

# STEREO MEASUREMENT ON IMAGESTATION WITH STARIMAGER - AIRBORNE THREE-LINE SCANNER - IMAGERY

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Commission II, WG 3

**KEY WORDS:** Airborne Three-Line-Scanner, Stereo Measurement, Image Rectification, 3-D Feature Collection, Accuracy Assessment

## ABSTRACT:

STARIMAGER is a helicopter-borne high resolution digital Three-Line Scanner (TLS) imaging system developed by STARLABO Corporation jointly with the University of Tokyo and ETH-Hoenggerberg for large scale mapping, linear-shaped ground objects investigation (such as roads, rivers, railways, pipelines, etc.), and remote sensing applications. As with other airborne and spaceborne linear imaging sensors, STARIMAGER is equipped with GPS/IMU to record the exterior orientation parameters of each obtained image line per forward, nadir and backward views during a flight. This paper describes the integration and ingestion of the TLS images that have been rectified and triangulated by STARLABO Corporation into Z/I Imaging Corporation's 3-D feature and DTM collection and orthophoto production products. The paper also presents some field results of the 3-D feature collection and accuracy evaluation with real TLS flight data.

## 1. INTRODUCTION

STARIMAGER is a helicopter-borne high resolution digital Three-Line Scanner (TLS) imaging system (Figure 1).



Figure 1. STARIMAGER

Line sensor systems are widely used in satellites for the acquisition of panchromatic and multi-spectral imagery, while area sensor systems are used as the extension of analogue aerial cameras (Murai, 1994). These two different digital sensors have been intensively studied as airborne fully digital spatial data acquisition systems. The line sensor system, however, is easier to manufacture than the area sensor system due to the constraints of semiconductor manufacturing processes. This paper briefly explains the system configuration, features, and applications of the STARIMAGER sensor system and how this type of imagery with its orientation and camera data are used in the Z/I Imaging product line allowing for 3-D feature collection, DTM generation, and orthophoto production.

## 2. STARIMAGER

### 2.1 Principle and features

The stabilizer with the STARIMAGER TLS camera is equipped on the arm outside a helicopter and absorbs the vibration by the helicopter movement. As shown in Figure 2, four CCD line sensor packages are placed in parallel on the focal plane of the camera lens system. Three of the sensor packages are for forward, nadir, and backward looking, and each sensor package has three line sensors that are R (Red), G (Green), and B (Blue) to generate color images. The fourth CCD line sensor package contains a single near infrared (NIR) line sensor located between the nadir and backward looking RGB color sensor packages. Each line sensor can collect a high resolution, two-dimensional image in accordance with the flight of the helicopter, bringing 10 images in total which are 100% overlapped with each other (Figure 2). The position and attitude data of the TLS camera are acquired with GPS (Global Positioning System) and IMU (Inertial Measurement Unit). An antenna for the GPS is equipped on the top of the helicopter, while a set of fiber optic gyroscopes is placed on the TLS camera inside the stabilizer. Such a spatial data acquisition system does not ideally in principle need aerial triangulation with ground control points at all, as described in (Murai, 1994). STARLABO Corporation has acquired the patent rights for the system in Japan, the USA, Europe, Australia, and Canada (Murai, 1993).

The advantages of STARIMAGER are described as follows (also described in (Tsuno, 2002)):

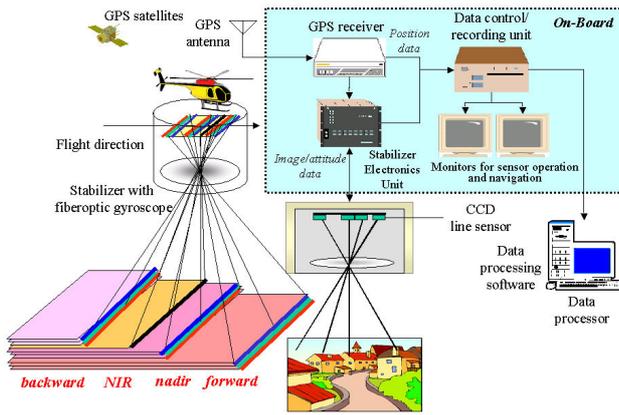


Figure 2. Principle of STARIMAGER

- 1) Photo developing and scanning processes are unnecessary and there is no image deformation such as damage or deterioration on a film. Moreover, since the dynamic range of an output image that is linearly proportional to the luminance of the image plane is wide, it is possible to recover easily even an image part that is in the shade of a building, a cloud, and so on by increasing its image intensity, which reduces the field survey after data acquisition.
- 2) The ground control points (GCPs) for the orientation can be unnecessary, or fewer due to the existence of a GPS/IMU. It is therefore suitable for data acquisition at an emergency, on the sea, and so on, where GCPs are difficult to get.
- 3) Due to a high-performance stabilizer, the original image is not waving and has no blurs, thus it is suitable for the image at an emergency and the burden for post-processing can be reduced (Figure 3). And, the oblique photography that is realized by slanting the stabilizer is effective in the texture acquisition of building walls.
- 4) A helicopter allows low altitude and low speed operation, leading to a high-resolution image. Since the influence of field visibility and weather condition is small due to low altitude, photography can be done more frequently than conventional aerial photography. And, a helicopter can take pictures of the linear-shaped objects efficiently by tracking them over at a low speed.
- 5) With the TLS principle, an image has very little distortion caused by the height of ground objects in the flight direction (a line-perspective image as compared with a conventional central perspective image), and suitable for less-distorted ortho-image generation. One does not need mosaic processing in the flight direction and it can get the spatial data of linear-shaped objects seamlessly, such as roads, railways, rivers, etc. Moreover, the system can get an image that is redundant and with little loss due to the photography in three different directions (three different times), leading to fewer field survey burdens after the data acquisition. Furthermore, a corresponding point searching in stereo matching is easy due to the stereo angles being constant, and measurement precision improves by triplet matching (Shibasaki, R., 1987). The STARIMAGER sensor system also allows multispectral data acquisition and allows generating a multispectral image by integrating RGB three line sensor images and an NIR image as an index which

shows vegetation and water in the soil more distinctively than a color image only.

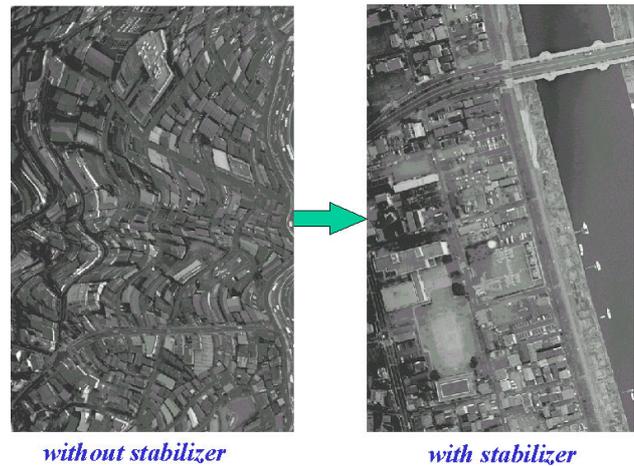


Figure 3. Stabilizer's Effect

## 2.2 System configuration

The focal length of the TLS camera lens system is 60 mm, and the stereo angles are 17, 23 and 40 degrees between forward and nadir, nadir and backward, and forward and backward, respectively (see Table 1 for the STARIMAGER SI-250 specifications). Each line sensor consists of 14,400 CCD pixels with 5  $\mu$ m spacing, and acquires 500 line images in a second (2 msec acquisition interval). The image data is recorded in a controlling and recording device that is installed in the helicopter cabin. The GPS antenna acquires the camera position signal at 5 Hz and the IMU acquires the camera attitude signal at 500 Hz. The camera is calibrated in a laboratory as well as through a self-calibration process in a test field (Chen, T., 2003). The TLS sensor model and triangulation are described in (Gruen, A., 2002).

configuration	item		specification
TLS Camera	CCD Elements	pixels/line	14,400
		pixel pitch	5 $\mu$ m
	Number of Sensors	10 (3 directions – with RGB - and NIR)	
	Intensity dynamic range	9 bits or more	
	Lens focal length	60 mm	
	Stereo angle	17°, 23°, 40°, etc.	
Stabilizer	Number of capturing lines	125, 250, and 500 lines/sec	
	Angle resolution in attitude	0.00125°	
	Spatial stability	0.00029°	
	Maximum angle velocity	30° /sec	
	Data output (acceleration/attitude)	500 Hz	
GPS Receiver	2f kinematics (post processes)	planimetric accuracy	2 cm + 2 ppm
		height accuracy	3 cm + 2 ppm
	Data output	5 Hz	
Recorder	HDD recording	recording speed	150 MB/sec or more
		recording capacity	320 GB

Table 1. SI-250 Specifications

## 2.3 Applications

The features of the TLS data are stimulating more demand for 3-D seamless geographical information of linear-shaped man-made objects and terrain with high resolution and efficiency. Those objects include roads, bridges, railways, power cables, pipelines, etc. for investigation before the construction of those, maintenance and management after the construction, and base data for a variety of GIS systems (Tsuno, K., 2002).

TLS data can also be used to acquire the base ground data for flooding simulation with high precision, for example to determine whether water goes over a Japanese raised floor or below, which can not be judged based on conventional 50 meter meshed terrain data. The TLS imagery can also be used for three-dimensional city models with high definition, which is expected to be used for city planning, landscape simulation, auto navigation, gaming, and so on. When the helicopter flies along a road, the wall textures facing the road can be acquired with a nadir looking image. The wall textures that are perpendicular to the road can be acquired with either a forward looking or backward looking image. Textures can be semi-automatically mapped onto 3-D polygons. The acquisition of the texture of the building walls facing a trunk road also can be efficiently acquired with an oblique-viewing image.

Furthermore, using the characteristics that can acquire an image of three directions in the constant time lag, the systems can measure the speed of a car, running water, etc. And, it can be applied to the traffic flow measurement which goes along a road and illegal parking investigation judging from the image deformation of a car, a distance from a road edge, etc.

### 3. DATA PROCESSING ON IMAGESTATION

The effort of supporting the STARIMAGER imagery into the Z/I Imaging suite of photogrammetry products is divided into 2 phases (Madani, 1999). Phase 1 deals with necessary changes in several Z/I Imaging products for the purpose of 3-D feature and DTM collection and orthophoto creation. These changes impact ImageStation Photogrammetric Manager, ImageStation Stereo Display, ImageStation OrthoPro, and other components. Phase 2 requires some changes in the ImageStation Automatic Elevation product for the purpose of automatic DTM generation.

#### 3.1 Requirements and software architecture

As STARIMAGER is a new camera type, the existing functions in Z/I Imaging's Photo Foundation cannot handle the imagery acquired by STARIMAGER. Some new definitions and functions need to be added into Photo Foundation and some existing functions need to be modified in order to process STARIMAGER images.

The Phase 1 requirement was to use the Tokyo State Plane coordinate system (Japan Plane Rectangular system with Tokyo datum). The provided TLS library provides the STARIMAGER sensor model and uses this coordinate system as the real ground mapping system when transforming image to ground and ground to as shown in Figure 5. The Z/I Imaging coordinate system component is used in the initial release of functionality to transform from Tokyo State Plane to all other valid mapping coordinate systems for this area. The STARIMAGER library uses the Japan Geographical Survey Institute (GSI) implementation of the WGS84 to Tokyo datum transformation, while the Z/I Imaging library uses the Standard Molodensky transformation. While the GSI implementation is slightly more accurate, it is slower, and it cannot be re-distributed. Z/I Imaging compared the accuracy of the two methods during Phase 1 development.

Phase 1 required a new command to import STARIMAGER images and automatically create associated photos and models. The ImageStation Photogrammetric Manager product is used to import and manage STARIMAGER data. Existing methods for

creating the project and project mapping coordinate system were utilized. The STARIMAGER camera is automatically created based on the input STARIMAGER camera calibration files.

The new Import STARIMAGER Images command resides under the Tools pulldown menu similar to the IKONOS tools. The user selects this command to bring up the new Import STARIMAGER Images dialog (Figure 4).

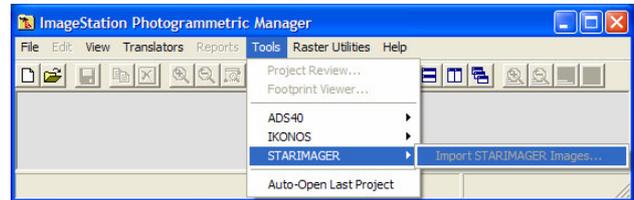


Figure 4. ISPM Main Window

The ImageStation Stereo Display product was modified to handle this type of imagery for heads-up digitising and to permit the STARIMAGER models to be used in the same fashion as stereo models from other sensors. At this time, ImageStation Stereo Display has no new perceived requirements for Phase 2.

A user wanting to work with STARIMAGER images typically follow the steps below. These steps are for Phase 1 of the STARIMAGER effort only and do not include any triangulation of STARIMAGER imagery.

- (1) Create the aerial project using the New Project wizard.
- (2) Run the new Import STARIMAGER Images command to create Camera, Photos, and Models
- (3) One can use the footprint viewer to visualize the spatial relationships of the imported images for verification or go straight to ImageStation Stereo Display to do feature collection.

One can view models in ImageStation orientation/triangulation products. Measuring points on photos have no effect on the EO parameters of the images (no adjustment is computed).

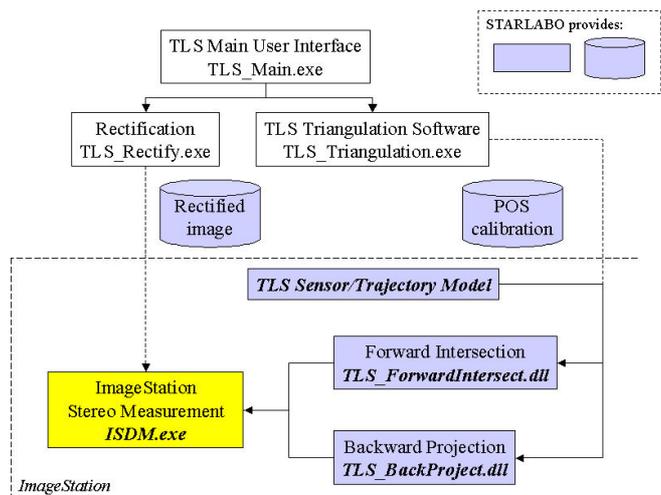


Figure 5. ImageStation module with STARIMAGER library

#### 3.2 Data pre-processing

The Import STARIMAGER Images command expects a set of STARIMAGER data to be triangulated and rectified to level 1

beforehand. The future work should include efforts for performing those processes directly within ImageStation software components.

Certain assumptions are made as to the naming conventions used for the images and their associated support files. Two methods are supported. First, the base name (less extension) of the “.info” file for a rectified image and “.psb” file for orientation data are contained within the base name of the image file (or vice versa). Second, the first N characters of the image, info, psb, and optional parallax grid file to reduce y-parallax are the same (where N is user-definable on the user-interface). The system also requires the images be converted into a Z/I Imaging-supported format such as TIFF before importing into ImageStation Photogrammetric Manager. This includes tiling, adding overviews, transposing, and converting to TIFF format. The ImageStation software includes the necessary utilities for converting the STARIMAGER raw images.

### 3.3 Processes on ImageStation

This section describes the dialogs used in the Import STARIMAGER Images command (Figure 6).

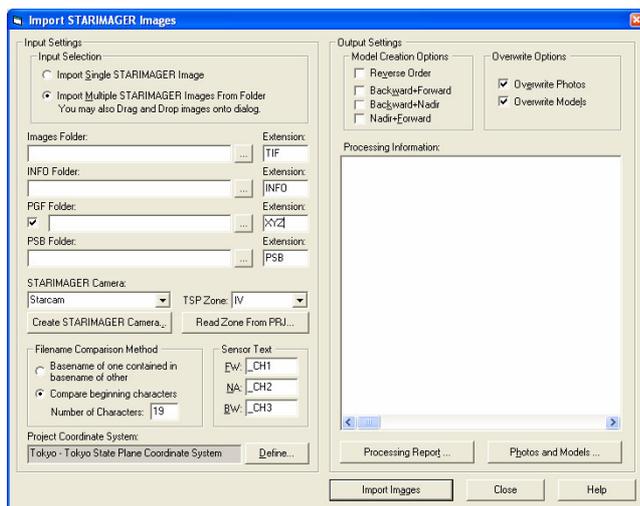


Figure 6. Import STARIMAGER Images Dialog

**Import Single STARIMAGER Image** – Select this option if one wants to import one image and create one photo. Selecting this option toggles the three Folder fields to three File text fields where one selects STARIMAGER Image File, INFO File, optional Parallax Grid File (PGF), and PSB File.

**Import Multiple STARIMAGER Images From Folder** – Select this option if one wants to import a folder of images with one click. Multiple photos and models are created during the import. Selecting this option toggles the three File fields to three Folder text fields where one selects STARIMAGER Image Folder, INFO Folder, optional PGF folder, and PSB Folder.

**STARIMAGER Image Folder/File** – This field toggles between Folder and File based on the Input Selection option. When toggled to folder, the user provides the input folder containing the STARIMAGER Images. When toggled to file the user provides the full file path (including the filename itself) of the image to be imported.

**INFO Image Folder/File** – This field toggles between Folder and File based on the Input Selection option. When toggled to folder the user provides the input folder containing the Orientation Information Files (INFO) of the images to be imported. When toggled to file the user provides the full file path (including the filename itself) of the associated INFO file of the image to be imported.

**Optional PGF Folder/File** – This field enables when checked and toggle between Folder and File based on the Input Selection option. When toggled to folder the user provides the input folder containing the Parallax Grid Files (PGF or in some cases XYZ extensions) of the images to be imported. When toggled to file the user provides the full file path (including the filename itself) of the associated PGF file of the image to be imported.

**PSB Image Folder/File** – This field toggles between Folder and File based on the Input Selection option. When toggled to folder the user provides the input folder containing the STARIMAGER PSB Support Files (PSB) of the images to be imported. When toggled to file the user provides the full file path (including the filename itself) of the associated PSB file of the image to be imported.

**File/Folder Browse Buttons** – These buttons display a simple common browse dialog that allows the user to browse the file system for the desired file/folder depending on the Input Selection.

**File Extension Fields** – These fields are enabled when importing multiple STARIMAGER images from folders. These extensions are used as filters when collecting the list of files in the user-defined folders. This allows the user to have different extensions for the image, INFO, PGF, and PSB files. This may be useful if the user has renamed the files to use an extension of their choice instead of the defaults delivered by STARLABO.

**STARIMAGER Camera** – This combo box is used to select the desired camera from the available list of STARIMAGER cameras in the project to associate with the photos created during the import of the STARIMAGER Images. If none are available and the user attempts to import images an error message is displayed informing them to create an STARIMAGER camera before attempting to import any images.

**Create STARIMAGER Camera** – Select this button to bring up the Create STARIMAGER Camera dialog. A STARIMAGER camera must be selected before importing images.

**TSP Zone**– This dropdown combo box allows the user to specify the Tokyo State Plane zone number for the images being imported. If the STARLABO project support file (PRJ) file is available then the user can select the “Read Zone from PRJ” button and let the application automatically determine the zone number by reading it from the PRJ file.

**Identifying Text** – These fields allow the user to specify the text string used to identify to which sensor an image belongs. For each of the sensors the user can specify a sub-string that occurs somewhere within the base name of the image file being imported. For example, if the base name of an image file contains the string “\_CH1” then it is interpreted as a Forward sensor image. This information is then used to during model creation to create the models selected by the user. This information is also needed during the orientation process to determine which orientation parameters from the

STARIMAGER camera to be used when computing image-to-ground and ground-to-image coordinates.

**Project Coordinate System/Define** – This field shows the currently defined project coordinate system. The user has the ability to change the project coordinate system by clicking the Define button. This is the same project coordinate system definition dialog that is available in the Edit Project command. This field is provided here as a convenience/reminder to the user in case they forgot to define a valid mapping coordinate system when they created the project. The default coordinate system of “Rectangular Grid” is invalid for the project when importing STARIMAGER images. This is because there must be a valid transformation between the EO defined in the INFO file and the Project Mapping Coordinate System. There is no transformation between Rectangular Grid and any “Mapping” coordinate system. If the user attempts to import images when the current Project Coordinate System is set to “Rectangular Grid” an error message will be displayed.

**Model Creation Options** – These checkboxes are used to select which models are created during the import of the STARIMAGER Images. The STARIMAGER has three sensors (Forward, Nadir and Backward). The software allows the user to differentiate the three sensors from the same strip using an embedded string. This string is user-defined in the text fields provided to the right of the Model checkboxes. After photos have been imported, the list is examined again. As each photo is examined, the user-defined string for say, Backward (\_CH3/\_ch3, case is insignificant), is searched for in the image file basename. If found it is assumed that this is a Backward image. If the checkbox is selected for Backward/Forward model creation, the \_CH3 is replaced with \_CH1 (user-defined text for Forward images) and the list is searched for a photo whose image file matches the Forward name created with the replaced \_CH1. If found these two photos are used to create a model. The model name uses the naming convention of LeftPhotoID+RightPhotoID (since strip IDs are not defined for the import they are not used in the model names). The same string replacement and search is used for the remainder of the photos for creating the other checked model types until all scenarios are covered.

**Overwrite Options** – Select these checkboxes to allow the software to overwrite any existing photos or models when re-importing images. Unselecting will cause the command to skip any pre-existing photos it attempts to create during the import.

**Processing Information** – This information area echoes statistics and processing status for each photo and model that is created during the import. This area will contain any problems or warnings that occur during the import as well as successful reporting for each photo/model.

**Processing Report...** - This button allows the user to save the Processing Information to an ASCII text file. Selecting this button brings up the common browse dialog allowing the user to specify the location and filename to be saved.

**Photos and Models...** - This button brings up the Photos and Models dialog. This dialog is used to View and Delete existing photos and models.

**Import Images** – This button initiates the Import process using the user-defined parameters. Any status messages are reported in the Processing Information field. Also, a percent complete

bar is displayed at the bottom of the dialog. A valid project mapping coordinate system must be defined prior to the import as well as an active STARIMAGER camera.

Figure 7 is the dialog for creating a STARIMAGER camera. Following are descriptions of the fields on the dialog:

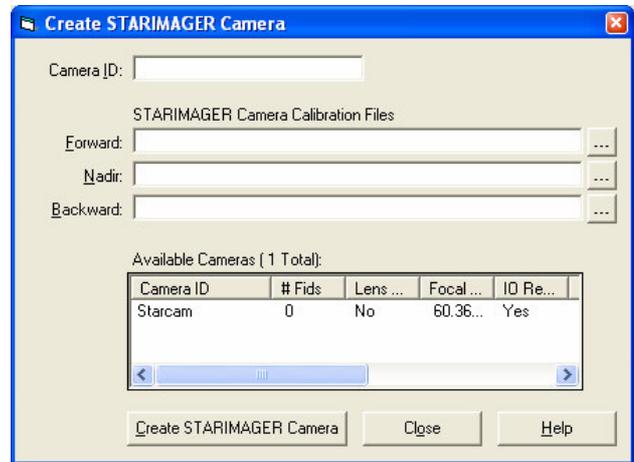


Figure 7. Create STARIMAGER Camera Dialog

**Camera ID** – This field is used to define the name of the new STARIMAGER camera to create. As with any valid camera ID, no spaces or special characters are allowed.

**STARIMAGER Camera Calibration Files** - Use these fields to specify the full path to the three calibration files associated with STARIMAGER camera. All three files must be specified before creating the new camera.

**Available Cameras** – Informational list of available cameras defined for the project.

**Create STARIMAGER Camera** – Select this button to create the new camera. All calibration files must exist and a valid camera ID must be specified.

Figure 8 is the dialog for photos and models. The following describes items on the dialog:

**Photos List** – This list contains the available photos in the project. It allows multi-select to facilitate the deletion of photos when the Delete Selected Photos button is used.

**Delete Selected Photos** – Use this button to delete the photos that are currently selected in the Photo List. Any models that reference a deleted photo will be deleted as well.

**Models List** – This list contains the available models in the project. It allows multi-select to facilitate the deletion of models when the Delete Selected Models button is used.

**Delete Selected Models** – Use this button to delete the Models that are currently selected in the Model List.

**Refresh Status** – This button is used to populate the Status column on the Photo list. The initial display of this dialog has “-----” for the Status column for performance purposes. If the

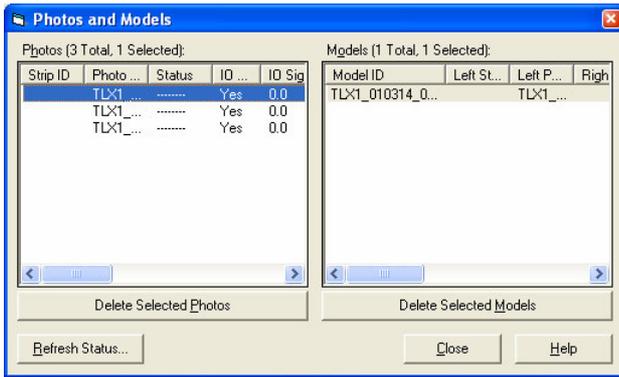


Figure 8. Photos and Models Dialog

Online/Offline status of the image is needed simply select this button and the status column will be populated.

#### 4. PROCESSING RESULTS

Figure 9 is a screenshot for confirming ground control points before collecting features.

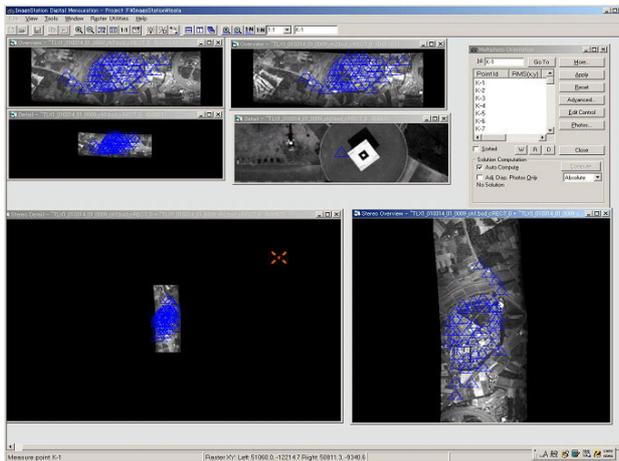


Figure 9. ImageStation Digital Mensuration Windows

An example orthophoto created from a nadir STARIMAGER and corresponding DTM is shown in Figure 10.



Figure 10. An Example STARIMAGER Orthophoto

#### 5. CONCLUSION

ImageStation now supports STARIMAGER data to collect feature and terrain data as well as to generate an orthophoto. The future work is scheduled to support triangulation and level 1 image generation so that the system can process the raw data set acquired by the STARIMAGER.

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