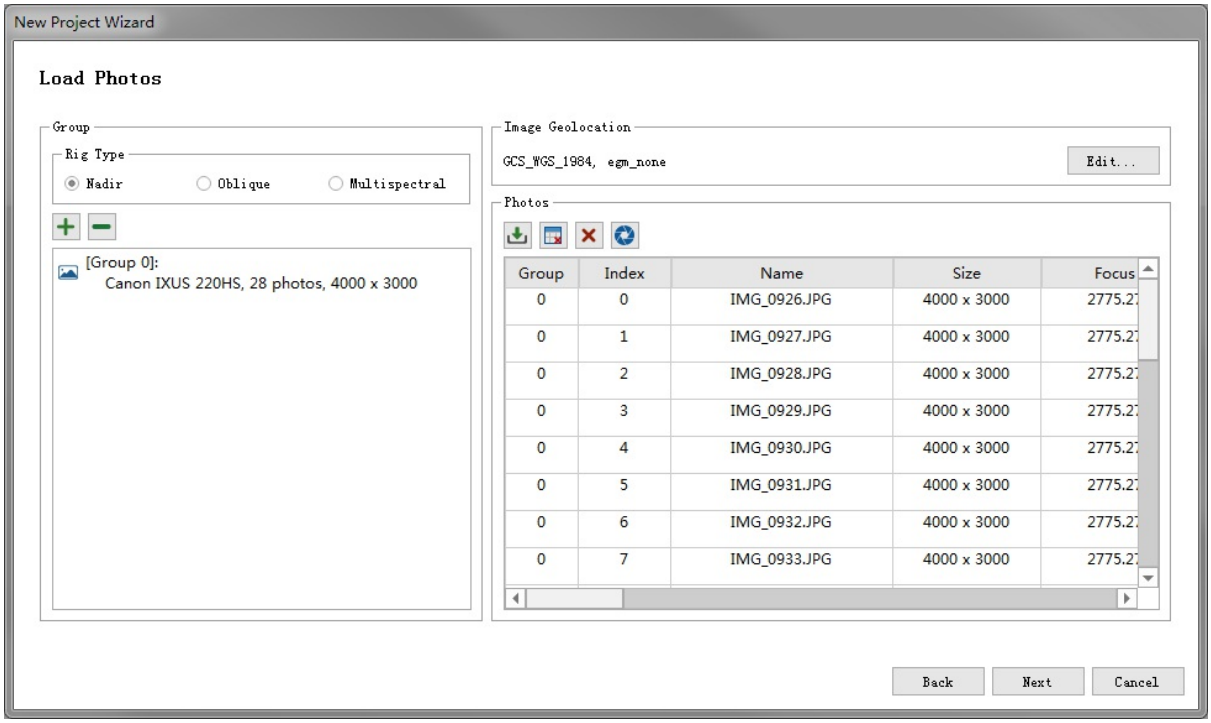


New Project Page



- Project Name： Input project name
- Project Path： Input or browse project path
- Project Template：Selected template. *Project Template* can be changed here

Load Photos Page



Rig Type

The following rig types are supported：

- Nadir：For nadir photos

- Oblique： For oblique aerial photos
- Multispectral：For multispectral photos.

Group

Photos in each group share the same camera intrinsics. At least one group is required. Supported actions are listed below：

- Add Group：Add at least one photo as a group
- Delete Group：Delete the selected group(s).

> At least five photos are required to run LiMapper.

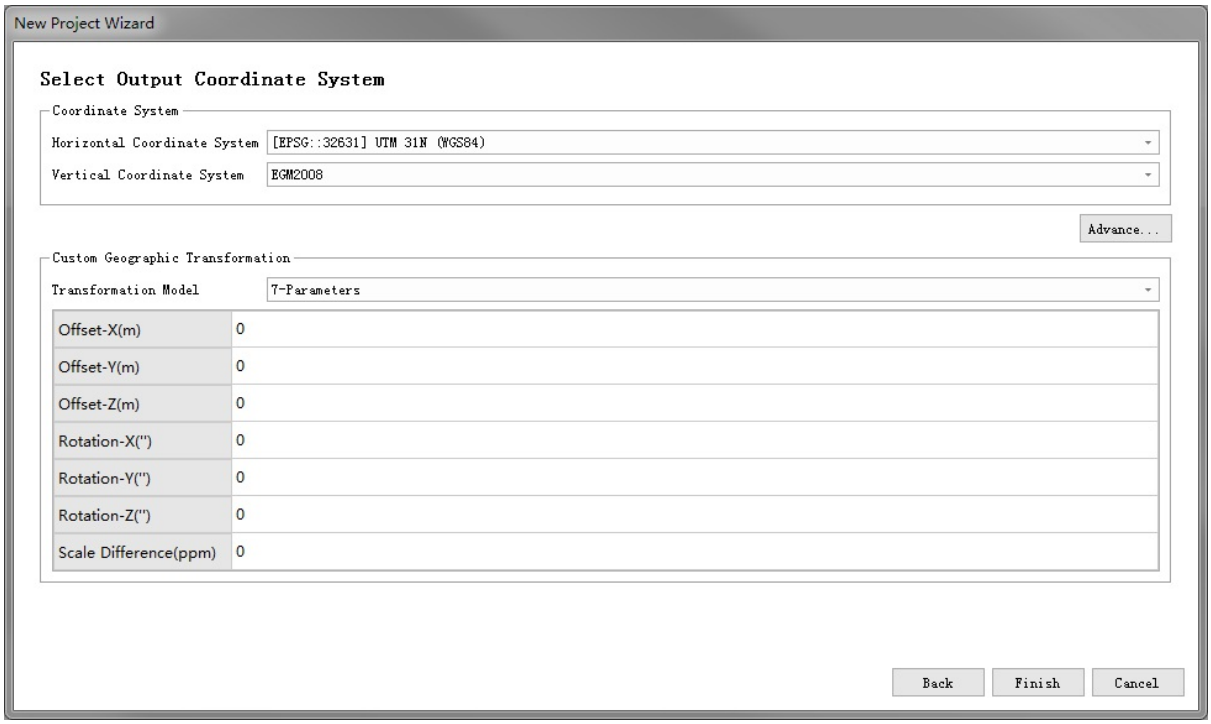
In a group's context menu, click button to add photos to this group.

Photos

Edit photos through the following buttons:

- Import POS：Please refer to Using POS.
- Reset POS：Reset the imported POS.
- Delete Photo：Select at least one photo and delete it.
- Camera Calibration：Please refer to Camera Calibration. For multispectral photos, Master Band can be set here, too.

Select Output Coordinate System Page



Coordinate System

The target coordinate system. The software would give a default value based on the POS information of the input photos.

- Horizontal Coordinate System: The default value is a UTM projected coordinate system. User could select a different projected coordinate system (such as the Gauss-Krüger projected coordinate system) or a custom projected coordinate system. In addition, the selected coordinate system must be able to be converted from the POS coordinate system.
- Vertical Coordinate System: The options are EGM2008, EGM96, EGM84 ,and custom *Geoid Undulation*. It is recommended to use EGM2008, which has higher accuracy.

  > Geoid Undulation：The distance between the spheroid(h) and geoid surface(H): h-H.

Custom Geographic Transformation

Click *[Advance...]* to show the custom geographic transformation setting interface. Users can set custom 7/4/3 parameters to wrap the POS data to the target coordinate system in order to get high accuracy.

Following Procedures

- Please refer to Using GCP/MTP if GCP or MTP is required.
- Please refer to Process to start processing.

One Stop Process

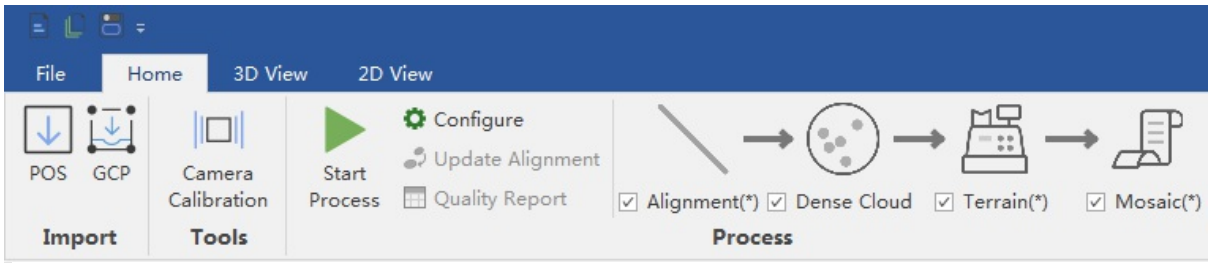
Prerequisite

The only mandatory pre-request is creating project.

- If extra input data is required, please refer to Using POS, Using GCP/MTP, Using Calibrated Camera Intrinsics, Set Main Band for Multispectral Camera.
- If some photos need to be removed, please refer to Delete Images.

Start Processing

Click  in the *[Home]* ribbon bar to start the one-stop processing:



> The steps to be processed are already determined when the template is selected. Here you can only run part of the steps by unchecking. Note:
>
> - There are dependencies between different steps, if dependencies were not satisfied,  button would be disabled.
> - Finished step would be displayed in unchecked, re-check this step and then click the *[Start Process]* button will recalculate this step.
> - Click  button to configure parameters in each step, please refer to Align Photos, Build Dense Cloud, Build DEM/DSM, Build Orthomosaic.

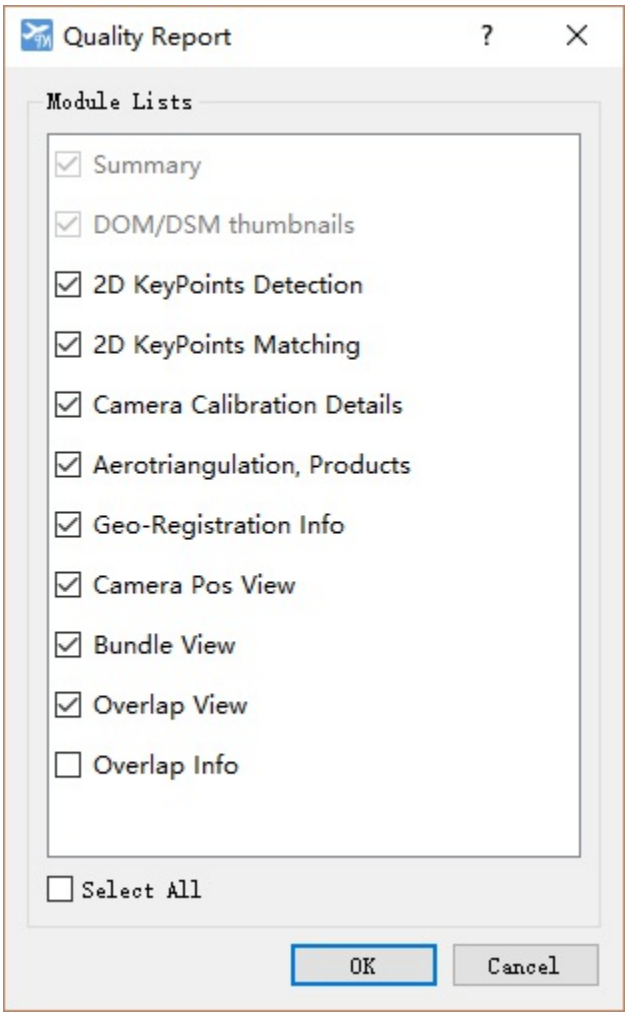
Next steps

- Refer to Generate Quality Report or Export Products if current results are satisfying.
- Refer to Adjust ROI if user wants to process partial scene only to improve efficiency.
- Refer to Adjusting Stitching lines if user is not satisfied with the current Orthomosaic and wants to manually adjust stitching lines.

Generate Quality Report

Quality report can be generated after each step of Process. Quality report contains project summary, parameters, results and running time, etc.

Click *[Home]->[Generate Quality Report]* on the menu bar to generate quality report in PDF format. The report will be generated to the [1_Report] folder under project path and opened by the PDF reader.



Export Product

Export Camera Orientation

Camera orientation optimized by LiMapper could be exported to other software after completing photo alignment by clicking *[Home]->[Export]-> [Camera]* on the menu bar. Refer to Camera Orientation Exporting Settings for detail.

Export Undistorted Photos

Click *[Home]->[Export]->[Undistorted Photos]* on the menu bar after completing photo alignment.

> Note: The undistorted photos will be saved in group and remain their origin filenames.

Export Point Cloud

3D Point cloud can be exported after completing photo alignment or dense cloud generation：

- Click *[Home]->[Export]->[Point Cloud]* on the menu bar.
- Right click on Tie Points or Dense Cloud under *[Product]* entry in the WorkStation Window, then click *[Export Point Cloud]*.

Refer to Export 3D Points Dialog for detail.

> Note: Dense cloud can be exported only after completing dense cloud generation.

Export DEM/DSM

DEM/DSM can be exported after completing DEM/DSM generation.

- Click *[Home]->[Export]->[DEM/DSM]* on the menu bar.
- Right click on "DEM" or "DSM" under *[Product]* entry in the WorkStation Window, then click *[Export DEM/DSM]*.

Refer to Export DEM/DSM Dialog for detail.

Export Orthomosaic

Orthomosaic can be exported after completing Orthomosaic generation.

- Click *[Home]->[Export]->[Orthomosaic]* on the menu bar.
- Right click on "Orthomosaic" under *[Product]* entry in WorkStation Window, then click *[Export Orthomosaic]*.

Refer to Export Orthomosaic Dialog for detail.

Export Stitching Line

Stitching line can be exported after completing Orthomosaic generation.

- Click *[Home]->[Export]->[Stitch Lines]* on the menu bar.
- Right click on "Orthomosaic" under *[Product]* entry in WorkStation Window, then click *[Export Stitching Lines]*.

Refer to Export Stitching Lines Dialog for detail.

Using POS

LiMapper uses POS information to speed up processing and transform the scene into real world coordinate system.

Supported POS types

	Photo EXIF	txt, csv File
Position	longitude,latitude,altitude	longitude,latitude,altitude / XYZ
Orientation	-	Roll, Pitch, Heading/Omega, Phi, Kappa

Import POS

Refer to Import POS for details.

Apply POS

POS information can be used in the following three aspects:

- Used in image pair selection during image matching to speed up processing.
- Used in **Update Alignment** to transform the scene into real world coordinate system(click ).
- As a **Weight Factor**, participate in bundle adjustment to increase robustness.
  - In cases of dealing with large-scale and high-resolution photos, perform Photo Alignment with the photos alone may sometimes unable to obtain optimal results(there are outliers caused by mismatch and errors when estimating camera distortion)
  - In order to improve the robustness of photo alignment, LiMapper adopts the strategy of simultaneously adjust POS and photos. The weight of POS is of course important.

> Note: If the imported camera intrinsics are inaccurate or the quality of the original photos are pool, the reconstructed cameras may deviate significantly from the corresponding POS. In this situation, **adjust POS accuray** can significantly improve the photo alignment results (for example, adjust the accuracy from the default 10 meters to 1 meter)

Subsequent Steps

- For a new project, after importing POS, please refer to one-stop process, the POS will be applied automatically.
- For project that has generated dense cloud, DEM/DSM or Orthomosaic, these previous results will be cleared, but the photo alignment results will be preserved. If you want to use previous photo alignment results, click *[Home]->[Process]->[Update Alignment]* on the menu bar to apply the imported POS, then refer to one-stop process.

Using GCP/MTP

The quality and absolute accuracy of photos alignment can be improved by using GCP(Ground Control Point). After photos alignment a photo of hard-to-match area, which failed to be registered automatically, could be manually registered by using MTP(Manual Tie Point), so that a more complete result would be achieved.

Using GCP

After switching to GCP Panel, you can edit GCPs following the steps below:

1. Add or import GCPs: Please refer to the usage of Point Table;
2. Add 2D Observations: Please refer to the usage of 2D Observation Table.

> Note: At least 4 uniform distributed GCPs are needed. Each GCP must be observed in at least 2 photos.

Besides, you can configure the mode how GCPs are used by clicking  in the GCP Panel.

After editing GCPs, there are 2 ways to use them:

- Run *Photos Alignment* immediately;
- Run *Update Alignment* in the GCP Panel by clicking  , if *Photos Alignment* has been done before.

Using MTP

After switching to MTP Panel, you can edit MTPs following the steps below:

1. Add MTP: Please refer to the usage of Point Table. Note that the flag of the point should be changed to "Tie Point"
2. Add 2D Observations: Please refer to the usage of 2D Observation Table. MTPs should be observed both in unregistered and registered photos.

> Note: At least 4 MTPs are needed for a unregistered photos. Each MTP must be observed in at least 2 registered photos.

After editing MTPs, you can *Update Alignment* photo in Photos Panel.

Using Calibrated Camera Intrinsics

User could setup camera intrinsics in LiMapper before photo alignment.

Instructions

There are two ways to setup camera intrinsics:

1. After loading photos at the [Load Photos] page of the New Project Wizard, click  for a photo group, then setup camera intrinsics in the pop-up dialog.
2. After creating a project: click *[Home]->[Tools]->[Camera Calibration]* on the menu bar, then setup camera intrinsics in the pop-up dialog.

Refer to Camera Calibration Dialog.

Set Master Band for Multispectral Data

For multispectral data, in consideration of the rigid transformation between different bands, and the difference features of each band, it is a common strategy to select one band as master band to align first, and then align other bands to master band using to rigid transformation constrain. Dense matching only uses master band as well.

- Instructions: Click *[Home]->[Tools]->[Camera Calibration...]* on the menu bar, then choose master band.
- **Green** band is recommended for common multispectral cameras (such as Micasense RedEdge).

Remove Photos

There are two ways to remove some photos after creating project.

Remove Photos through [Workstation] or [Photo] Window

Select photos to remove in Workstation or Photo window and click *[delete image]* in the context menu.

Remove Photos through the polygon selection in the [3D Viewer]

One of the following conditions need to be satisfied:

- After creating project, POS has been imported, and 3D Viewer is enabled to [Show POS].
- After photo alignment, 3D Viewer is enabled to [Show Camera].

Procedures:

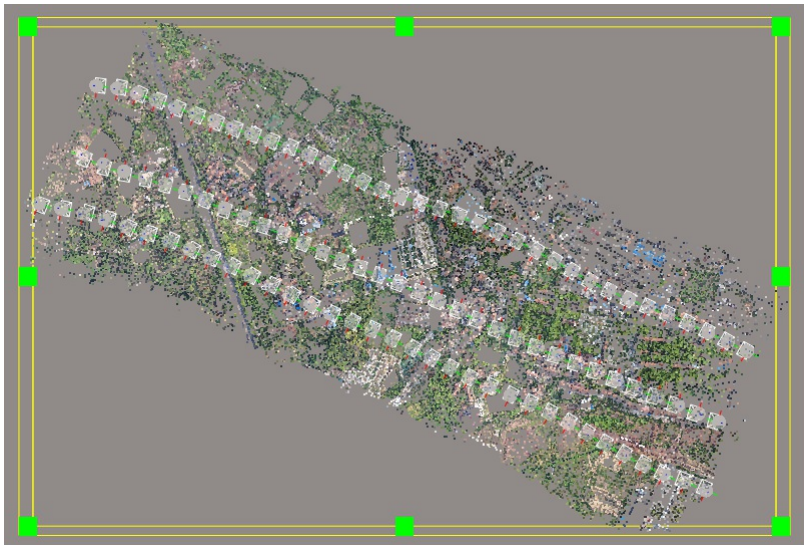
- Switch to the 3D Viewer and click *[3D View]->[Select Cameras]*  on the menu bar to enter the editing mode.
- Draw a polygon to cover the photos need to remove, right-click to finish and select those photos.
- If inverse selection is needed, click *[3D View]->[Invert Selection]*  on the menu bar.
- Selected photos would be rendered in red. Click *[3D View]->[Remove Cameras]*  on the menu bar to remove them.
- Click *[3D View]->[Select Cameras]*  on the menu bar again to quit editing mode.

Adjust ROI

After Photo Alignment, 3D Viewer should display the tie points and a yellow Region of Interest (ROI) box. The default ROI covers all of the scene. If you only need to reconstruct some region, you can adjust the ROI to reduce computation for future steps. Building Dense Cloud, Building DEM / DSM and Building DOM / TDOM only work in ROI.

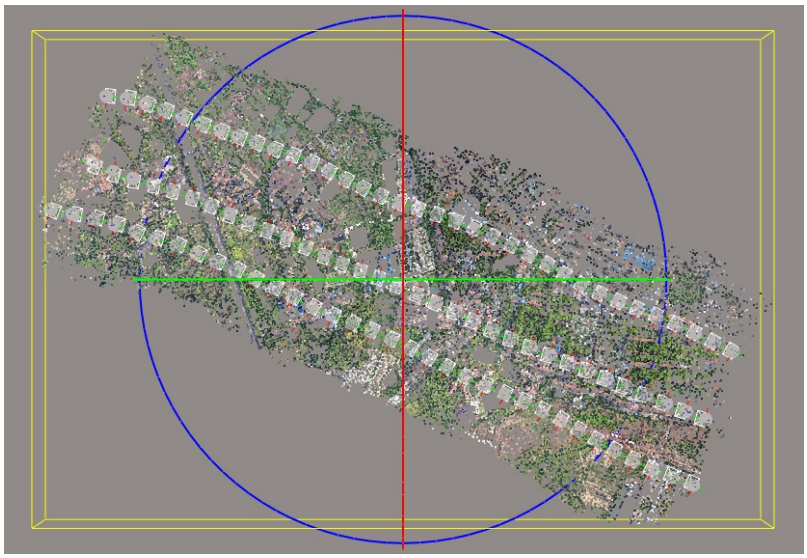
Resize ROI

Click *[3D View]->[ROI]->[Resize]* on the menu bar to start resizing ROI，then drag the ROI corner to resize. Click again to stop resizing.



Rotate ROI

Click *[3D View]->[ROI]->[Rotate]* on the menu bar to start rotating ROI. Click it again to stop.



- Drag to rotate the ROI

- Drag the rotation circle to rotate around axis

Reset ROI

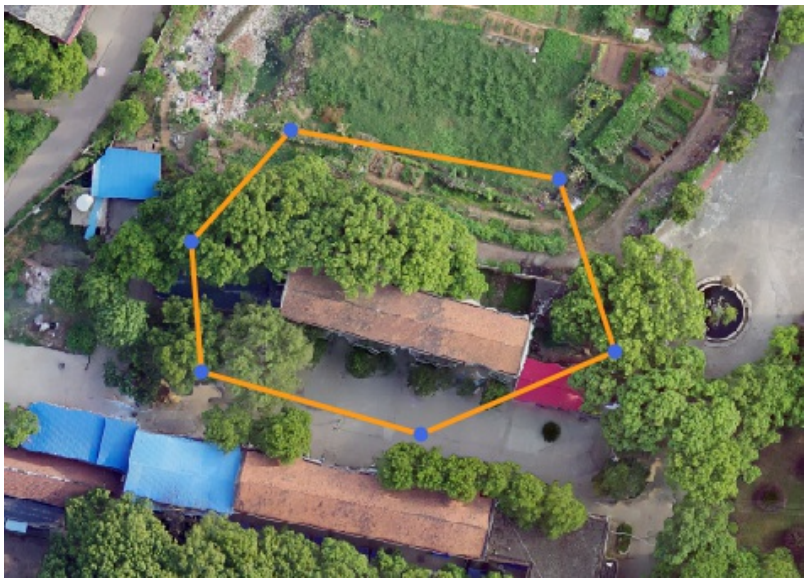
Click *[3D View]->[ROI]->[Reset]*  on the menu bar to reset ROI.

Adjust Stitching Lines

After building Orthomosaic, user could exam the quality. If obvious seams or poor quality areas were found, adjusting stitching lines might produce better result.

Procedure

1.**Select Target Area**: Click *[2D View]->[Draw Polygon]*on the menu bar to activate adjustment, then left-click to draw a polygon around the target area, right-click when finished, as shown bellow:



- After drawing the polygon, if you find that you need to re-draw it, just right-click in the selected polygon area and select *[Delete Shape]* in the pop-up menu.
- If you need to add new vertex to the current polygon, right-click on the target place and select *[insert vertex]* in the pop-up menu, the new vertex will be inserted.

2.**Assign Photos**: Right-click in the selected polygon area and select *[Assign Photo]* in the pop-up menu, then images visible to this area will appear in the Mosaic Photos Window, as shown below:

Pick the desired image and click the *[Assign]* button to apply adjustment. Click *[Cancel]* if you want to cancel adjustment.

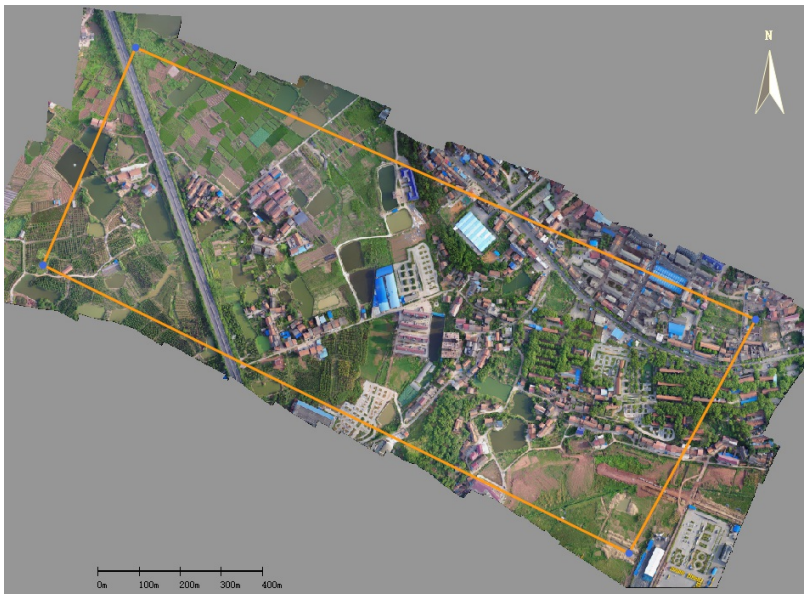
3.**Update Orthomosaic**: Click *[2D View]->[Update Orthomosaic]* on the menu bar to update the adjustment to the final Orthomosaic. The updated Orthomosaic with the polygon deleted is shown below:

Clip Orthomosaic

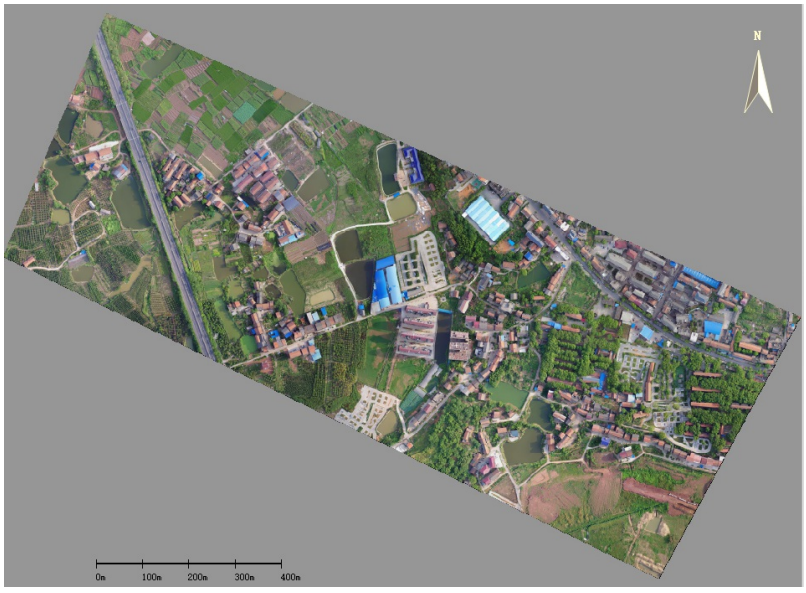
After building Orthomosaic, if you want to adjust the boundary of the orthophoto to make it more regular, then you can crop the unwanted boundary via clipping funtion.

Procedure

1.**Select Target Area**: Click *[2D View]->[Draw Polygon]*on the menu bar to activate adjustment, then left-click to draw a polygon around the target area, right-click when finished, as shown bellow:



2.**Clipping image**:When a target area is selected, click *[2D View]->[Clip Mosaic]* on the menu bar, then the clipped orthomosiac will be updated. Please be patient when dealing with a big image, the result is showed bellow:

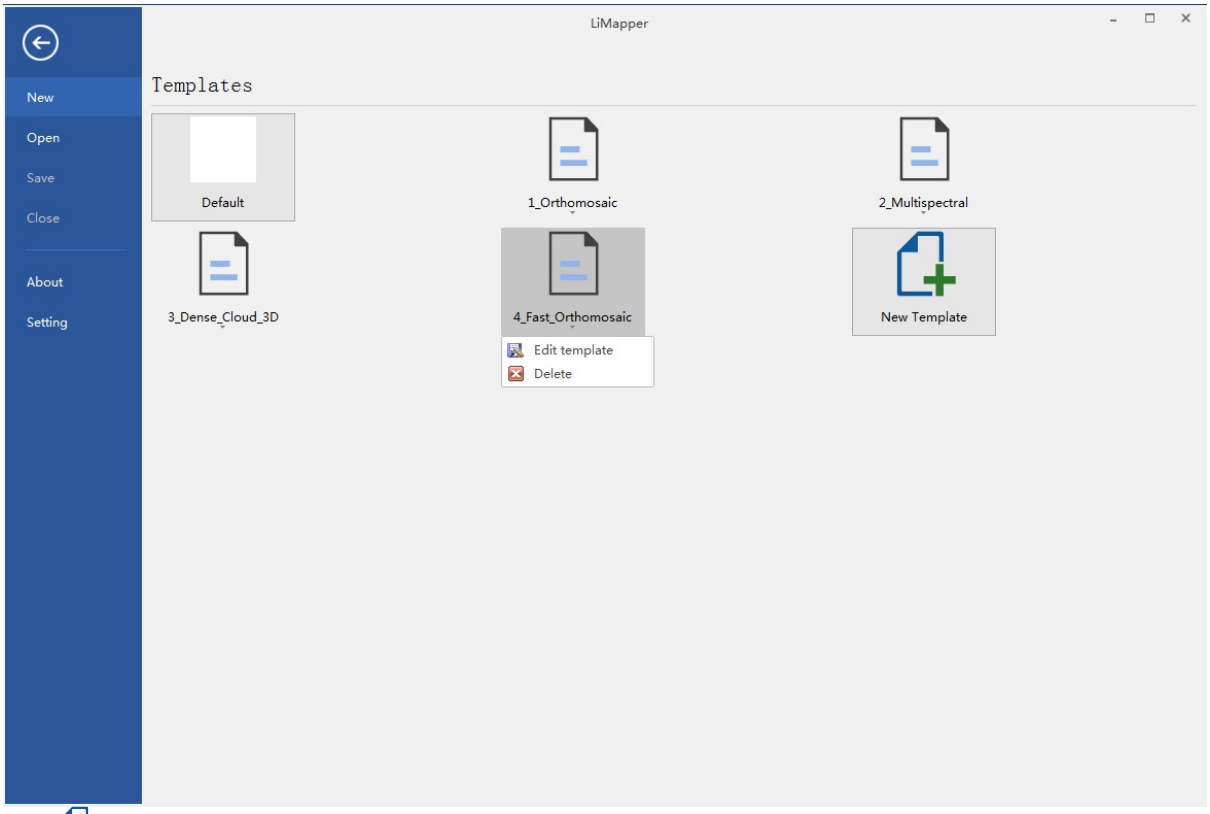


Project Template

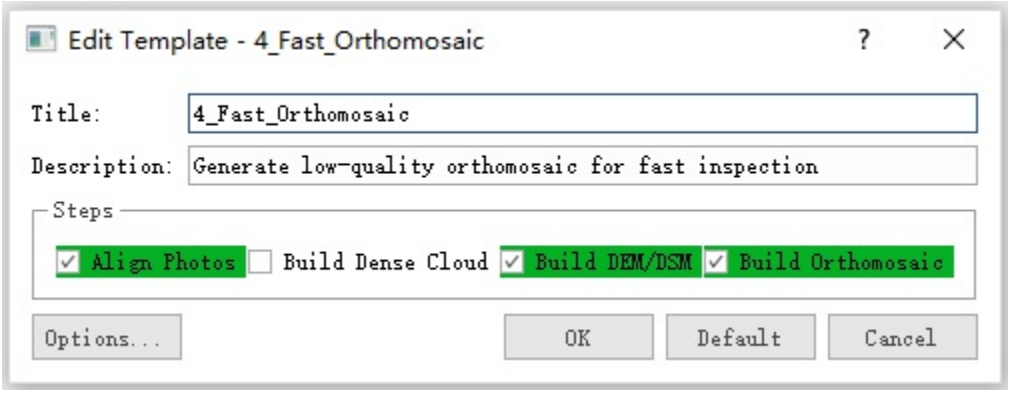
In practice, it is common to use the same set of parameters to process different tasks in production. If user had to configure the parameters every time, the workload would be huge, and the risk of human error would increase. Project template is a way to solve this problem. After setting up a project template, user could use it to create new project everytime.

Creating Project Template

Click *[New]* in the side menu to enter the new project page, preset templates will be listed here。



Click to activate the template setting dialog where users can type in template title, short description (optional) and check the steps that need to be processed, then click *[OK]* to generate the template.



修改工程模板

Clicking the ▼ arrow below a template can expand a drop-down menu where users can edit or delete a template.

> Note:
>
> - There are dependencies between different steps, if dependencies were not satisfied, *[OK]* button would not be enabled.
> - Click *[Options ...]* button to configure parameters in each step, please refer to Align Photos, Build Dense Cloud, Build DEM/DSM, Build Orthomosaic.

Tutorials

- True Orthomosaic Generation Tutorial
- MultiSpectral Processing Tutorial

True Orthomosaic Generation Tutorial

Description

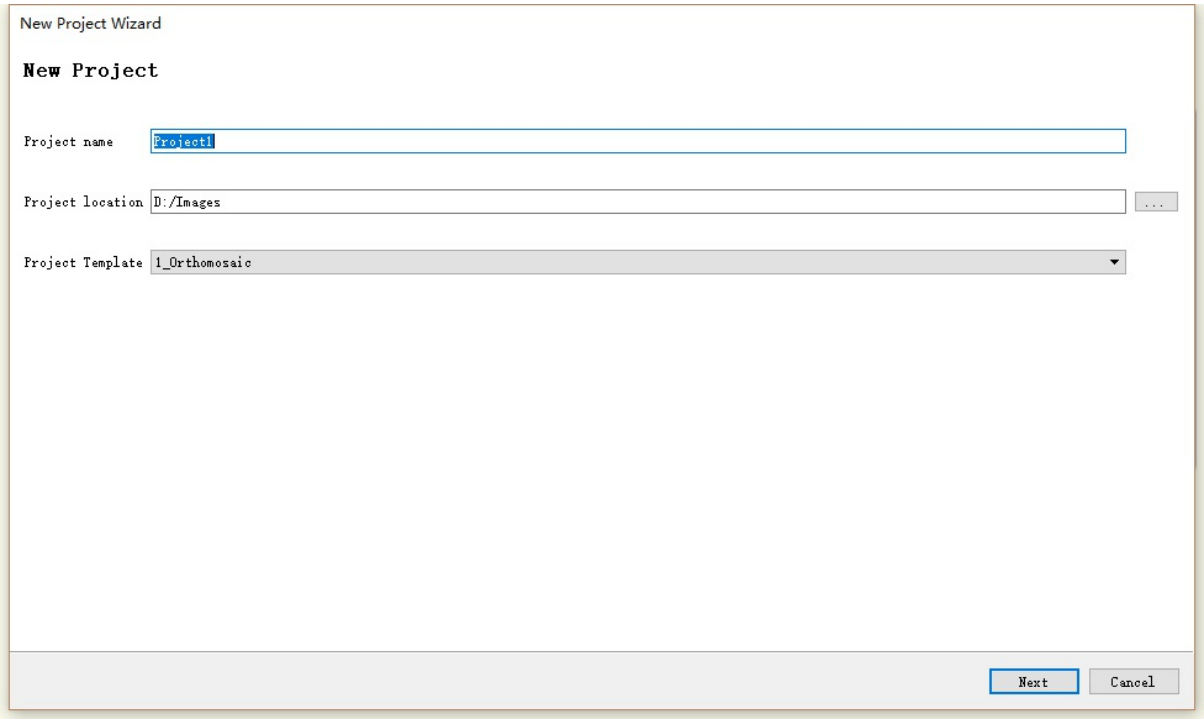
Processing of single/multi-camera photos of single/multiple flight(s) is supported in LiMapper, which is widely applied to geological disaster monitoring, surveying and mapping, forestry analysis, environmental protection, etc.

Workflow

1. Preparation

(1) New Project

- Input the project name and project path in New Project Wizard;
- Edit project template.

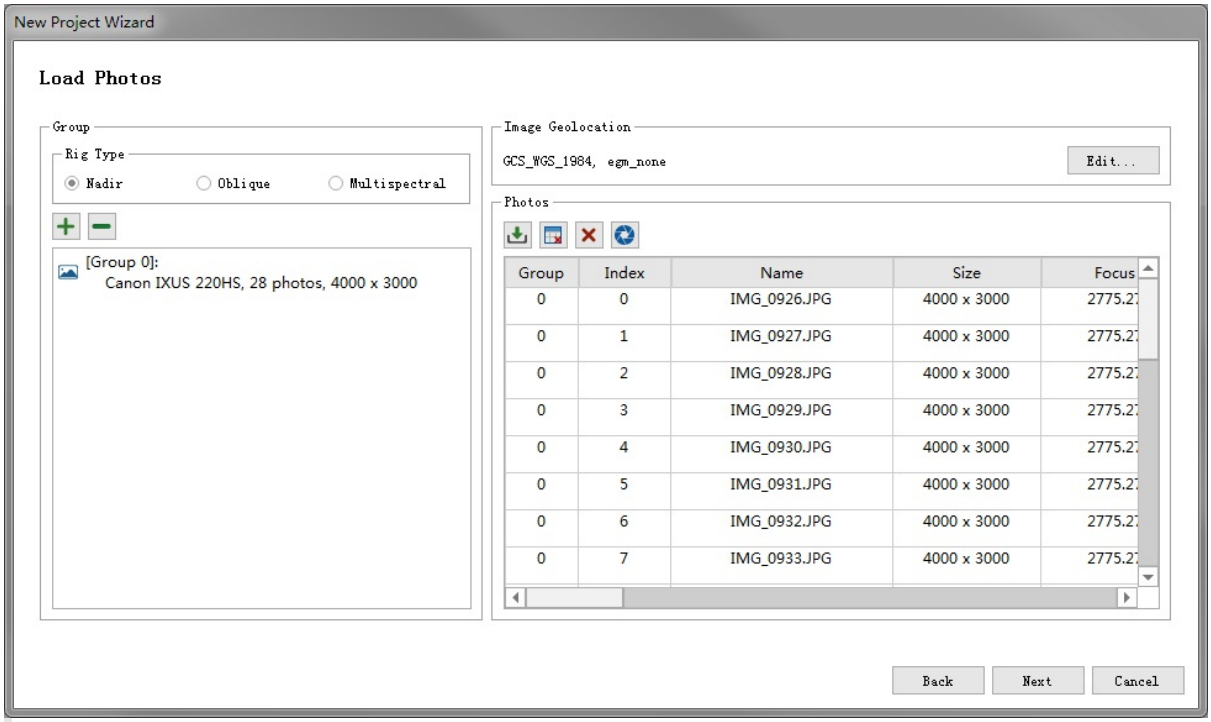


(2) Load Data

Firstly, set data type as nadir. Photo group(s) should be managed as follows:

- Single camera, single flight or multiple flights with overlaps: Load all photos as one group.
- Multi-camera, single flight or multiple flights with overlaps: Load photos acquired by the same camera in a group, repeat it several times to finish loading all photos.

Please refer to Loading Photos for detailed introduction.



> Note: Photos in the same group shoudn't have identical names.

(3) Import POS (Optional)

If location informations in EXIF are not available, POS files of formats TXT or CSV can be imported. Please refer to Importing POS.

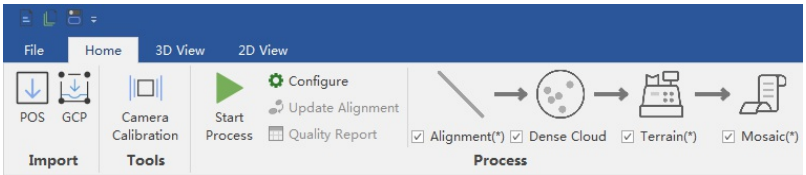
Output results are in local coordinate system if project is not georeferenced.

2. Processing

(1) Mosaicking

In the Process GUI below, you can check/uncheck procedures depending on need. After clicking "Configure" button, you can configure related template parameters.

> Note: The dense point cloud type is only editable when creating template.



3. Export

(1) Export Point Cloud

Both Sparse and dense point cloud can be exported after processing. Supported formats are PLY, LAS, and OBJ. In addition, dense point cloud can also be exported as OSGB file. Please refer to Exporting Cloud

(2) Export DEM/DSM

Users can specify coordinate system, compress method and resolution before exporting DEM/DSM. More details can be found in Exporting DEM/DSM.

(3) Export Orthomosaic

Users can specify coordinate system, compress method and resolution before exporting Orthomosaic. More details can be found in Exporting DEM/DSM.

(4) Export Byproducts

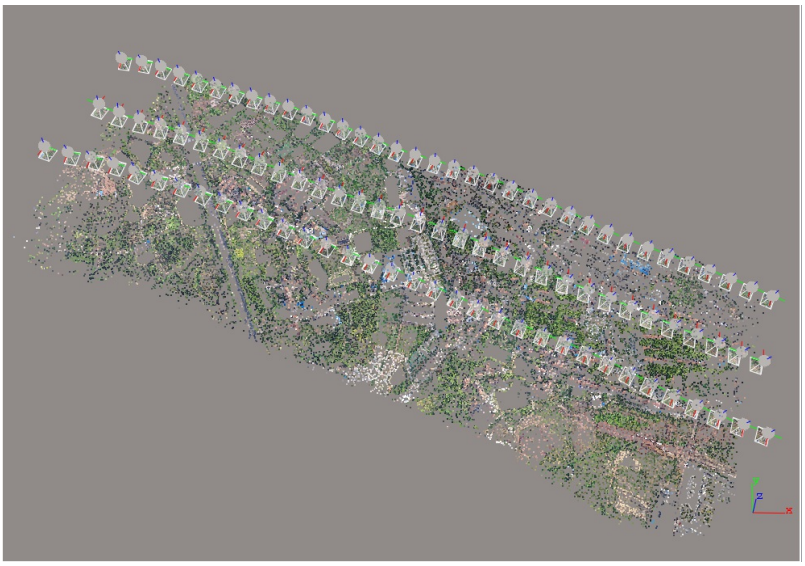
Please refer to Exporting Camera Parameters, Exporting Undistorted Photos, Exporting Stitching Lines, Exporting Reports.

Example

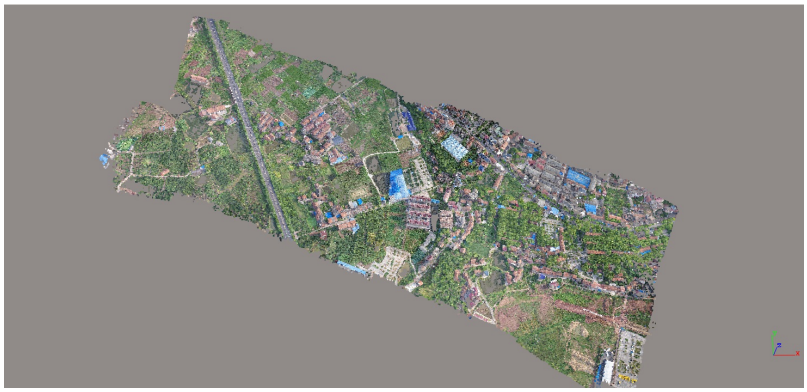
Photos used in this case are taken in a suburb scene. There are 102 photos with the size 8256 x 6192.

Source Data

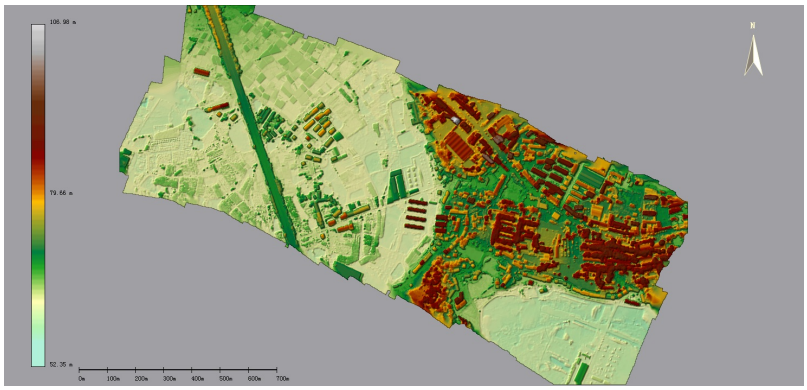
Sparse Point Cloud



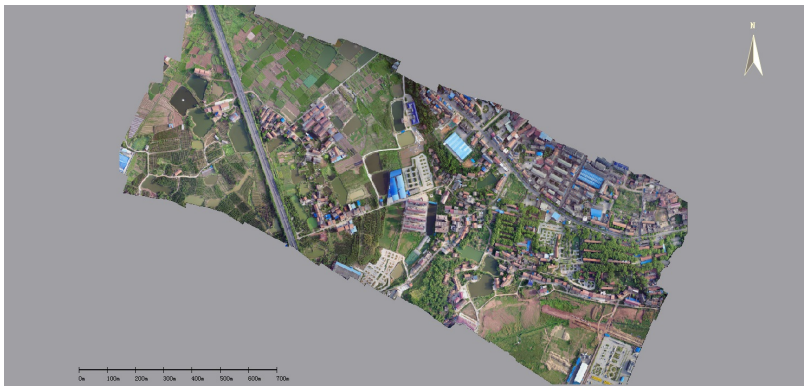
Dense Point Cloud



DSM



True Orthomosaic



MultiSpectral Processing Tutorial

Description

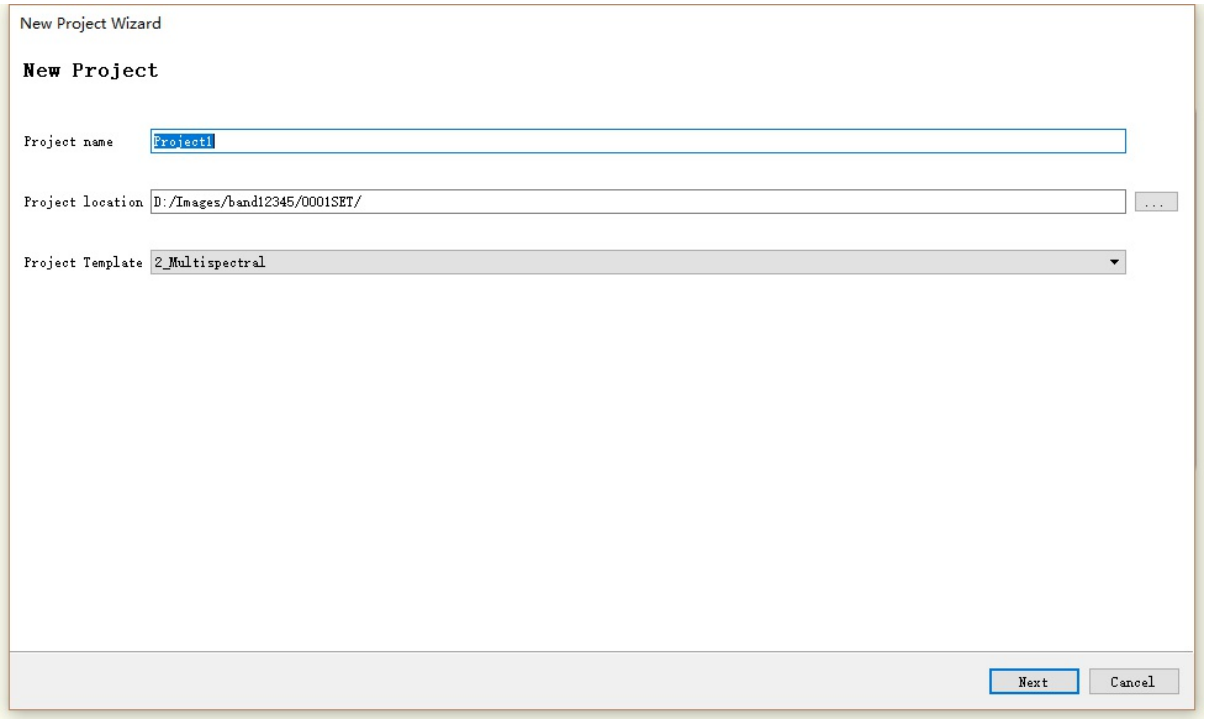
Processing of multispectral photos of single flight is supported in LiMapper, which is widely applied to geological disaster monitoring, surveying and mapping, forestry analysis, environmental protection, etc. Multiple bands can be processed simultaneously and exported using custom combination.

Workflow

1. Preparation

(1) New Project

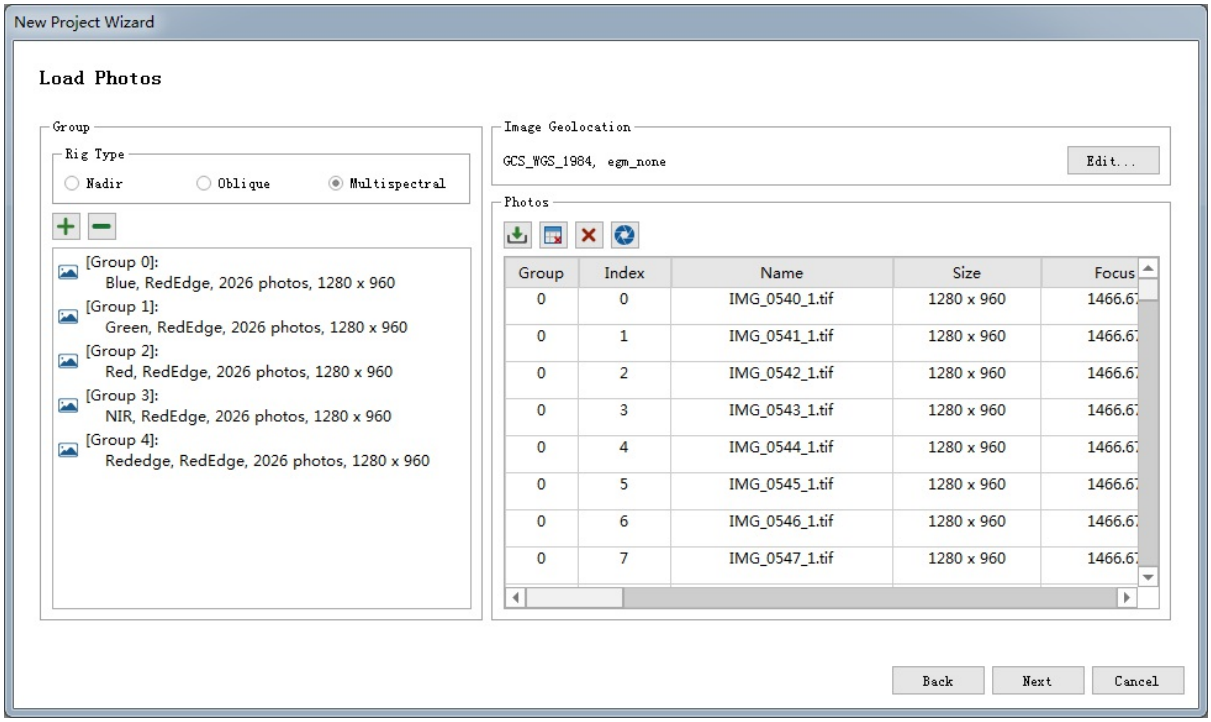
- Input the project name and project path in New Project Wizard;
- Edit project template.



(2) Load Data（Single flight）

Set data type as multispectral. Photos of same band should be imported as a group. Please refer to Photo Editing.

> Note：Photos in the same group shouldn't have identical names. It's not recommended to process multispectral photos of multiple flights simultaneously.



(3) Import POS (Optional)

If location informations in EXIF are not available, POS files of formats TXT or CSV can be imported. Please refer to Importing POS.

Output results are in local coordinate system if project is not georeferenced.

> Note：There is no need to import POS separately for each band in principle, because different bands share the same POS in general; But import per band is still supported in case of independent bands.

(4) Set Master Band (Optional)

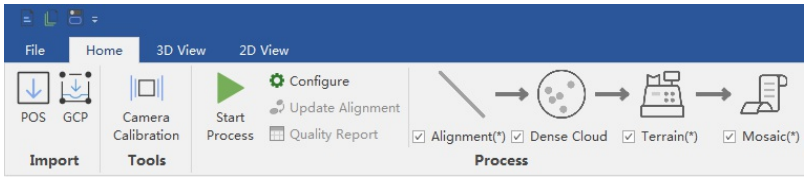
After data import, a custom master band is also supported if needed, please refer to Master Band Setting.

2. Processing

(1) Mosaicking

In the Process GUI below, you can check/uncheck procedures depending on need. After clicking "Configure" button, you can configure related template parameters.

> Note: The dense point cloud type is only editable when creating template.



3. Export

(1) Export Point Cloud

Both Sparse and dense point cloud can be exported after processing. Supported formats are PLY, LAS, and OBJ. In addition, dense point cloud can also be exported as OSGB file. Please refer to Exporting Cloud

(2) Export DEM/DSM

Users can specify coordinate system, compress method and resolution before exporting DEM/DSM. More details can be found in Exporting DEM/DSM.

(3) Export Orthomosaic

Users can specify coordinate system, compress method and resolution before exporting Orthomosaic. More details can be found in Exporting DEM/DSM.

(4) Export Byproducts

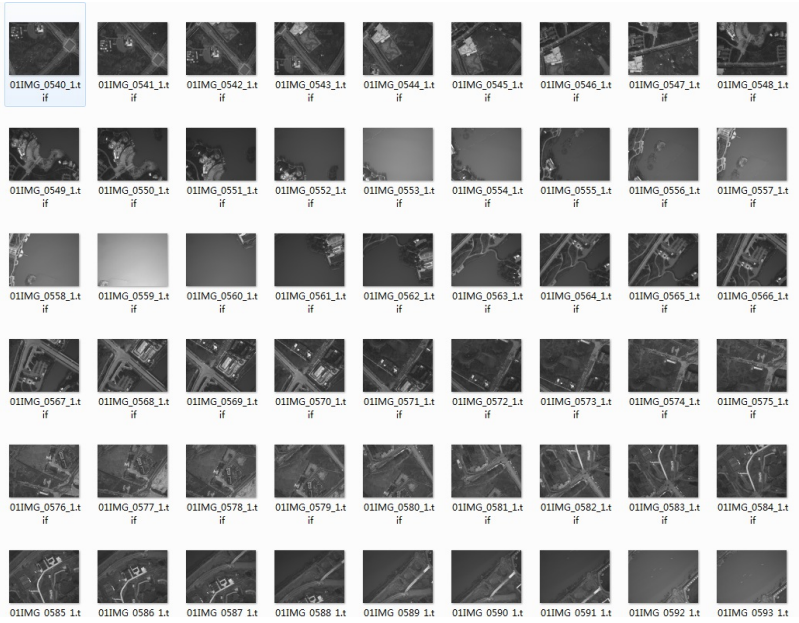
Please refer to Exporting Camera Parameters, Exporting Undistorted Photos, Exporting Stitching Lines, Exporting Reports.

Example

The data is acquired in a town using RedEdge multispectral camera with the image size 1280*960. There are 11000 photos of 5 bands in total, 2200 photos per band.

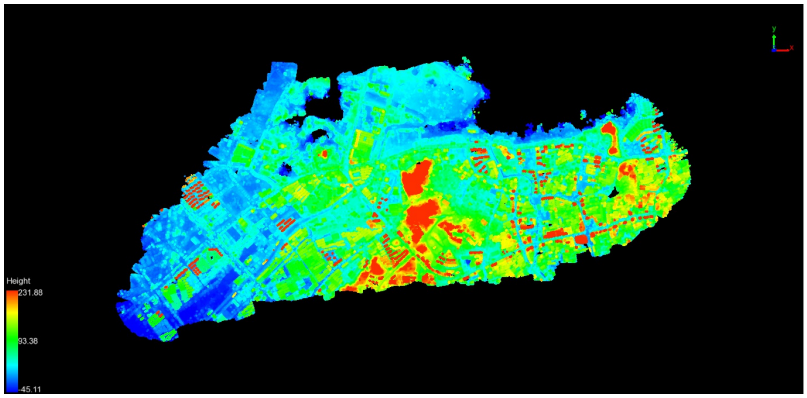
Source Data

Example of source data



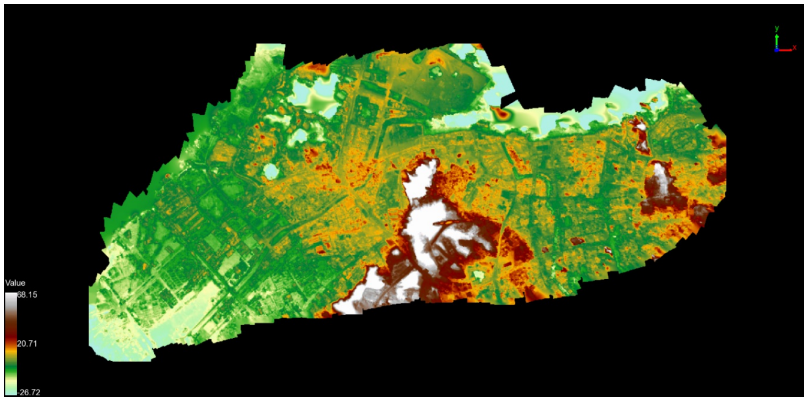
Dense Point Cloud

The dense point cloud is displayed by elevation in the software LiDAR360.



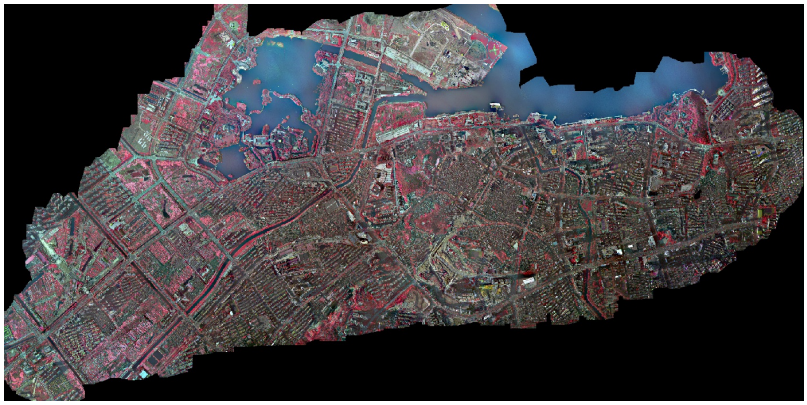
DEM

The DEM is displayed by elevation in the software LiDAR360.



Orthomosaic

The product is a pseudo-color mosaic image of bands 4,3,2.



Modules

Main User Interface

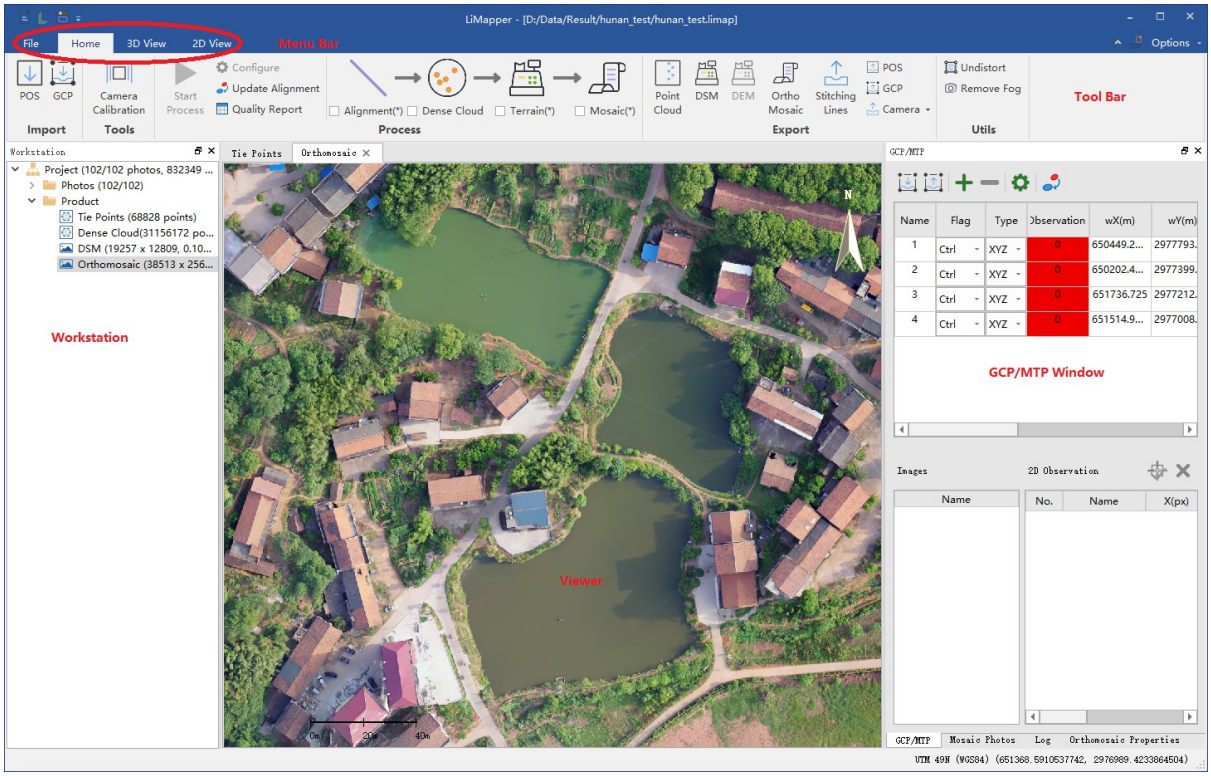
- Main Window
- Workstation Window
- GCP/MTP Window
- Photo Window
- Log Window
- Mosaic Photos Window
- 3D Viewer
- Photo Viewer
- DEM/DSM Viewer
- Orthomosaic Viewer

Dialogs

- Process Dialogs
  - Align Photos Settings
  - Build Dense Cloud Settings
  - Build DEM/DSM Settings
  - Build Orthomosaic Settings
- Export Product Dialogs
  - Export Camera Orientation Settings
  - Export Points Settings
  - Export DEM/DSM Settings
  - Export Orthomosaic Settings
  - Export Stitching Lines Settings
- Utility Dialogs
  - Import POS Settings
  - Export POS Settings
  - Import GCP/MTP Settings
  - Camera Calibration Settings
  - Undistort Settings

Main Window

The main interface of the software contains four parts: menu bar, toolbar, viewers and docks.



- Menu Bar
  - File
    - New

      Create a new project.
    - Open

      Open an existing project.
    - Save

      Save current project.
    - Close

      Close current project
    - Recent Projects

      Record projects opened recently.
    - About
    - Settings

      Refer to Software Settings.
    - Activate License

- Home
  - Import

    Including Import POS and Import GCP tools.
  - Camera Calibration

    Refer to Camera Calibration
  - Process

    The one-stop workflow of the software.
  - Update Alignment

    Align to GPS or GCP, dense cloud, DEM/DSM, Orthomosaic would be removed.
  - Generate Quality Report

    Generate a quality report in PDF format.
  - Export

    Including [Export GCP] and Export POS. And several products like camera orientation parameters, undistorted photos, tie points, dense cloud, DEM/DSM, Orthomosaic and stitching lines can be exported.
  - Utils

    Including Undistort and Haze Removal tools.
- 3D View
  - Measure
  - Edit Camera

    Refer to Remove Photos images.
  - Edit ROI

    Refer to Adjust ROI.
  - Increase Camera Size

    Increasing camera frustum size in 3D viewer.
  - Decrease Camera Size

    Decreasing camera frustum size in 3D viewer.
  - Show ROI

    Show or hide ROI in 3D viewer.
  - Show GPS

    Show or hide GPS location in 3D viewer.
  - Show Camera

    Show or hide camera frustum in 3D viewer.

        - Show Thumbnail

          Show or hide thumbnail in 3D viewer.

        - Show Ground Control Points

          Show or hide GCP in 3D viewer.

        - Effect
          - Eye-Dome Lighting

            Enable or disable EDL effect in 3D viewer.

          - Point and Line Setting
    - 2D View
      - Manipulator
        - Move, measure, zoom in/out, draw polygon in 2D view
      - Show
        - Show Feature Points

          Show or hide feature points in Photo viewer.

        - Show Shape

          Show or hide Shape in DEM/DSM viewer or Orthomosaic viewer.

        - Show Stitching Line

          Show or hide stitching lines in Orthomosaic viewer

        - Show Hillshade

          Enable or disable hillshade effect in DEM/DSM viewer.

      - Update

        Update DOM

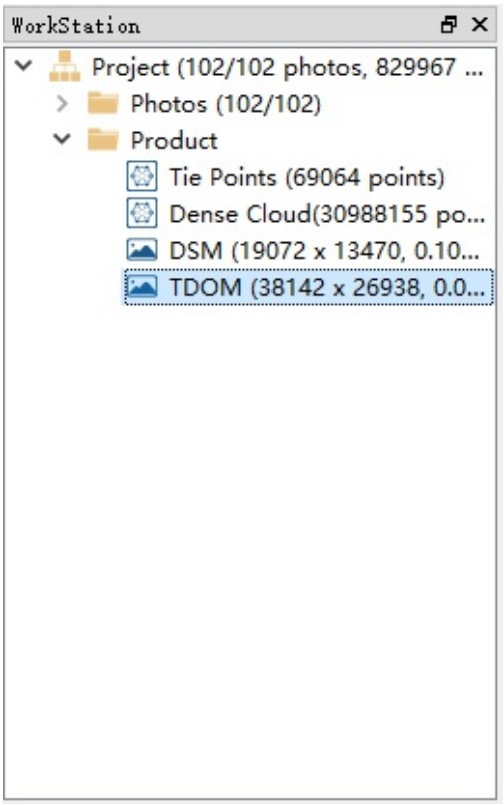
    - Options
      - Window

        Show or hide or Rest:

        - Tool Bar
        - Workstation Window
        - GCP/MTP Window
        - Photos Window
        - Log Window
        - Mosaic Photos Window
- Viewers
  - 3D Viewer
  - Photo Viewer
  - DEM/DSM Viewer

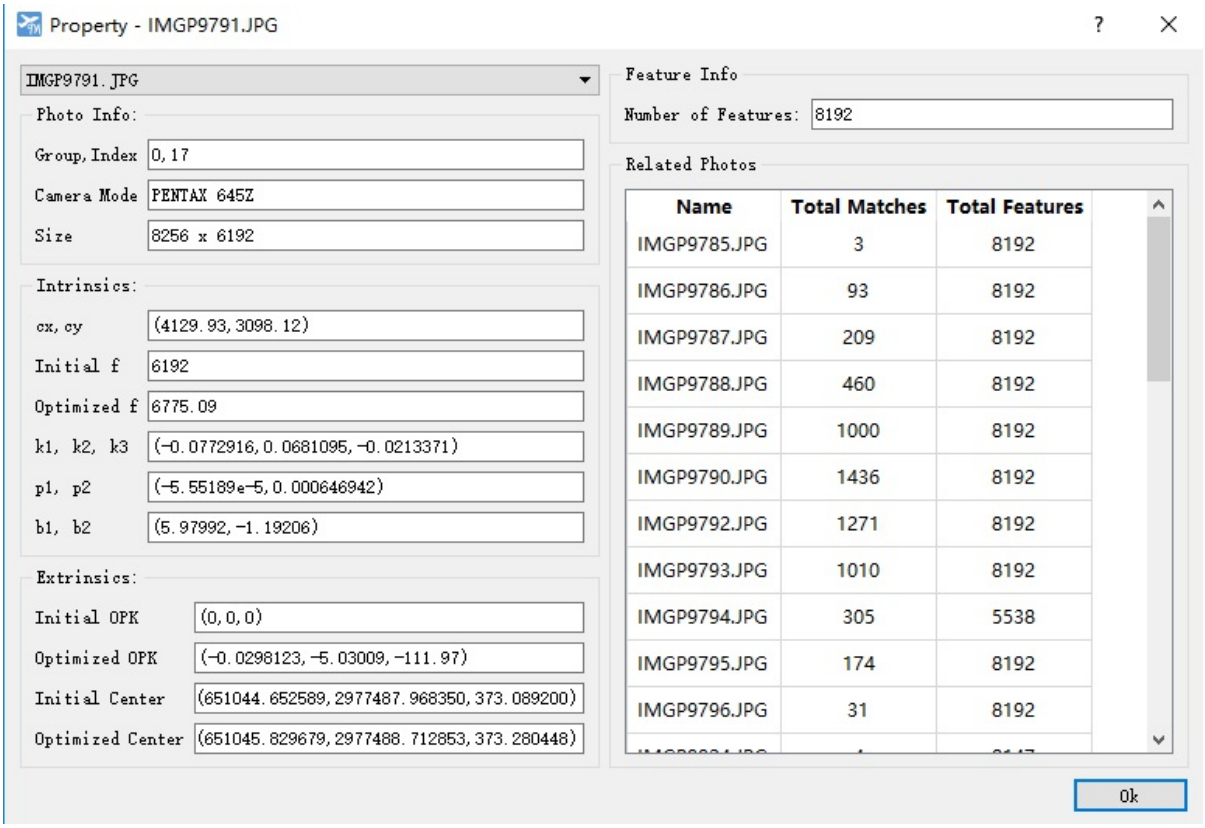
Workstation Window

Workspace window is to manage inputs images and products of current project. Products include tie point, dense cloud, DEM/DSM, and Orthomosaic. The tree structure of the workstation window is shown below:



Functions

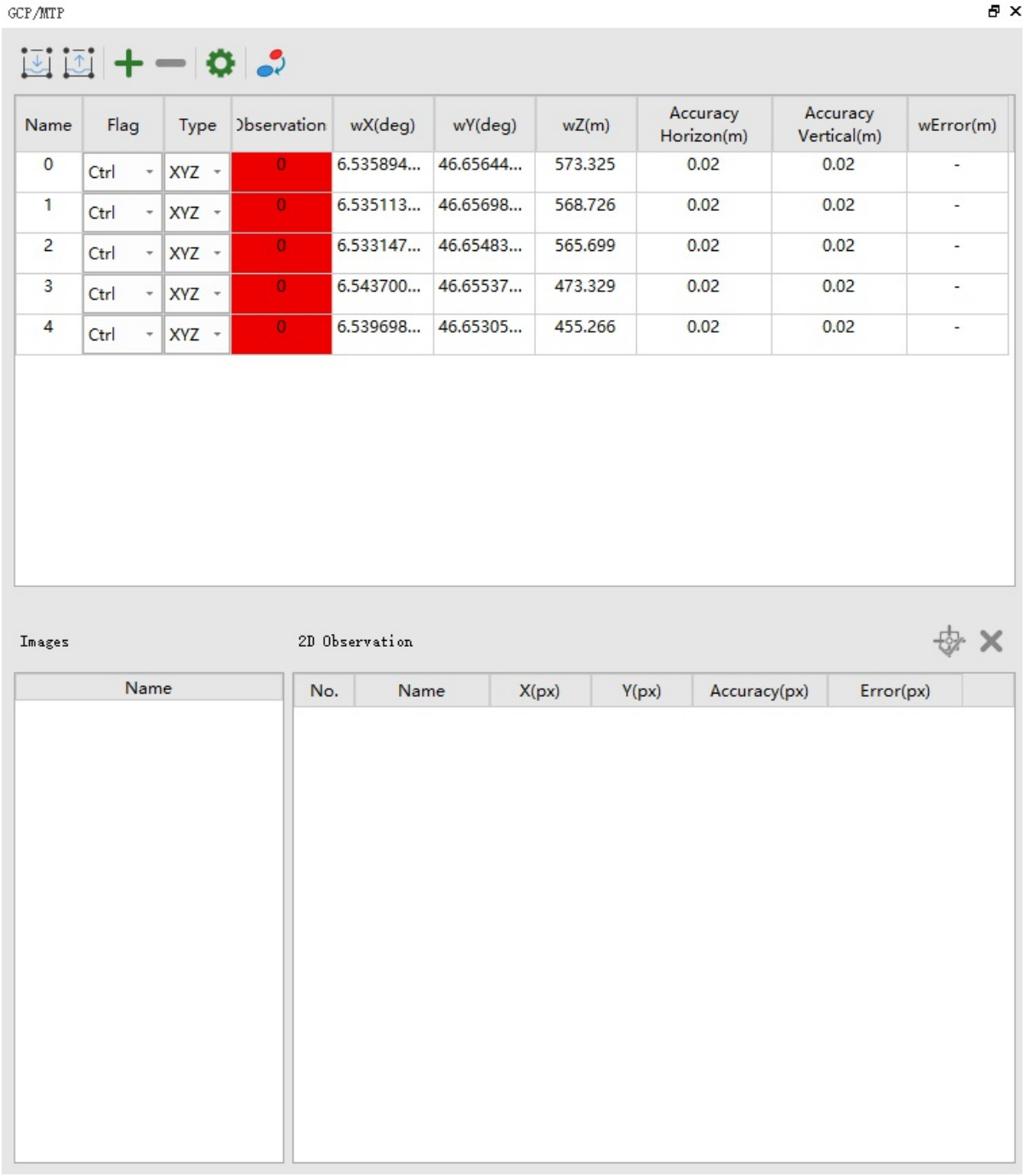
- **Start one-stop processing:** Right click *[project]*, select *[process]* to open the Process wizard.
- **Open source image:** Double click any image under *[photo]* entry to show it in the Photo viewer.
- **Delete source image:** Right click image that need to be deleted under *[photo]* entry, then select *[Delete Photo]*.
- **Re-register image:** All the registered input images has "aligned" suffix after photo alignment. If you want to try re-register some image, right click it and choose *[Re-Register Photo]*.
- **Photo Properties:** Right click image under *[photo]* entry and select *[Properties]*, then the [Properties] window will pop up. As shown below:



- **Export Product:** Products under *[Product]* entry (eg. Tie Point, Dense Cloud, DEM/DSM, Orthomosaic) can be exported, just right click it and select *[Export xxx]*. For detail, please refer to export product.

GCP/MTP Window

The GCP/MTP Window is used to import, export, and edit GCPs(Ground Control Points) as well as MTPs(Manual Tie Points). As shown below the GCP/MTP Window contains 3 tables from the top down: Point Table, 2D Observation Table, and 2D Prediction Table.



Functions

Point Table

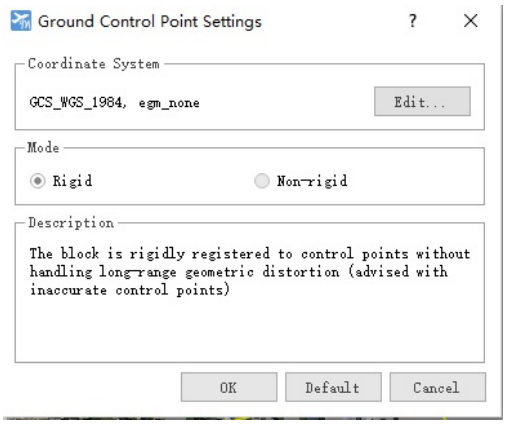
The Point Table is used for display and editing GCPs, Check Points and MTPs. The table headers are as follows:

- Name：Editable point name.
- Flag：Editable point flag. Supported options are GCP (used for absolute alignment), Check Point (used for checking absolute accuracy), MTP (used for registration of photos in difficult area).
- Type：Editable point type. Supported options are XYZ (horizontal and vertical), XY (horizontal), Z (vertical).
- wX, wY, wZ： Editable 3D point coordinates in object space.
- wError：3D point error after absolute alignment.
- Relative Photos：Photos in which the point is observed.

> Note: Type and 3D coordinates are deactivated if point flag is MTP.

The toolbar above the Point Table contains the following functions：

- Import GCP/MTP：Import GCP/MTP from file.
- Export GCP/MTP：Export GCP/MTP in the Point Table to file. Supported formats are TXT, XML.
- Add GCP/MTP：Add new point into the Point Table.
- Delete GCP/MTP：Delete selected point(s) in the Point Table.
- GCP Settings：Set coordinate system



- Update Alignment：You can run *Update Alignment* after Photos Alignment if there exist at least 4 valid GCPs.

2D Observation Table

If a point in the Point Table is selected, its corresponding 2D observation(s) in photo(s) will be shown in the 2D Observation Table. The table headers are as follows:

- No.：Photo's Number.
- Name：Photo's Name.
- X, Y：Observation (i.e. pixel coordinates) of this point in photo.
- Error：Observation's error after absolute alignment.

The toolbar above the 2D Observation Table contains the following functions：

- Add 2D Observation：Firstly, you have to double-click a relative photo in the *Prediction Photo(s) Table*, in order to show this photo in the Photo Viewer. Then you can click the pixel position of the point in the photo and add this 2D observation.
  - An observation (i.e. pixel position) is shown as a red cross after clicking in the photo.

- The red cross turns green after clicking .

- Delete 2D Observation：Delete selected Observation(s) in the table.

Prediction Photo(s) Table

If a point in the Point Table is selected, its corresponding photo(s) will be shown in the Prediction Photo(s) Table. After clicking a photo in the Prediction Photo(s) Table, the Photo Window will jump to this photo and draw 2d prediction position immediately, so that manual search is avoided. The table headers are as follows:

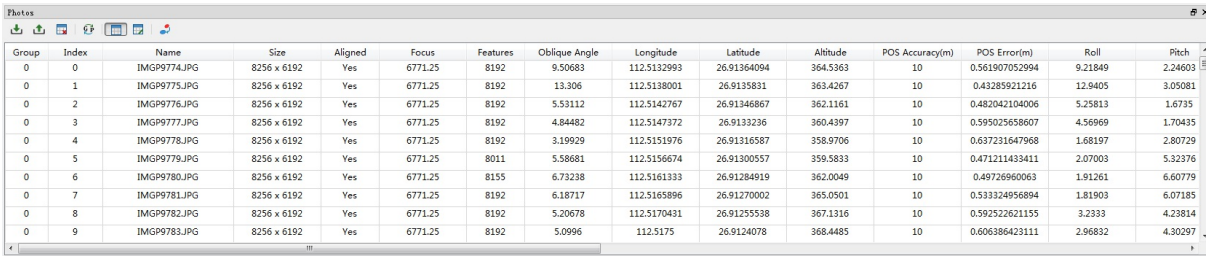
- Name：Photo's Name.

Predicted position is shown as green X within circle.

> Note: The current version supports importing control points before *Photos Alignment* or not, and both import methods support *Prediction Table*. But.
>
> 1. Use the *Prediction Table* before *Photos Alignment* does not support auto marker 2D observation position, and must first import GPS data and select at least 2 2D observations of current point before use, otherwise the prediction may have large errors.
> 2. When using the *Prediction Table* after *Photos Alignment* without GPS data, you need to select at least 2 2D observation of current point in registered photos manually in advance.

Photo Window

Photo window is to manage inputs images of current project, as shown below:



Group	Index	Name	Size	Aligned	Focus	Features	Oblique Angle	Longitude	Latitude	Altitude	POS Accuracy(m)	POS Error(m)	Roll	Pitch
0	0	IMGP9774.JPG	8256 x 6192	Yes	6771.25	8192	9.50683	112.5132993	26.91364094	364.5363	10	0.561907052994	9.21849	2.24603
0	1	IMGP9775.JPG	8256 x 6192	Yes	6771.25	8192	13.306	112.5138001	26.9135831	363.4267	10	0.43285921216	12.9405	3.05081
0	2	IMGP9776.JPG	8256 x 6192	Yes	6771.25	8192	5.53112	112.5142767	26.91346867	362.1161	10	0.482042104006	5.25813	1.6735
0	3	IMGP9777.JPG	8256 x 6192	Yes	6771.25	8192	4.84482	112.5147372	26.9133236	360.4397	10	0.595025658607	4.56969	1.70435
0	4	IMGP9778.JPG	8256 x 6192	Yes	6771.25	8192	3.19929	112.5151976	26.91316587	358.9706	10	0.637231647968	1.68197	2.80729
0	5	IMGP9779.JPG	8256 x 6192	Yes	6771.25	8011	5.58681	112.5156674	26.91300557	359.5833	10	0.471211433411	2.07003	5.32376
0	6	IMGP9780.JPG	8256 x 6192	Yes	6771.25	8155	6.73238	112.5161333	26.91284919	362.0049	10	0.49726960063	1.91261	6.60779
0	7	IMGP9781.JPG	8256 x 6192	Yes	6771.25	8192	6.18717	112.5165896	26.91270002	365.0501	10	0.533324956894	1.81903	6.07185
0	8	IMGP9782.JPG	8256 x 6192	Yes	6771.25	8192	5.20678	112.5170431	26.91255538	367.1316	10	0.592522621155	3.2333	4.23814
0	9	IMGP9783.JPG	8256 x 6192	Yes	6771.25	8192	5.0996	112.5175	26.9124078	368.4485	10	0.606386423111	2.96832	4.30297

Functions

Photo Management

- Photo selection: Both "Shift" style and "Ctrl" style multiselection and supported. As well as "Ctrl+A" for selecting all.
- Photo deletion: Right click any selected photo and choose *[Delete Photo]*.
- Photo sorting: Click the header of any column to sort the table. Click the same header to switch between ascending and descending.

POS Management:

- Import POS: Refer to Import POS for detail.
- Export POS: Refer to Export POS for detail.
- Reset POS: remove the existing POS.

Photo Information Management

- Switch Coordinate: switch POS presentation between (X, Y, Z, Omega, Phi, Kappa) and (Longitude, Latitude, Altitude, Roll, Pitch, Heading).
- Source data: display imported POS.
- Optimized data: display optimized POS.
- Photo Properties: Right click any photo and select *[Properties]* to view detail information about this photo.

Update Alignment

If photo alignment was completed, clicking would align current project to imported POS.

Re-register Image

If photo alignment result was obviously wrong for some photo, user could try right-click it and choose *[Re-Register Photo]*.

Set POS Accuracy

Select some photos, right click and choose *[Set POS Accuracy]*. Then, modify the value of *[Location Accuracy]* or *[Rotation Accuracy]* in the pop-up dialog. Refer to Use POS.

Log Window

Log window shows the log of the software. Logs are generated all over the software to tell user the status of the software. If the software run into any trouble, logs would help to locate the problem. Logs are showed in different colors:

- **Black**: black log indicates the begin/end of a processing step (align photos, build dense cloud, etc).
- **Blue**: blue log is the normal type. Parameters and progress are showed in blue. If a blue log started with a **Warning**, user should take caution as there might be something wrong. In most case, the software could keep running after warning.
- **Red**: red log indicates critical error, such as file I/O error.

Mosaic Window

Mosaic panel is to assist stitching lines editing(refer to Adjust Stitching Lines for details of editting stitching lines). It consist of *Visible Orthophotos* list, *Assign* button and *Cancel* button, as shown below:


Mosaic Photos
Visible Orthophotos:
IMG_0434.JPG
IMG_0435.JPG
IMG_0450.JPG
Assign
Cancel

Functions

Browse the Effect of Stitching Lines Adjusting

Visible Orthophotos lists all the visible photos in the edited area of the Orthomosaic viewer, orthophotos are sorted by valid area in descending order. Click a photo to view the overlay effect in Orthomosaic viewer.

Assign Photos

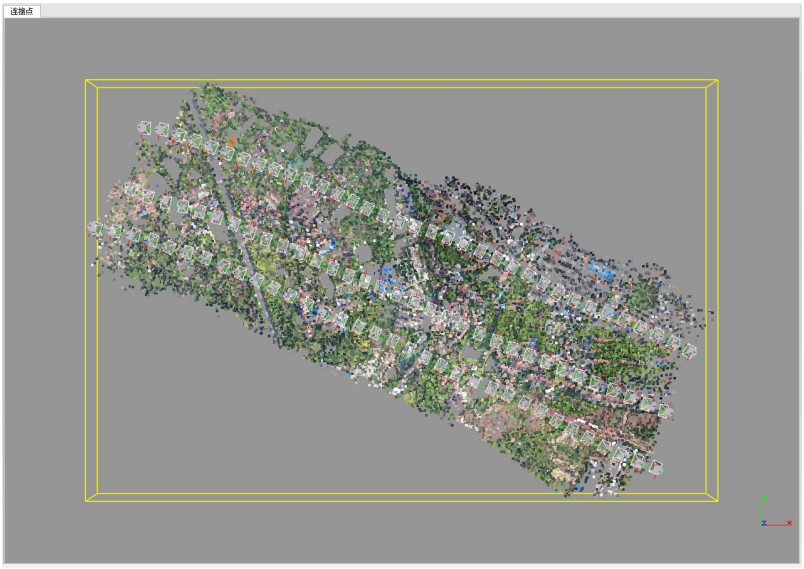
After determining the best overlay orthophoto, click [*Assign*] to adopt the overlay and clear *Visible Orthophotos* list..

Cancel

Click [*Cancel*] to abandon current editing and clear *Visible Orthophotos* list.

3D Viewer

3D viewer is to show cameras, tie points, and dense cloud. After finishing photos alignment and dense cloud generation, user could double-click the tie points or dense cloud at Workstation Window to show it in the 3D viewer.

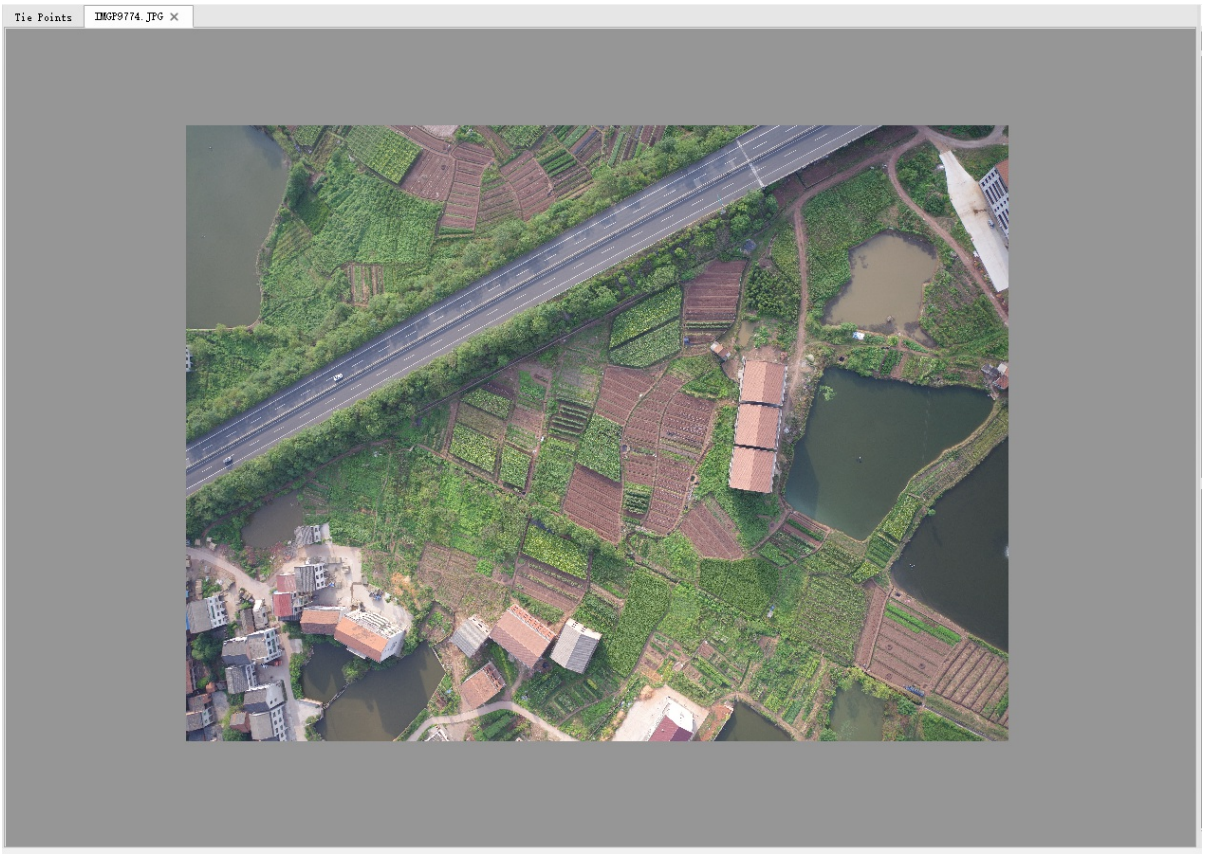


Functions

- **Pan**: Press mid-key then drag.
- **Zoom**: Scroll up/down the mouse wheel.
- **Rotate**: Press left-key then drag.

Photo Viewer

Photo viewer is to show the input photos. After creating project or opening project, user could double-click the input photo at Workstation Window or Photo Window to show it in the Photo viewer.

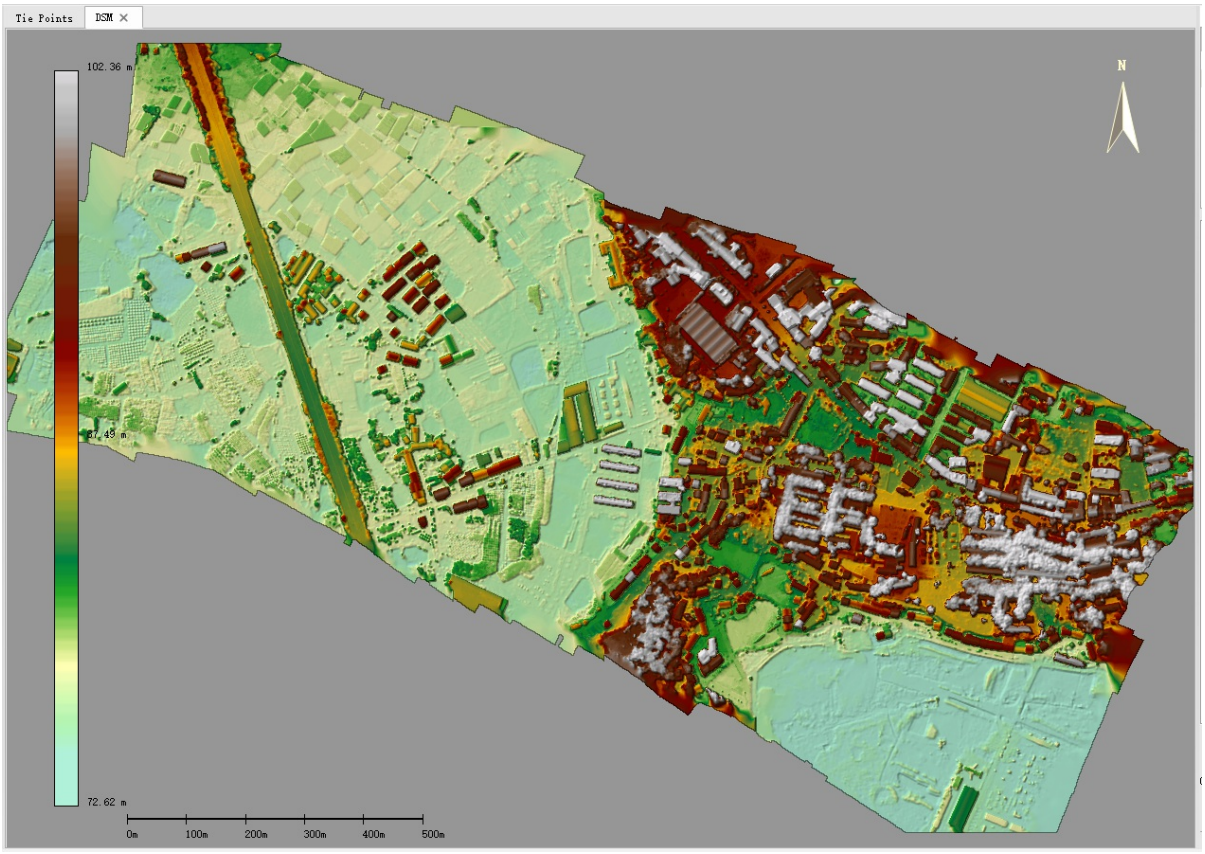


Functions

- **Pan**: Press left-key or mid-key then drag.
- **Zoom**: Move the mouse to the expected zoom center then scroll up/down the mouse wheel.

Viewer DEM/DSM

DEM/DSM viewer is to show DEM/DSM. After Building DEM/DSM, user could double-click the DEM or DSM at Workstation Window to show it in the DEM/DSM viewer.



Function

- **Pan**: Press left-key or mid-key then drag.
- **Zoom**: Move the mouse to the expected zoom center then scroll up/dowm the mouse wheel.

Orthomosaic Viewer

Orthomosaic viewer is to show Orthomosaic. After Building Orthomosaic, user could double-click the Orthomosaic at Workstation Window to show it in the Orthomosaic viewer. User could also adjust stitching lines in the Orthomosaic viewer.

Function

- **Pan**: Press left-key or mid-key then drag.
- **Zoom**: Move the mouse to the expected zoom center then scroll up/down the mouse wheel.

Align Photos

Brief

Photo alignment is to reconstruct camera orientation and sparse 3D scene structure based on input image, geographical location information(GNSS, GCP, optional) and Initial Camera Intrinsics(optional). Currently, result of photo alignment can be used for building dense cloud, building DEM/DSM, and building Orthomosaic.

Settings

Photo alignment procedure includes feature point detection, feature point matching, and bundle adjustment. The parameters are described below:

Feature Point Detection

- **Max Dimension**: Input images are sampled during feature point detection (upsampling or downsampling) according to this parameter.
  - **High(Default)**: Detects the largest number of feature points, more robust than *Medium* and *Low*, meanwhile, consumes the longest time.
  - **Medium**: Detects less feature points than *High*, consumes less time than *High*.
  - **Low**: Detects the smallest number of feature points, consumes the least time.

> Note: Within a certain range, detecting more feature points could improve robustness. However, if feature points were too many, result might get bad as too much noise might been introduced. The software has made the trade-off between efficiency and robustness, in most cases using the default *High* option could get the best result.

- **Max Features(Default"8192")**: The max number of feature points in each image. Increasing this threshold could lead to a longer processing time.

> Note: The software has made the trade-off between efficiency and robustness, in most cases using the default 8192 threshold could get the best result.

Feature Point Matching

- **Pair Selection Mode**: In order to improve the efficiency of feature point matching, image pair selection is performed. Feature point matching is only performed between the selected image pairs. Currently, there are three image pair selection modes: *Generic*, *Exhaustive*, *Reference*.
  - **Generic(Default)**: Down-sampling original image and matching low-resolution images to select image pairs.
  - **Exhaustive**: Selecting all image pairs, which is time consuming.
  - **Reference**: Selecting image pairs according to the geographic location information of the image (read from EXIF or imported from POS file).

> Note: The *Reference* mode is valid only in the presence of geographic information. In most cases, using the default option *Generic* could get the best result. If the photo alignment result is obviously wrong, try *Exhaustive* mode might get better result.

- **Max Tie Points(Default"1024")**: The maximum number of two-view tie points between two images. Too few two-view tie points will affect the accuracy of processing results and might even lead to processing failure. In

most cases, using the default 1024 could get the best result.

Bundle Adjustment

- **Refine Intrinsics(Default"Refine All Intrinsics")**: Check to refine specific intrinsics, supported intrinsics include focal length (f), principal point (cx, cy), radial distortion parameters (k1, k2, k3), tangential (eccentric) distortion parameters (p1, p2), the imaging plane distortion parameters (b1, b2). The self-calibration algorithm within the software can obtain good estimation of intrinsics even if there are no initial intrinsics provided. Using Calibrated Intrinsics is also supported. If the imported intrinsics are very accurate, there's no need to check *Refine Intrinsics*, thus the camera intrinsics remain unchanged during bundle adjustment.
- **Refine Extrinsics(Default"Refine All Extrinsics")**: Check to refine specific Extrinsics, supported extrinsics include rotation(R) and translation(T) parameters. Don't change default value unless you have known accurate parameters.
- **Estimate Offset(Default"Estimate None")**: Check to estimate GPS/IMU offset and the GPS offset can only be accurately estimated in the case of high GPS accuracy and accurate ground control points (GCP).
- **Outliers Threshold(Default"6.00")**: The upper bound of the inlier reprojection error (in pixels) during bundle adjustment. Tie point with reprojection error larger than this value would be treat as outliers and removed. This strategy could suppress the influence of the outliers.

Build Dense Cloud

Brief

Based on cameras' intrinsics, positions and orientations, which are optimized in photos alignment, the program generates a dense point cloud from the input images utilizing state-of-the-art MVS(Multi-View Stereo) algorithms. This dense point cloud can be exploited to analyze the geometry of the reconstructed objects or be used as input to build DEM/DSM.

Settings

The parameters are described below:

- **Quality**: This parameter defines the pyramid level of input images. Higher quality corresponds to larger image scale, which takes longer processing time.
  - **Ultra High**: Original image scale is used to build dense cloud. More details are reconstructed with this option than with **High** quality, especially in easy-to-match areas(e.g. city). This option takes the longest time.
  - **High(Default)**: 1/2 image scale is used to build dense cloud. This is the default option.
  - **Medium**: 1/4 image scale is used to build dense cloud. Less details are reconstructed with this option than with **High** quality. However, more points are generated in difficult areas(e.g. vegetation). This option takes less time than default.
  - **Low**: 1/8 image scale is used to build dense cloud. Less details are reconstructed with this option than with **High** or **Medium** quality. However, more points are generated in difficult areas(e.g. vegetation). This option takes the shortest time.
- **Type**: This parameter defines the type of output dense cloud. It can be edited only in template creation.
  - **2.5D(Default)**: Rasterized 2.5D result excluding vertical faces is outputted.
  - **3D**: 3D result including vertical faces is outputted. This option is suitable for complete dense cloud reconstruction.

Build DEM/DSM

Brief

The program builds DEM (Digital Elevation Model) or DSM (Digital Surface Model) from object 3D points. If dense cloud were built, dense points would be used as input source data; If not, sparse tie points from photos alignment would be used. DEM/DSM can be outputted as production or be used as input data to build Orthomosaic.

Settings

The optional modes and their parameters are described below:

Build DEM

In this mode, ground points are extracted with the algorithm CSF(Cloth Simulation Filter). DEM is then built from ground points using IDW (Inverse Distance Weighted) interpolation. The related parameters are as follows.

- **Terrain Type（Default"normal"）：** This parameter defines the terrain type(three options: flat, normal, steep). Generally, the urban area is flat or normal, and the mountainous area is steep. Please set this parameter according to the actual topographic relief in the region.
- **Filter Size（Default"2.0"）：** This parameter defines the grid size of cloth which is used to cover the terrain. Keep the default value in the most case unless the terrain is steep(set 0.5~1 for mountain area).
- **Resolution：** This parameter defines the spatial resolution (Unit: [m]) of the output DEM. Smaller value corresponds to higher resolution, which takes longer processing time.
  - **Auto（Default）：** If checked, the highest resolution with a scale factor is used. This option is checked with scale factor 2 by default.
  - **Manual：** If checked, you can input a value.

> [1] W. Zhang, J. Qi*, P. Wan, H. Wang, D. Xie, X. Wang, and G. Yan, “An Easy-to-Use Airborne LiDAR Data Filtering Method Based on Cloth Simulation,” Remote Sens., vol. 8, no. 6, p. 501, 2016.

Build DSM

In this mode, DSM is built from all input points using IDW interpolation. The related parameters are as follows.

- **Resolution：** This parameter defines the spatial resolution (Unit: [m]) of the output DSM. Smaller value corresponds to higher resolution, which takes longer processing time.
  - **Auto（Default）：** If checked, the highest resolution with a scale factor is used. This option is checked with scale factor 2 by default.
  - **Manual：** If checked, you can input a value.

Build Orthomosaic

Brief

Based on cameras' orientations and DEM(Digital Elevation Model), DSM(Digital Surface Mmodel), the program builds a Digital Orhomosaic or True Digital Orhomosaic from the input images. Image undistortion, image orthorectification, exposure compensation, color correction, image stitching, and image blending are included in this program.

Settings

The optional modes and parameters are described below:

Modes

The generation mode includes five types, which are divided according to data source and mosaicing mode. The data source includes DSM, DEM(generated by "Build DEM/DSM" or self-defined). Generally speaking, the high accuracy of DSM makes it easier to get the correct pixel position in the process of ortho-rectification, so as to obtain a better quality orthomosaic. For example, in urban areas, some buildings always inclined in the orthomosaic generated by DEM beacuase of the big elevation difference of buildings. On the other hand, for some flat areas with little elevation difference, the orthomosaics generated by DEM or DSM may not have distinct difference. In addition, the software provides two mosaicing methods: pixel-level mosaic and object-level mosaic. Pixel-level mosaic is generating orthomosaic with weighted ortho region of the image, which requires DSM/DEM in high accuracy and in accordance with the actual terrain, otherwise it is prone to distortion and stretching. Object-level mosaic reduces geometric distortion by generating intelligent stitching lines around ground objects. This method is a traditional method to generate orthomosaic using DEM, and can be used as a good alternative.

- **Pixel-level mosaic based on DSM (Digital Surface Model)**: Generating orthomosaic by Pixel-level method based on DSM. In most cases, this mode has the fastest processing speed and the best result.
- **Pixel-level mosaic based on DEM(Digital Elevation Model)**: Generating orthomosaic by Pixel-level method based on DEM. this mode may have a good result in some area forests with big canopy. And the position accuracy of ground objects in orthmosaic may decrease because the using of DEM.
- **Object-level mosaic based on elevation model**: This model uses DEM to generate orthophoto images, and generates intelligent bypass stitching lines to reduce deformation. It has good result in vegetation environment such as farmland, grassland and shrub. When the result of "pixel-level mosaic based on DSM" is not very good, this mode can be used as an alternative. Note that this mode will take more time.
- **Pixel-level mosaic based on self-defined Model**: Generating orthomosaic by Pixel-level method based on self-defined surface，DSM is recommended.
- **Object-level mosaic based on self-defined Model**: Generating orthomosaic by object-level method based on self-defined surface，DEM is recommended.

> Note: The coordinate system of self-defined terrain data will be converted to the current project coordinate system when imported. If there is no coordinate system information contained in the terrain data, the user must set the correct coordinate system first. When choosing a mode, the user must build or import cooresponding DEM and DSM, if not, the calculation will be terminated.

Parameters

- **Blend Level**（**Default"High"**）: including 5 options such as: **"High"**, **"Medium"**, **"Low"**, **"Very Low"**, and **"No"**. "No" means skipping image blending. If the average size of orthophotos was larger than 3000 x 3000, blend level would be the higher the better. If the average size of orthophotos was smaller than 1000 x 1000, a "Low" or "Very Low" blend level would be recommended as higher blend level might result in a low contrast Orthomosaic.
- **Color Correction**（**Default"Enabled"**）: If enabled, the program wound adjust input images' brightness, contrast, saturation and white balance during orthorectification. In most case, enabling this function could result in a visually better Orthomosaic. If input images were multispectral images, this function would be banned.
- **Max Oblique Angle**（**Default"60 degree"**）: Images with oblique angles larger than this value is filtered as they tend to cost too mush computation resource but generate pool results.
- **Resolution**: This parameter defines the spatial resolution (Unit: [m]) of the output Orthomosaic. Smaller value corresponds to higher resolution, which takes longer processing time.
    - **Auto**（**Default**）：If checked, the highest resolution with a scale factor is used. This option is checked with scale factor 1 by default.
    - **Manual**：If checked, you can input a value.

Export Camera Orientation

Brief

Exporting camera Orientation into Bundler (*.out), Omega Phi Kappa (*.txt), BlocksExchange XML format (*.xml), Inpho Project File (* .prj) and other third-party formats so that third-party software could use the result of LiMapper.

Settings

The parameters are described below:

- **Coordinate System**: This parameter defines the target coordinate system of the output data
- **Export Undistorted Photos**: Check this option to export undistorted Photos

> Note：Different softwares using different definitions of camera model, in order to maintain the commonality of data, the distortion parameters are set to 0, so it is recommended to export the corresponding undistorted photos.

Export Point Cloud

Brief

Export point cloud generated by LiMapper into common point cloud formats, such as PLY, OBJ, LAS and so on.

Settings

The parameters are described below:

- **Coordinate System**: This parameter defines the target coordinate system of the output data，including horizontal coordinate system and vertical coordinate system. Please refer Coordinate System
- **Custom Geographic Transformation(optional)**：Custom parameters used to convert the output data to the selected horizontal coordinate system
- **Source**： Choose data source
  - **Sparse Point Cloud**: Choose Tie Points generated by photo alignment as data source
  - **Dense Point Cloud**: Choose Dense Cloud generated by dense matching as data source
- **Point colors**: Export point color if checked
- **Point normals**: Export point normal if checked

> Note: LAS format does not support *"Point nornamls"* option

- **Point classification**: Export point classification if checked

> Note: if DEM is not generated, all point clouds are not classified. DEM generation divides point clouds into two class: ground and non-ground.

Export DEM/DSM

Brief

Export the DEM/DSM generated by LiMapper into common raster data format, such as TIF, KML and so on.

Setting

The parameters are described below:

- **Coordinate System**: This parameter defines the target coordinate system of the output data，including horizontal coordinate system and vertical coordinate system. Please refer Coordinate System
- **Custom Geographic Transformation(optional)**：Custom parameters used to convert the output data to the selected horizontal coordinate system
- **Compression**: Select the compression method
  - **NONE**: No compression
  - **LZW**: Use LZW compression which is lossless
- **Resolution X (m)**：X-direction resolution
- **Resolution Y (m)**：Y-direction resolution
- **Saving KML**：Check to export the KML format file simultaneously

  > Note：The KML format file only supports the WGS84 coordinate system, so this option is only available if you choose WGS84 coordinate system

Export Orthomosaic

Brief

Exporting Orthomosaic generated by LiMapper into common raster data format such as TIF or KML.

Settings

The parameters are described below:

- **Coordinate System**: This parameter defines the target coordinate system of the output data，including horizontal coordinate system and vertical coordinate system. Please refer Coordinate System
- **Custom Geographic Transformation(optional)**：Custom parameters used to convert the output data to the selected horizontal coordinate system
- **Compression**: Select the compression method
  - **NONE**: No compression
  - **LZW**: Use LZW compression which is lossless
  - **JPEG**: Use JPEG compression which has a high compression ratio but is loosy
- **Resolution X (m)**：X-direction resolution
- **Resolution Y (m)**：Y-direction resolution
- **Saving KML**：Check to export the KML format file simultaneously

  > Note：The KML format file only supports the WGS84 coordinate system, so this option is only available if you choose WGS84 coordinate system

Export Stitching lines

Brief

Exporting the stitch lines generated by LiMapper into common vector data format such as Shape File (* .shp).

Settings

The parameters are described below:

- **Coordinate System**: This parameter defines the target coordinate system of the output data，including horizontal coordinate system and vertical coordinate system. Please refer Coordinate System
- **Custom Geographic Transformation(optional)**：Custom parameters used to convert the output data to the selected horizontal coordinate system
- **Export orthophotos**: Check this option to export orthophotos
  - **Compression**: Select compression method for orthophotos
    - **NONE**: No compression
    - **LZW**: Use LZW compression which is lossless
    - **JPEG**: Use JPEG compression which has a high compression ratio but is loosy
  - **Resolution X (m)**: X-direction resolution for orthophotos
  - **Resolution Y (m)**: Y-direction resolution for orthophotos

> NOTE: Stitch lines are associated with orthophotos. Both of them are needed for stitching lines editing. So it is recommended to export orthophotos.

Import POS

There are two types of POS supported to import to LiMapper.

Import POS from EXIF Embedded in the Photo File

Most GNSS receiver integrated UAV can write longitude, latitude and altitude in WGS84 coordinate system to photo file as EXIF when capturing photos. LiMapper can read these POS information automatically when loading photos. By the way ,the UTM projection coordinate system is determined by longitude, latitude and altitude of the first photo.

Import POS in TXT and CSV Format File

There are three ways to import POS file in LiMapper, as described below:

1. Click  button in the [Load Photo] dialog of New Project Workflow
2. Click  button in the Photo Window
3. Click  in the *[Home]* ribbon bar

Select POS file in the pop-up [Open POS] dialog and click open button. Set related parameters and click OK button in the [POS Editor] dialog to import POS.

If the imported POS is incorrect, user could click  button in Photo Window to clear current POS.

The parameters in the [POS Editor] are described below:

- **Separator** (optional)

Adjust the separator to allow the data to be displayed normally. "TAB", "\t", "\n" "," and any combination of them are supported by LiMapper. The combination separator is default. User could also input other delimiter.

- **Rotation Angles** (optional)

Select the type of imported rotation angles. User could discard rotation angles by setting the rotation angle column headers to *ignore*.

- **Skip Lines** (optional)

Ignore some lines at the beginning of the POS file. Skipping no line is default.

- **Coordinate System** (required)

Coordinate system of imported POS， click the *[Edit...]* button to change it, options for horizontal coordinate system are arbitrary, geographic systems, and projection systems, options for vertical coordinate system are EGM2008, EGM96, EGM84 and custom geoid undulation.

- **Column Header** (required)

Select valid column header for each column.

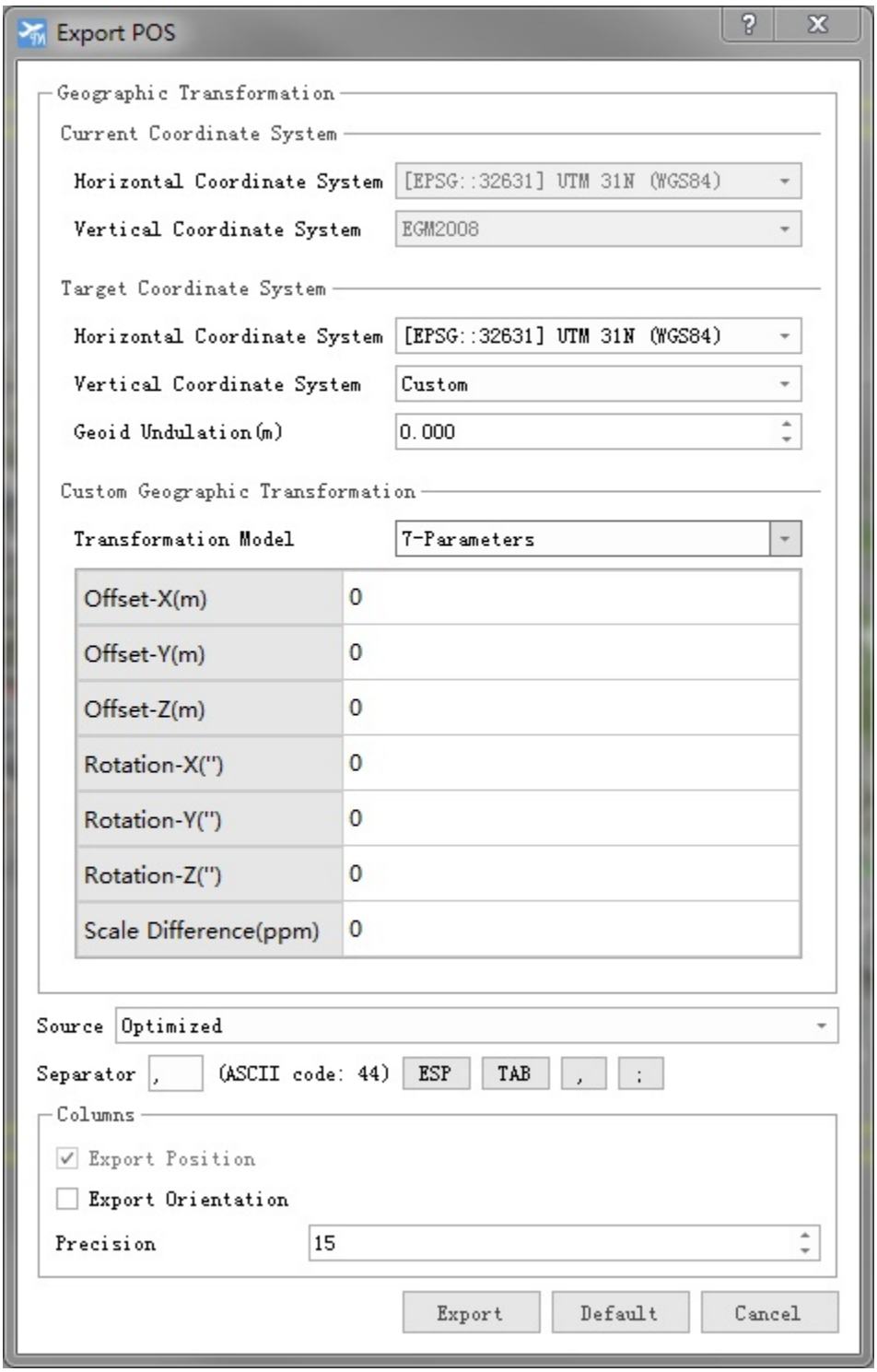
> FAQ：
>
> 1. Q: Is it allowed to assign the same header to two columns or more ？
>   A: It is prohibited.

2. Q: Is it needed to import POS group-wise？
   A：No need. Bud if the POS is organized separately, group-wise import are supported.
3. Q: What does the hint of "Photo name does not match!" mean? And why are some items highlighted in red? A：The hint of "Photo name does not match!" means that part of photos could not find corresponding POS in the imported POS file. The highlighted items contains invalid value.
4. Q: What does the warning of “GPS data out of range！” mean？
   A：The selected coordinate system does not match the coordinate system of the imported POS.

Export POS

Brief

Exporting initial or LiMapper optimized image POS into a text file.



Settings

The parameters are described below:

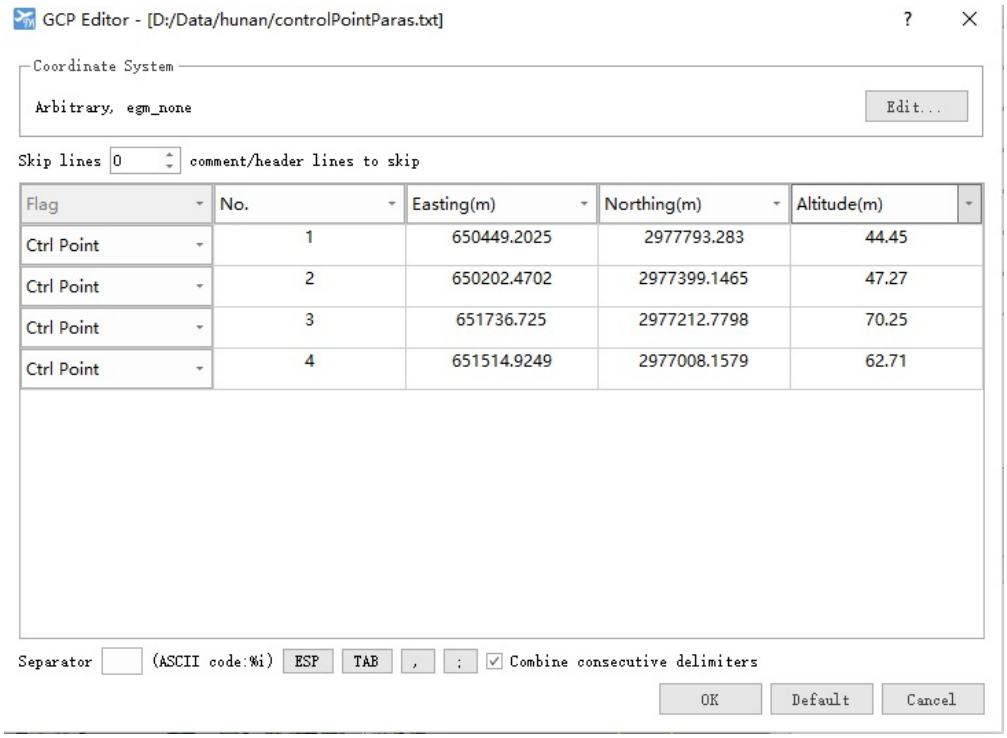
- **Coordinate System**: This parameter defines the target coordinate system of the output data，including horizontal coordinate system and vertical coordinate system. Please refer Coordinate System
- **Custom Geographic Transformation(optional)**：Custom parameters used to convert the output data to the selected horizontal coordinate system
- **Data source**: Select data source
  - **Source data**: Initial POS
  - **Optimized data**: LiMapper optimized POS
- **Separator**: Set the data column delimiter
- **Column settings**: Select columns to export
  - **Export Position(Mandatory)**: Export the position of the image
  - **Export Orientation**: Export the orientation of the image
  - **Accuracy**: Set the precision of the exported data

Import GCP/MTP

You can click  in the *[Home]* ribbon bar, or click  in the GCP/MTP Window to browse file for GCPs import. Supported formats are as follows:

- TXT：This file must contain point names and 3D coordinates informations. Data columns have to be separated using specific symbol(s).
- XML：Proprietary format of LiMapper. It contains point names, 3D coordinates, 2D observations, etc.

While importing TXT file, the GCP Editor will be shown:



Configuration options in this interface are as follows:

- **Coordinate System**
  The coordinate system of imported data, click the *[Edit...]* button to change it, options for horizontal coordinate system are arbitrary, geographic systems, and projection systems, options for vertical coordinate system are EGM2008, EGM96, EGM84 and custom geoid undulation.

- **Skip Lines**
  The leading lines (e.g. comments) can be skipped. No lines are skipped by default.

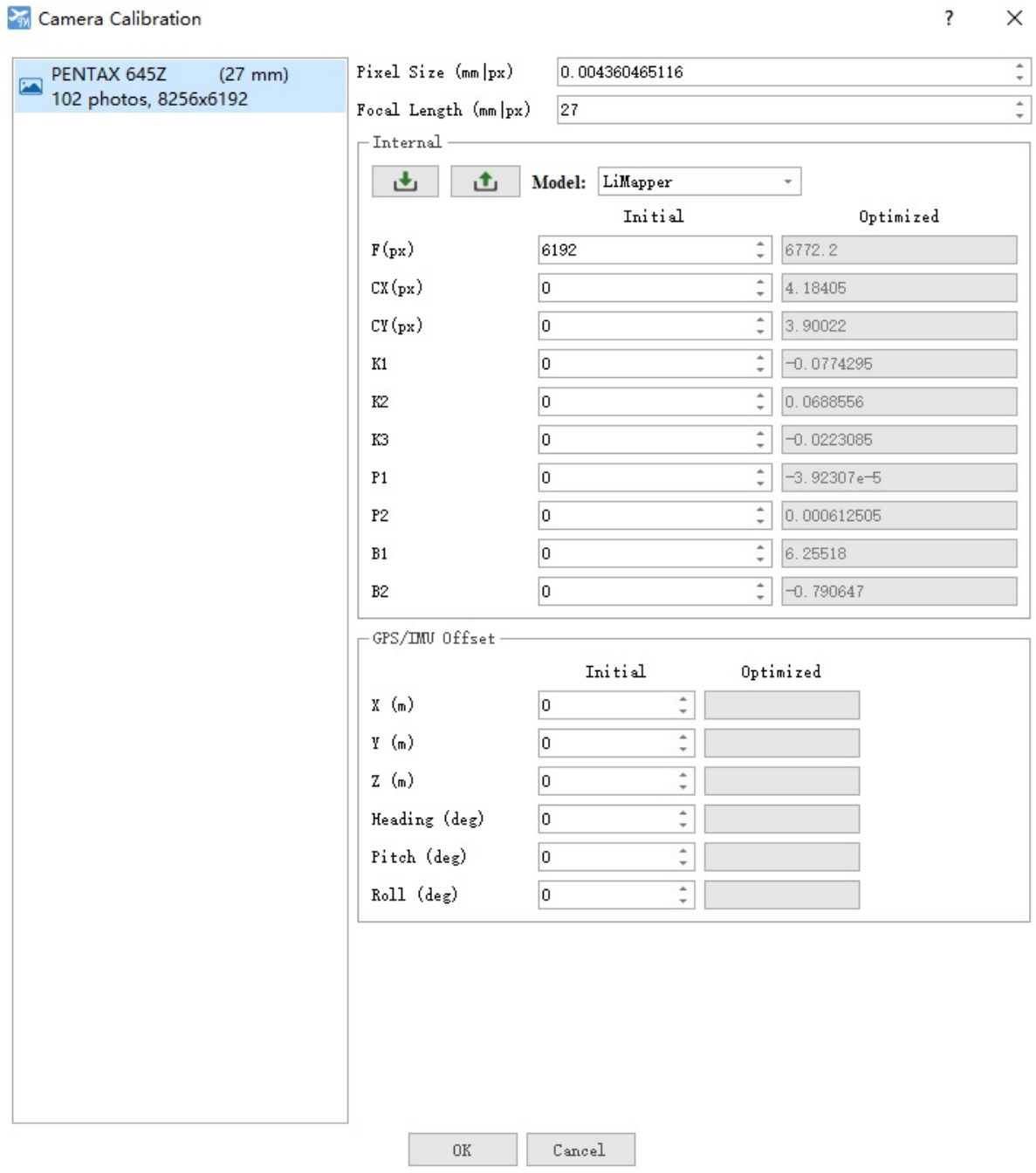
- **Headers**
  A column header (e.g. Latitude, Longitude, Height) can be specified by clicking the header and selecting attribute in the pop-up list.

- **Separator**
  The Separator is used for data column separation. Supported separators are SPACE, TAB, COMMA, SEMICOLON, and their combination. The combination is used by default. Besides, custom symbol can be inputted in the textbox.

Camera Calibration

Camera distortion is inevitable and harmful to accuracy. In practice, cameras are often pre-calibrated in order to achieve high accuracy. This software could use pre-calibrated camera intrinsic as initial value to run photo alignment.

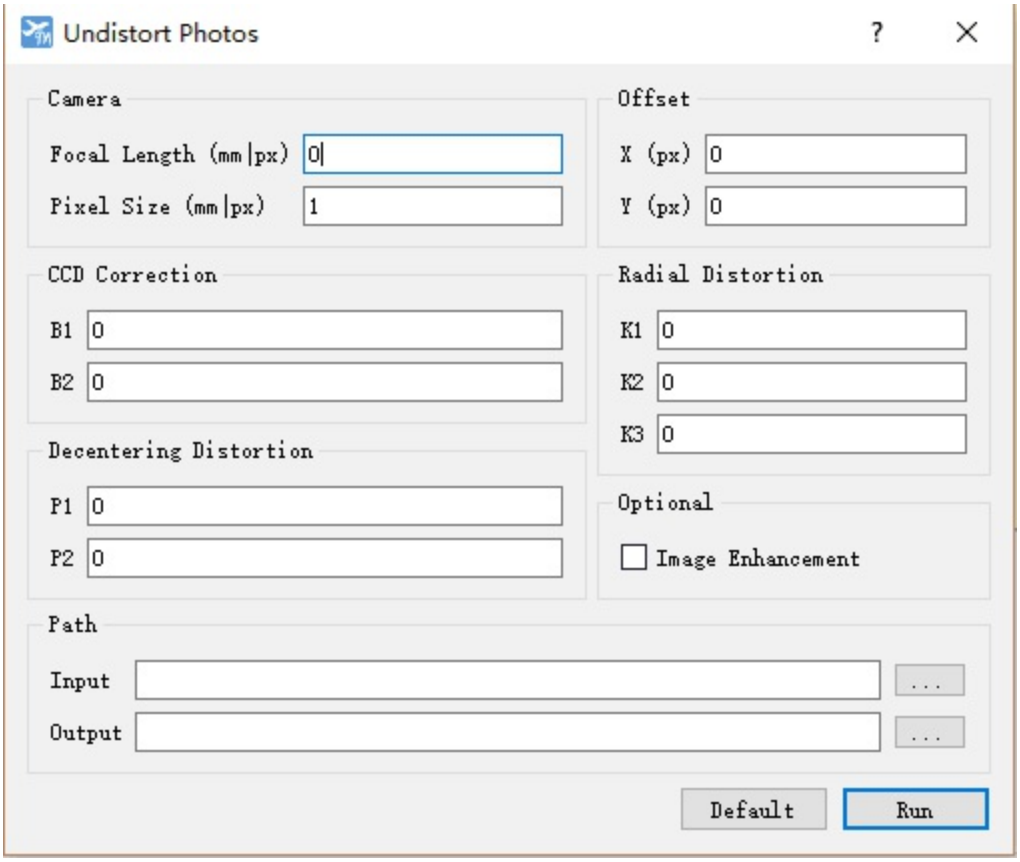
- In this dialog, user could edit the camera intrinsic manually. Refer to Camera Model for definition.
- In this dialog, user could import and export camera instrinsic. Australis camera model(.txt), LiMapper camera model(.txt) are supported. PhotoScan camera model(.xml) without k4, p3, p4 is also supported.
- In this dialog, user could set master band for multispectral photos.
- In this dialog, user cloud also view the optimized camera intrinsic.



Undistort

Brief

Undistort dialog allows users to correct the distortion of images caused by CCD or lens defects. To fulfill the job, users should specify the parameters of the camera.



Parameter Description

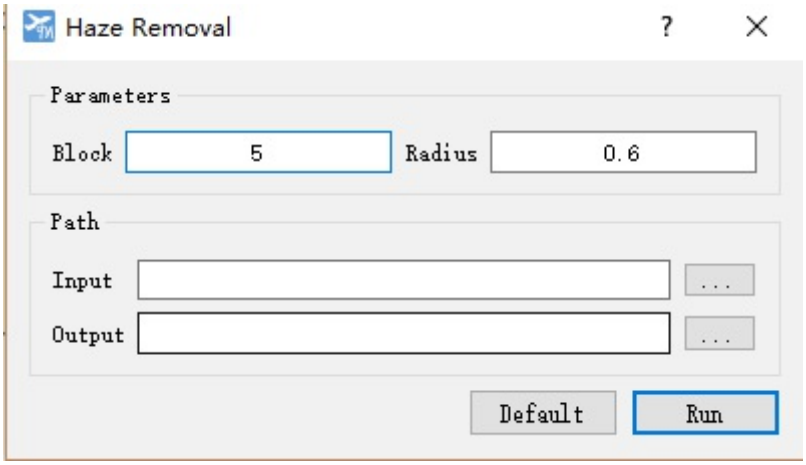
These parameters include focal length, pixel size, principal point offset, CCD correction, radial distortion and decentering distortion. Please refer to camera model for interpretation.

In addition, User can check *[Image Enhancement]* to improve image sharpness and contrast.

Haze Removal

Brief

The purpose of Haze Removal is to improve image quality. Haze Removal dialog is shown below:



Settings

Available parameters are described below:

- **Block**: An image is divided into blocks, the larger the block size is, the smaller the number of the divided image blocks is.
- **Radius**: The size of the filtering radius of the guided filtering, which affects the quality of the filtered image.
  - The smaller the filtering radius is, the clearer the image detail is.
  - The larger the filtering radius is, the more blurred the detail of the image is.
- **Input**: Select the input image folder.
- **Output**: Select the output image folder.

Software Settings

Brief

Set the global parameters and show the current coordinate system.

Settings

Available parameters are described below:

- **CUDA Device**: Set the CUDA device to be used
- **Language**: Select the display language
  - **Chinese(Simplified)**
  - **English(US)**

FAQ

Installation And Licensing

What are the hardware requirements to install LiMapper?

- **CPU**：Intel Core i5 or equivalent(minimum), Intel Core i7(recommended)
- **GPU**：NVIDIA GTX750 Ti or equivalent(minimum), NVIDIA GTX1060 or better(recommended). CUDA, SM20 or better, 2GB Memory at least
- **DISK**：1GB free disk space for installation; Required space for processing depends on data size, 500GB free disk space(recommended)
- **RAM**：16GB(minimum), 32GB or more(recommended)

What are the supported Operating Systems?

- **Windows 7**：Windows 7 SP1, Windows Update KB2999226 required.
- **Windows 8**：Windows 8.1, Windows Updates KB2919355, KB2919442 required.
- **Windows Server 2012 RC2**：Windows Updates KB2919355, KB2919442 required.
- **Windows 10**：No additional requirements.

What if the hardware & system requirements are satisfied but the software still doesn't work properly ?

- Install Visual C++ Redistributable for Visual Studio 2015 x64.If failed, please update your operating system and try again.
- If your problem is still unsolved, please send an email with problem description to info@greenvalleyintl.com. and we will reach out to troubleshoot as soon as possible.

How to resolve the error "No CUDA device is found" when launching LiMapper?

- Please update the drivers of your CUDA devices. If no CUDA devices are available on your machine, please ignore the error.

> Note: CUDA device increases the software efficiency.

How to check if CUDA devices are available on the machine?

- Launch LiMapper, Click *[File]->[Settings]* , the recognized CUDA device(s) are listed.

What if LiMapper doesn't recognize your NVIDIA graphics card?

- Please download and update the driver to the latest version from the NVIDIA official website.

Tips And Tricks

How to change the menu language?

- Click *[File]>[Settings]>[Language]* , and change language. Language change needs a restart to be effective.

How to break processing?

- Click *[Stop Process]* in *[Process]* ribbon to break processing.Please note that you need to wait a while for all the multi-thread tasks and GPU calculation tasks to be terminated. A process can be resumed from the break point. Please refer to [How to resume from break point?]

Can I resume the process from the break point?

- Yes, in the cases that the system crashes, the computer is shut down by accident, or user breaks the processing, the process can be resumed from the break point, which saves a lot of processing time comparing to restarting from scratch. Resuming from the break point is supported in the following processes:
- *[Align Photo]*
- *[Build Dense Cloud]*
- *[Build Orthomosaic]*

How to resume the process from the break point?

- Click *[Start Process]* in *[Process]* ribbon to resume from the break point..

What if the deviations between initial camera positions and the positions after photo alignment are large (object in the scene is distorted)?

- Please evaluate the accuracy of the initial camera position information (coordinates embedded in photo EXIF or imported POS file), and Adjusting POS Weights in LiMapper to match before running the process. The higher the accuracy of initial position, the smaller the discrepancy between initial position and adjusted position after photo alignment.

Can I generate orthomosaic imagery using external DEM/DSM such as DEM/DSM generated from LiDAR point cloud, and how?

- Yes. Before processing *[Mosaic]*, click *[Configure]* in *[Process]* ribbon. Under *[Build Orthomosaic]* tab, select *[Pixel-level mosaic based on self-defined surface]* or *[Object-level mosaic based on self-defined surface]* mode, and enter the external DEM/DSM.

Trouble Shooting

Why does Create/Save Project fail?

- Please make sure you have read and write access to the project folder. Do not save your project in the system protected paths such as "C:/Program Files", "C:/Users", "C:/Windows", etc.
- Please make sure there is enough space in the project drive. The generated products such as dense cloud and orthomosaic imagery are usually large datasets which require large storage space..
- If the problem remains, please send an email with problem description to info@greenvalleyintl.com. We can provide remote assistance.

Why does different data crash frequently on one computer and work correctly on others?

- Check and make sure the current Windows user has read and write access to the project folder.
- If the current project folder is on a cloud drive, change project folder location to a local drive and try again.

In what cases would a project processing fail?

- The scene to reconstruct does not have enough texture features, such as large area of waterbodies and snow-covered landscape.
- There is not enough overlapping between photos. The minimum required flight front overlap is 60% and the minimum flight side overlap is 30%. Note: when the flight altitude is consistent throughout the flight but the elevation change of the landscape is large, the photos captured at the regions with high elevation might not have enough overlapping. Therefore, in this case, please increase the front and side overlapping ratio, or use terrain-followed mode for the flight.

What should I do if a BSOD happens during building dense cloud or building Orthomosaic?

- If your CPU is Intel I7-7820X, this is likely to be a driver bug. The solution is to switch the *[CPU Core Usage]* to "Auto" instead of "Sync All Cores" or "By Core Usage" in BIOS.
- If the problem remains, please send an email with problem description to info@greenvalleyintl.com

What should I do if the software crashed when building orthomosaic after loading the image infomation?

- If your graphic card is NVIDIA GTX 16 series(eg. GTX 1660) and LiMapper version is before 3.1Update5, try to uncheck the CUDA option checkbox in the settings, in this case, only CPU is running for program.

Appendix

Glossary

- POS: Position and Orientation System
- GCP: Ground Control Point
- MTP: Manual Tie Point
- DEM: Digital Elevation Model
- DSM: Digital Surface Model
- Orthomosaic: Digital Ortho Map
- True Orthomosaic: True Digital Ortho Map

Camera Model

Principle

The camera model defines the transformation between image space coordinate system and pixel coordinate system.

- **Image space coordinate system**: The origin is projection center. The Z axis points towards the viewing direction, X axis points to the right, Y axis points down.
- **Pixel coordinate system**: The origin is the top left corner of the top left pixel. In other words, the coordinates of the top left pixel's center is (0.5, 0.5). The X axis points to the right, Y axis points down.

The notations are described below:

(X, Y, Z) - point coordinates in the image space coordinate system

(u, v) - projected pixel coordinates

(c_x, c_y) - principal point offset

(K_1, K_2, K_3) - radial distortion coefficients

(P_1, P_2) - tangential distortion coefficients

(B_1, B_2) - affinity and non-orthogonality (skew) coefficients

(w, h) - image width and height in pixels

f - focal length

Equations of the transformation are described below：

$x = X / Z$

$y = Y / Z$

$r = sqrt(x^2 + y^2)$

$x' = x(1 + K_1r^2 + K_2r^4 + K_3r^6) + P_1(r^2+2x^2) + 2P_2xy$

$y' = y(1 + K_1r^2 + K_2r^4 + K_3r^6) + P_2(r^2+2y^2) + 2P_1xy$

$u = w * 0.5 + cx + x'f + x'B1 + y'B2$

$v = h * 0.5 + cy + y'f$

LiMapper Internal Parameters File(*.xml)

```
<?xml version="1.0" encoding="UTF-8"?>
<calibration>
    <width>8256</width>
    <height>6450</height>
    <f>6771.25</f>
    <ps>0.00436047</ps>  <!-- pixel size -->
    <cx>4.57016999999996</cx>
    <cy>3.04289000000017</cy>
    <k1>-0.0778992</k1>
    <k2>0.0695091</k2>
```

```
    <k3>-0.0223276</k3>
    <p1>-2.68206e-5</p1>
    <p2>0.000617037</p2>
    <b1>6.06111\</b1>
    <b2>-0.816488\</b2>
</calibration>
```

ChangeLog

LiMapper3.2

1. Solved the problem that CGCS2000 coordinate system under exported TIF image is not displayed correctly.
2. Fixed bug of generating DEM / DSM failed when using sparse point cloud sometimes.
3. Fixed bug when delete image group after extacting features.
4. Fixed error coding in the log when showing chinese character.
5. Fixed bug of coordinate transform in seven parameter transfromation when the target coordinate is georeference coordinate system.
6. Fixed bug of updating parameter incorrect in camera calibration panel。

LiMapper3.1 Update6

1. Modified the range of GSD.
2. Fix error of progress bar and user interface flash when image alignment failed.
3. Reconstruted image alignment module which is completely independent.

LiMapper3.1 Update5

1. Fixed crash when building orthomosaic with NVDIA 16 series graphic card.
2. Solved the problem that the project can't be opened after the project and data are moved. A wizard was provided to help the user to find the image directory in case of failure to automatically obtain the image of the project directory.
3. Improved the DSM algorithm.
4. Fixed bug in image alignment
5. Fixed the problem of warning box popping up when loading template each time.

LiMapper3.1 Update4

1. Fixed error of calibration parameter P1，P2 for building dense cloud points.
2. Added funtion for clipping orthomosaic
3. Fixed problem on the control point panel caused by signal reception error.
4. Fixed memory leak in the panel of attribution.

LiMapper3.1 Update3

1. Improved DEM filter algorithm
2. Support to build orthomosaic with cpu and cuda concurrence。
3. Fixed bug of importing POS and improve the accuracy of automatic setting table header (longitude, latitude, elevation) according to general practice.
4. Fixed bug of display dense cloud points and sparse points.
5. Solved image rotation when loading image.

LiMapper3.1 Update2

1. Improved rotation matrix calculation for camera.

LiMapper3.1 Update1

1. Imporved placement calculation, taking into account the effect of meridian deviation of projection.
2. Fixed the problem of incorrect estimation of parameters in different bands of the multispectral image.
3. Fixed the problem of rotation angle error calculation in the image information panel.
4. Fixed the bug of automatic work flow.
5. Solve the warning message of building orthomosaic when no valid DEM/DSM is found.
6. Fixed the terrain exporting function in the workspace.
7. Support omega, phi, kappa and roll, pitch, heading parameter when exporting POS.
8. Fixed bug of the double SpinBox garbage value in the GPS/IMU offset summary.
9. Fixed the bug of exporting quality report that there is no DEM/DSM thumbnail generated when user chooses external import.

LiMapper3.1

Highlights and Key Features

1. Add support to 2d,3d and elevation points in the GCP import panel and allow users to set control point types and add support for CSV format.
2. Adjust the layout and display of the GCP panel to make user operation and viewing more flexibility.
3. Adjust the logic of DEM/DSM generation to generate/export both DEM and DSM results.
4. Provide five modes in "Build Orthomosaic" configuration.
5. Support for DJI PHANTOM 4PRO wide-angle lens.

Fixed Bugs

1. Fix the bug that geographic transform may failed in three-parameter mode.

LiMapper3.0

Highlights and Key Features

1. Support to export tiled DEM/DSM/Orthomosaic

Fixed Bugs

1. Fix the bug that software stayed in file menu when opening a project by double-clicking its .limap file

LiMapper2.4 Update2

Highlights and Key Features

1. Add more bundle adjustment parameters in Quality Report
2. Add a new dock [Property] to show project/photos/products property
3. Improve log details

Fixed Bugs

1. Fix the bug that DEM/DSM maybe not be shown under right color

LiMapper2.4 Update1

Highlights and Key Features

1. Support 2% stretched display for DSM
2. Support to import and export GCP in GPX or SHP format
3. Remove thumbnail inside workstation
4. Support to import and export 7/4/3 parameters
5. Improve dense cloud

Fixed Bugs

1. Fix typo in UI
2. Fix a bug related to export DEM/DSM
3. Ban importing POS or GCP when project has no target coordinate system
4. Fix the bug that software may crash after removing photos
5. Fix the bug that the return button for the file menu may not be displayed properly

LiMapper2.4

Highlights and Key Features

1. Add an accuracy factor for GCP
2. Improve visual effect for dense cloud
3. Add a human-readable log file
4. Improve overlap report for hill area

Fixed Bugs

1. Fix a bug that measurement unit other than meter could not be rendered properly

LiMapper2.3

Highlights and Key Features

1. Change UI style to Ribbon
2. Support choosing target coordinate system when creating new project
3. Support vertical coordinate system
4. Support coordinate system wrapping using 7/4/3 parameters
5. Support importing camera parameters from Inpho
6. Support GPS/IMU offset calculation

Fixed Bugs

1. Fix a bug that the software might crash if project name has invalid character

LiMapper2.2

Highlights and Key Features

1. Improve color balancing quality when generating low-resolution orthomosaic
2. Add a scale factor when choosing auto resolution for DEM/DSM, orthomosaic generation
3. Support resuming from breaking-point for dense cloud generation
4. Update project templates
5. Support mannal editing of Australis camera model and support scientific notation in Camera Calibration dialog
6. Optimize user interface such as adding feature points notation

Fixed Bugs

1. Fix the problem that the software might crash during orthomosaic generation
2. Fix the problem that the default project location is invalid
3. Fix a bug during absolute alignment for multispectral photos

LiMapper2.1

Highlights and Key Features

1. Add project templates, including templates for checking flight quality, 3D point cloud production, and mosaicking orthophoto
2. Improve the algorithm for unifying ray and color and reducing the color difference of after image stitching, which has better adaptability for underexposed images;
3. Support to generate more accurate image mosaicking results by using LiDAR-based high-precision digital elevation models
4. Improve the aerotriangulation algorithm and the algorithm of mosaicking orthophotos, and support big data (300 million pixels per image) processing
5. Improve the dense image matching algorithm to increase the module stability;
6. Add new project wizard to simplify the operation process
7. Support multi-spectral data, including processing images with multiple bands simultaneously and exporting mosaicked multi-spectral data
8. Add more data statistics in the quality report, such as flight strip overlap rate, study site area, average flight height, and operation time
9. Support opening a project by dragging and dropping the project file into the software window
10. Compatible with project files of lower versions (v2.0 and v1.4)
11. Improve the visualization and saving of ground control points, which support to import ground control points in geographic coordinate system or projected coordinate system, and save ground control points and their corresponding paired images point
12. Add more accuracy levels for dense image matching, including ultra-high precision, high precision, medium precision and low precision
13. Add the option of whether to perform color unifying and color correction in the orthophoto mosaic module
14. Support editing stitching lines of multi-spectral data
15. Support changing of visualization color bar for DEM / DSM
16. Support adjusting the point size of a point cloud in 3D view
17. Add the EDL display mode in 3D view
18. Optimize the image information panel, in which the inclination angle can be displayed and the columns in a table can be sorted
19. Optimize the workspace panel, in which images can be displayed in groups and registration number of each group can be shown as well
20. Improve the visualization of the progress bar
21. Add tips for insufficient hard disk space
22. Support the size of bounding box can be adjusted, and selecting area of interest for data procession
23. Support defining customized coordinate systems
24. Add the Australis camera parameter model, and support converting with the existing internal parameter model
25. Improve the visualization of welcome widget
26. Add new project wizard
27. Suppprt continue running from break of project

Fixed Bugs

1. Fix the problem that the software works improperly due to lack of administrator rights
2. Fix the problem of unresponsive workspace panel when selecting images by pressing “ctrl + A”
3. Fix the problem that CUDA option is forced to activate when reopening the setting dialog after restarting the software
4. Other minor bug fixes

LiMapper2.0 update9

Highlights and Key Features

1. Add camera calibration window, which allows to set the initial internal camera parameters
2. Improve the visualization ground control points, which support to add function of predicting photo markers
3. Improve hillshade display effect for DEM / DSM
4. Improve the sparse point cloud filtering algorithm to noise points
5. Modify the default output resolution of Orthomosaic / TOrthomosaic to resolution of the original image
6. Support resetting POS information
7. Add close project function
8. Support writing the focal length information when the orthoscopic image is exported
9. Support switching the quality report language between English and Chinese
10. Support the size of bounding box can be reseted

Fixed Bugs

1. Fix the lack of data block in dense image matching;
2. Other minor bug fixes

LiMapper2.0 update6

Highlights and Key Features

1. Enhanced CUDA acceleration , increasing processing by 5~10 times.
2. Support for non-CUDA graphic cards.
3. Support for images without POS data. (Can only produce DSM. Does not generate DEM.)
4. Control DEM/DSM/Orthomosaic production area by adjusting bounding Box.
5. Support for concurrent instances.
6. Import Roll, Pitch, and Yaw data.
7. Export DEM/DSM/Orthomosaic, Stitching Lines, and individual Ortho Photo.
8. Auto UI language selection by system.
9. Display mouse point elevation in DSM view (right-click).
10. Option to disable Hillshade effect.
11. Improved speed and stability for Aerotriangulation.
12. Improved Sparse Cloud – Fast algorithm with reduced noses.
13. Enhanced Dense Cloud – Accurate algorithm.
14. Improved 3D visualization and user interaction.
15. Improved Stitching Lines editing.
16. Improved software UI.

Fixed Bugs

1. Fixed a bug that could cause crash when using Dense Cloud – Accurate option.

2. Fixed a bug that could cause coordinate system information loss when loading new images after removing all images previously loaded in the project.
3. Other minor bug fixes.

LiMapper1.4 update5

Highlights and Key Features

1. Capable of processing very large number (>10,000) of high resolution images.
2. Efficient and maximized utilization of computation resources.
3. Streamlined and simplified workflow.
4. Improved internal algorithms.
5. Import and Export of POS file.
6. Export to Point Cloud.
7. Export DEM/DSM as .tif files.
8. Hillshade effect for DEM/DSM display.
9. Support for the use of external DEM data.
10. Dense Cloud/Tie Points options for building DEM/DSM – High Density for best result; Spare Density for fast processing speed.
11. Options for different image blending modes – High for best results; Low for fast processing speed.
12. Display stitching lines.
13. Orthomosaic editing.

Fixed Bugs

1. Fixed a bug that read the EXIF exception
2. Fixed a bug that the exported bundler type is wrong
3. Fixed a bug that exist in the process of undistort photos
4. Other minor bug fixes.

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