Camera Measurements

Introduction

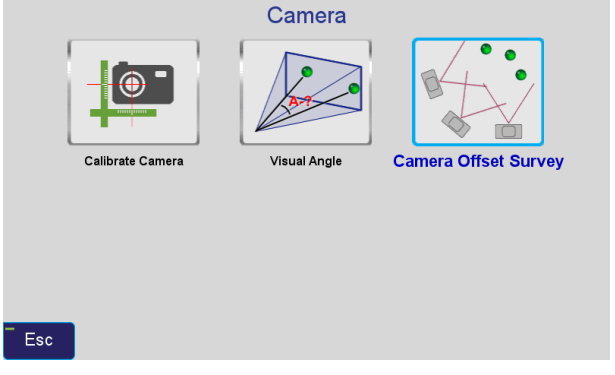
You can use the front camera of **Triumph LS** for performing photogrammetric measurements. Two kinds of measurements are possible:

- ***Visual Angle Measurement***, where angle between directions from camera to different image points is measured. GNSS position is not involved in this mode. Angular accuracy up to 5-10 angular minutes.
- ***Camera Offset Survey,*** where camera images in conjunction with GNSS positions are used to determine precise coordinates of offset points which cannot be mea-

sured directly. Depending on scene configuration and conditions, accuracy may reach 1-2 cm with control points and 5-10 cm based purely on known viewpoint positions.

Before using any of these functions, front camera must be calibrated (it is done once and needs to be repeated only after device repairs or when it suffers heavy mechanical stress). Camera Offset Survey function requires same-name option to be purchased.

All precision camera functions are grouped in ***CoGo Camera*** screen.

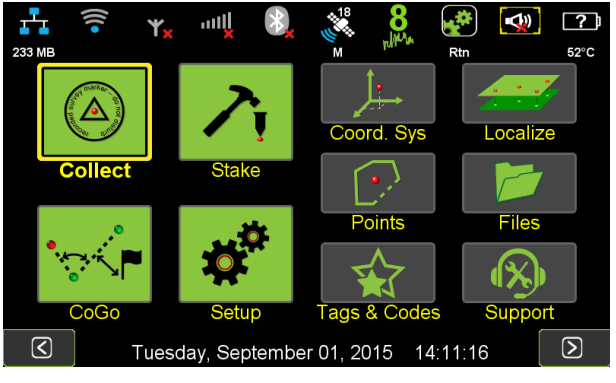


Camera Calibration

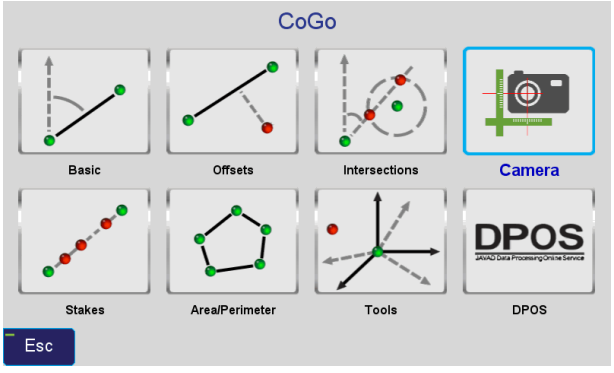
Before using ***Visual Angle*** or ***Camera Offset Survey***, camera must be calibrated. Calibration consists in determining the camera *interior orientation parameters*: focal length, principal point coordinates and radial distortion coefficients. These parameters tend to stay constant (with negligible variance) unless **Triumph LS** undergoes disassembly or heavy mechanical or thermal shock. When such conditions happen, camera should be recalibrated. Otherwise it is recommended to repeat calibration approximately once a year.

To perform calibration, you will need a flat 12-inch or larger computer screen (laptop, tablet, desktop monitor) for displaying calibration pattern image, which can be saved from ***J-Field*** to removable media (USB dongle or microSD card) or cloud drive.

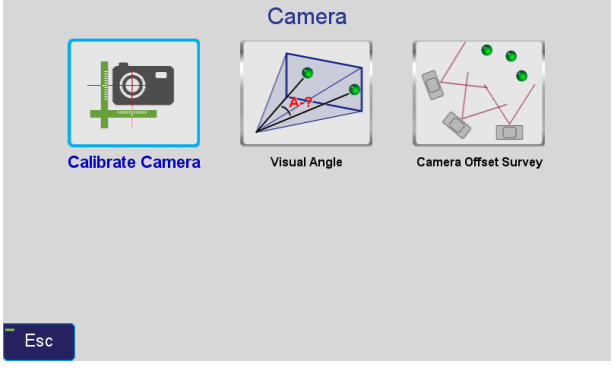
From the ***Home*** screen, tap ***CoGo***.

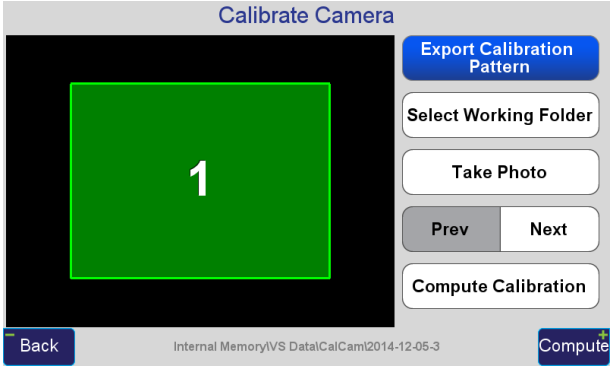


Tap ***Camera***.



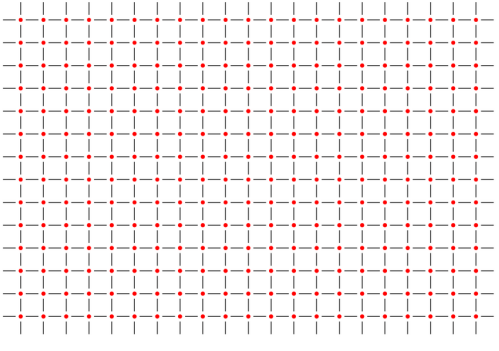
Tap ***Calibrate Camera***.



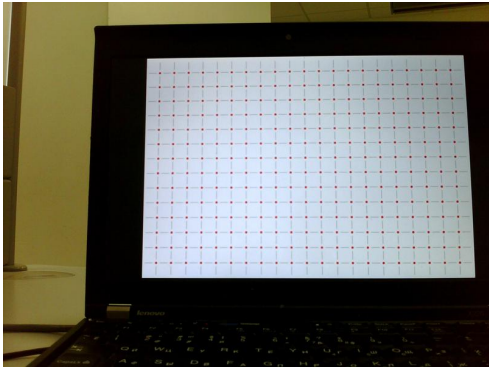


Tap ***Export Calibration Pattern***. You will be presented a standard file selection screen. Choose either a cloud shared folder or removable media for saving the file. It is a PNG-format image which can be viewed in any image viewing software. Transfer the saved file to a PC/notebook/tablet/etc. and open it in full screen mode.

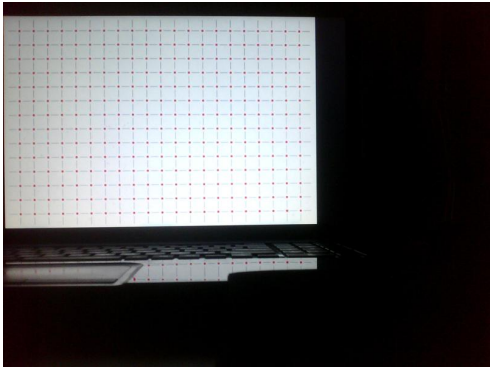
This is how the calibration pattern looks like:



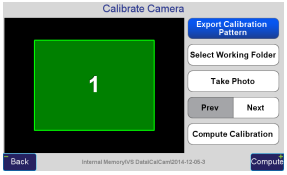
Note that calibration pattern image may change in future ***J-Field*** versions, so if you repeat calibration after upgrading ***J-Field***, export the calibration pattern file again.
Make sure that there are no other circular red objects, which also can get in the camera field of view, around the screen. Also avoid glossy surfaces which may produce pattern reflections in the image.
This is an example of good calibration photo installation:

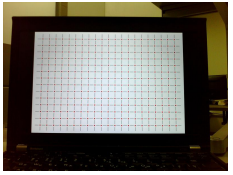


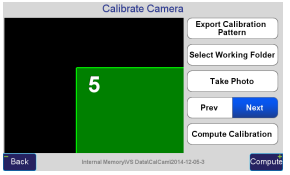
And following is an example of bad photo – note the clearly visible reflection of some of calibration pattern dots in the glossy laptop case:

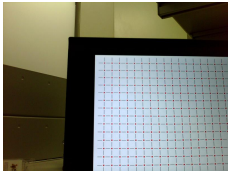


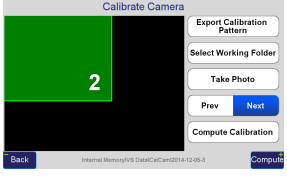
Next, tap ***Select Working Folder*** to select where to save calibration images and intermediate data (final calculated camera passport is always stored in the internal memory, intermediate data may be safely removed after performing calculations, but anyway it is recommended to store them). If there are no removable media attached, new folder is created in the internal memory (as indicated at the bottom of the screen).
Position the screen and the device so that green frame over camera image approximately covers the image of calibration pattern, make sure that the display with pattern and the **Triumph LS** are steady, and tap ***Take Photo*** button. There is a 2-second delay (indicated by circular progress) before image is taken, so that vibrations caused by touching the device do not influence the image, and green frame changes position hinting next photo layout. There are total of 8 different arrangements which must be photographed (5 from the front of the target, 1slightly from top and 2 slightly from left and right). List of arrangement templates with corresponding sample photos:

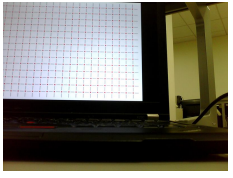


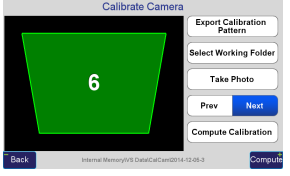


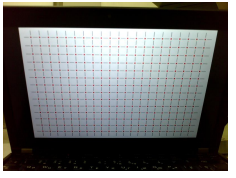


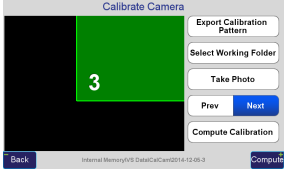


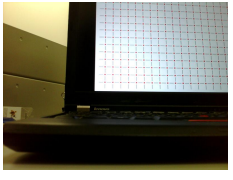


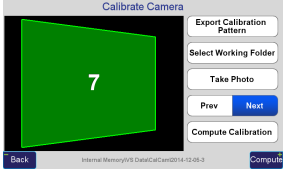


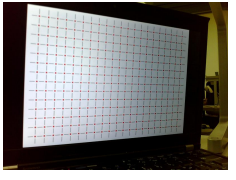


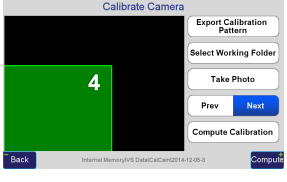


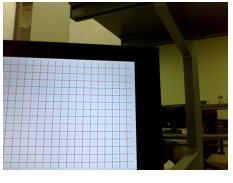


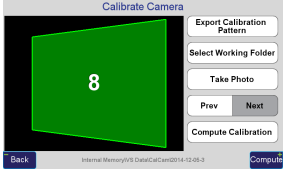


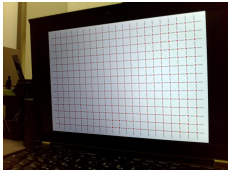








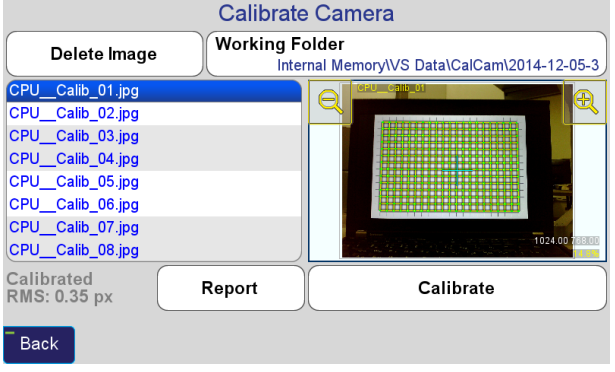




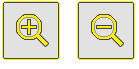
Note that it is not necessary to move the device if you can change the position of the display (e. g. if you use notebook or tablet). To review necessary arrangements, use ***Prev*** and ***Next*** buttons to navigate through the sequence of green

frame configurations.
After the last image is taken, a message box is brought up suggesting going to the next stage (compute calibration data). You can either agree to do this at once, or switch to computing calibration later by ***Compute Calibration*** button. Note that images are always taken at maximum resolution (2048×1536) regardless of current setup.

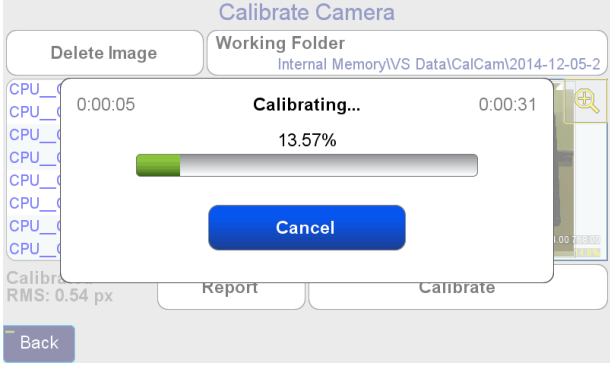
Computing Calibration



This screen is used to compute camera calibration parameters after the calibration template photos have been acquired on the previous stage. Review the images list to the left (select an image to view it in the right pane; use ***Zoom*** buttons

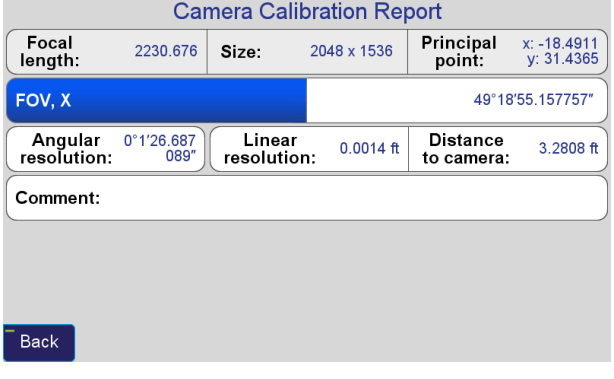


to zoom in and out). If there are some accidentally taken images where calibration target is not visible or shot when device was not steady (with motion blur or tear), use ***Delete Image*** button to delete such images. Use ***Working Folder*** to select another calibration images folder if necessary. Only images from currently selected folder are used to compute calibration; computed calibration replaces any previously computed data.
Tap ***Calibrate*** to start computing calibration.



Please be aware that the process takes several minutes to complete, and it is not recommended to interrupt it. Detected pattern is saved, so if you repeat the process later (e. g. after deleting some bad images or adding new images), it runs much faster.
After the process is complete, review the images in the list – the detected pattern is overlaid on the images. If there are some images where less than half of visible points is detected, or overlaid grid does not match the actual pattern, it is recommended to delete such images and repeat computing process. If there are finally less than 6 images left with reliably detected grid, return to the previous screen and shoot

some more images, and then repeat the computing process.
Note the residual value printed under the ***Calibrated*** status at the lower left corner: it must be less than 1 pixel. If there are more than 6 images in the list, detected grid is overlaid correctly and RMS is still larger than 1 px, please turn to the Technical Support.
Note: Calibrated residual value is RMS of difference between each detected pattern node position on image and its ideal projection reconstructed using computed interior and exterior orientation parameters. In perfect conditions, calibration RMS usually is 0.5 px or less, and while values between 0.5 and 1.0 px are acceptable and the calibration result can be used for further measurements, it is sign to recheck for misdetected grid nodes or motion blur on images.
When status label reads ***Calibrated*** with RMS less than 1 px, you can use camera for measurements (if camera calibration is missing, screens that employ it will warn you). Also you can review computed camera parameters by tapping the ***Report*** button.



The report screen contains:

- ***Focal length*** is considered equal for X and Y axes and expressed in pixels
- ***Size*** in pixels of calibration images (to check that proper resolution setting was used when taking images)
- ***Principal point*** coordinates in pixels relative to image center, X axis right and Y axis up
- ***FOV*** – field of view along X, Y axes and diagonal (tap label to toggle mode)
- ***Angular resolution*** – angle corresponding to one pixel (note that actual minimal resolved angular distance / object size is usually greater and depends on lens condition, scene lighting and colors, etc)
- ***Linear resolution*** @ given ***Distance to camera*** – simple calculator which can be used to assess the minimum details size when objects being photographed are located at given distance from **Triumph LS**
- ***Comment*** – arbitrary notes you wish to store regarding current calibration

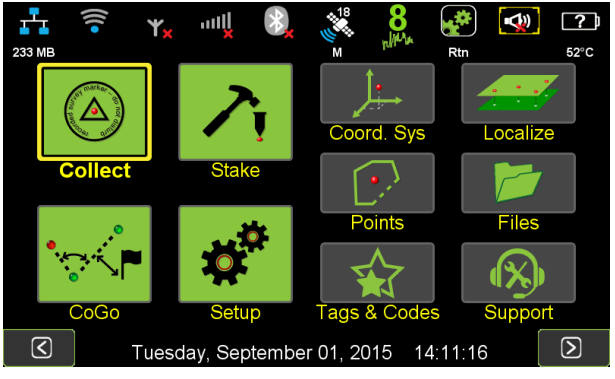
Note that camera intrinsics (interior orientation parameters) are expressed in pixels as convenient replacement for true linear units – all coordinates in images are also expressed in pixels and related to real-world dimensions via unitless proportions. If you still need to assess in-camera parameters in real-world units, use physical pixel size of 1.75 µm as conversion factor. Camera has fixed aperture of F/2.8.

Visual Angle Measurements

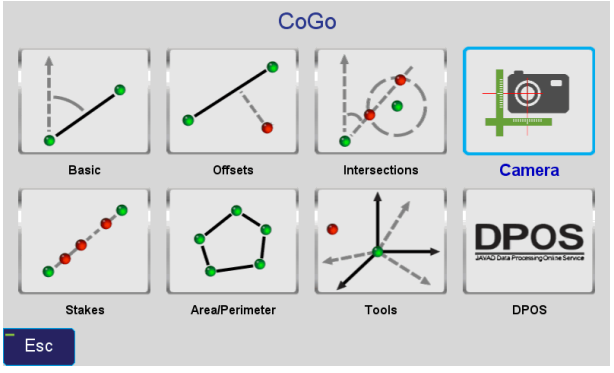
The ***Visual Angle Measurement*** function in ***J-Field*** allows measuring angles between rays from the device position (more exactly, front camera lens optical center) to any points by using photos of these points, taken by the **Triumph LS** front camera. Lens optical center is approximately 40 mm in front and 8 mm above ARP.

This function can be used to provide angles for ***CoGo*** tasks. Accuracy of this kind of measurements is about 10 angular minutes. The camera must be calibrated.

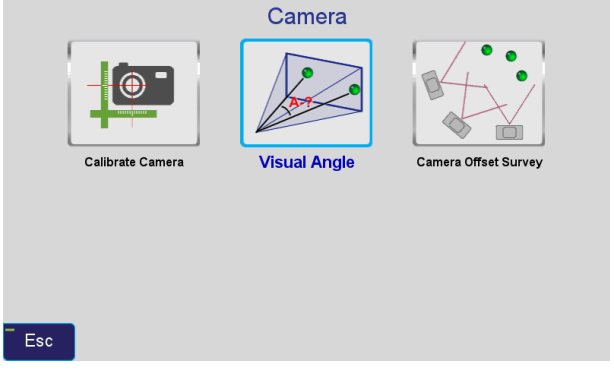
To perform measurements, from the ***Home*** screen tap ***CoGo***.



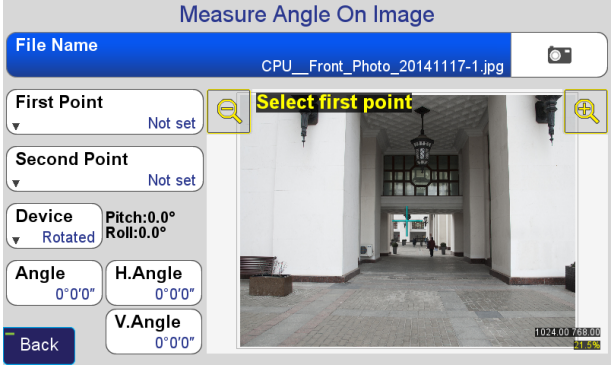
Tap ***Camera***.



Tap ***Visual Angle***.



Measure Angle On Image screen appears.

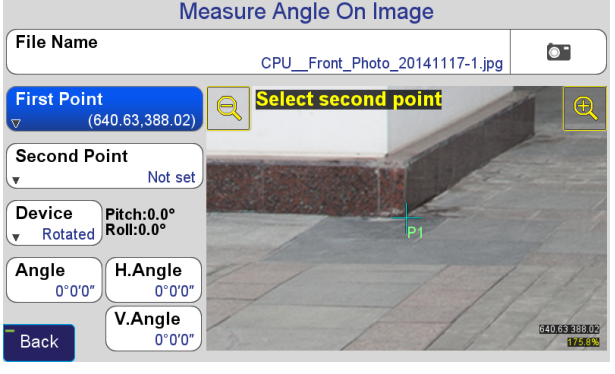


Use ***File Name*** button to select an existing image file (make sure the selected image is taken by the front camera of the same **Triumph LS** device). Or tap the ***Camera*** button

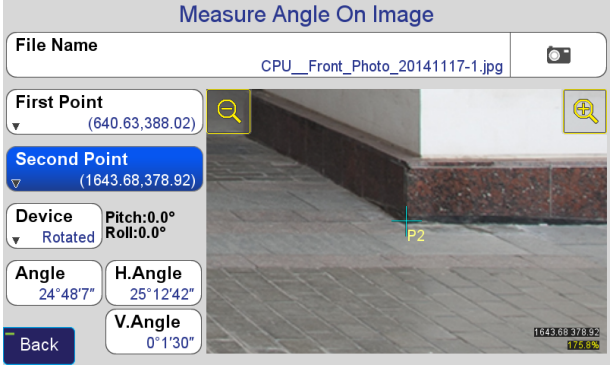
to go to the camera screen and acquire a new image. It is recommended to use images taken at full resolution (2048×1536).
Next, specify two points of interest on the image. Tap and drag the image to move it (cursor position is fixed at the window center, so image is moved to change cursor position). Click once or click and hold the ***Zoom In*** button

to zoom in. Double click this button to set zoom to 100% (1 image pixel = 1 screen pixel). Click once or click and hold the ***Zoom Out*** button

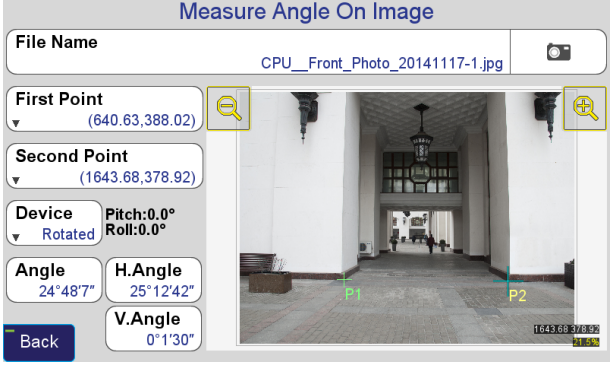
to zoom out. Double click this button to set zoom to fit image in window.
After the central cross (cursor) is positioned at the first point, tap the ***First Point*** button to fix the point position. To change the first position, reposition the cursor position and tap ***First Point*** button again. Tap and hold this button to clear the first point position.



Use the ***Second Point*** button to position the second point in the same manner as the first one.



After the second point has been marked, the following angle values are computed and displayed:



- ***Angle*** – slope (3D) angle
- ***H. Angle*** – horizontal angle
- ***V. Angle*** – vertical angle

Tap any of these fields to save the respective angular value to memory so that it can be used in calculations in other places of the software.

Use the ***Device*** button to toggle calculation modes:

- ***Level*** – the image is implied to be taken by the device positioned with zero inclination
- ***Rotated*** – orientation data saved with the image is used to adjust horizontal and vertical angles for the device inclination (slope angle is unchanged)

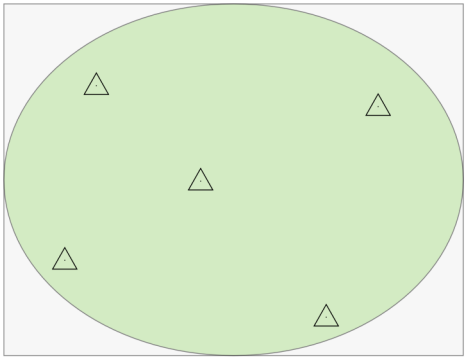
Keep in mind that the angle is measured between rays connecting marked points and camera projection center (a point several mm behind the front camera glass), not the ARP.

Camera Offset Survey

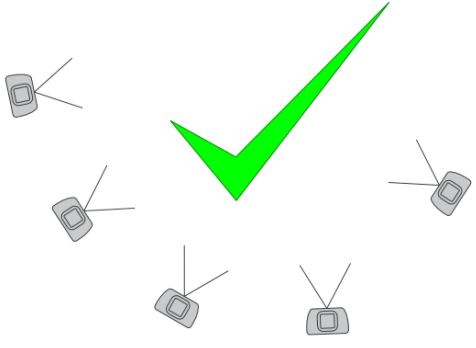
TODO (general introduction)

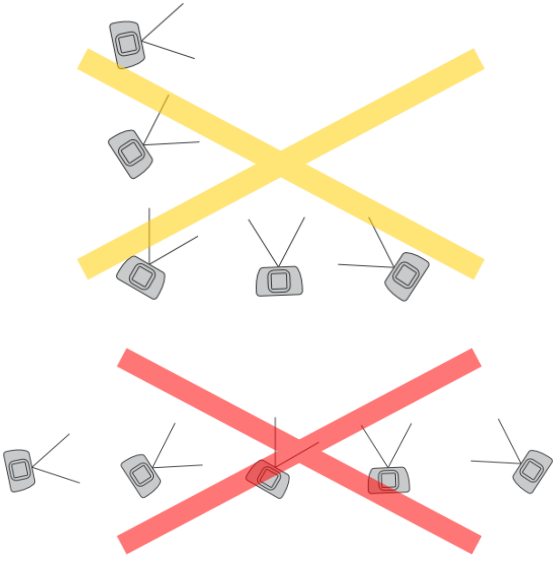
Recommendations for Taking Images

- For stable and accurate result, 4-5 images (min. 3 images required) containing points of interest should be taken from distinct positions not lying on a straight line. Each image is taken simultaneously with measuring GNSS coordinates of the viewpoint.
- The shooting should be performed as close as possible to the objects, but not closer than 1 m. The degradation of accuracy on the average distance between an object and cameras is about 5 cm for every 10 m (when there are no known points visible in images), when other shooting requirements are met.
- Use the maximum camera resolution (2048×1536) - this is granted if shooting is invoked from the Camera Offset Survey module.
- For maximum accuracy, it is recommended to take 5 photos of the object made from 5 different viewpoints. This allows compensating for the random error in determining the viewpoints coordinates. The minimum amount to obtain the solution is 3 photos of one object from different viewpoints, if there are no known points, and 2 photos if each image contains at least 2 points with all known coordinates (though in this case quality will be lower).
- It is recommended to place the investigated and additional points uniformly distributed in the highlighted area of the field of view (frame):



- The vantage points should not be located on a line. Furthermore, it is preferable that they are not located in one plane: change the height of the tripod or use small natural heights to take new shot.

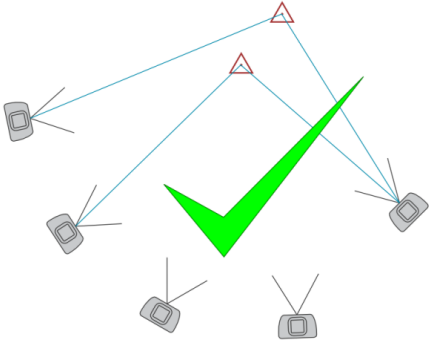


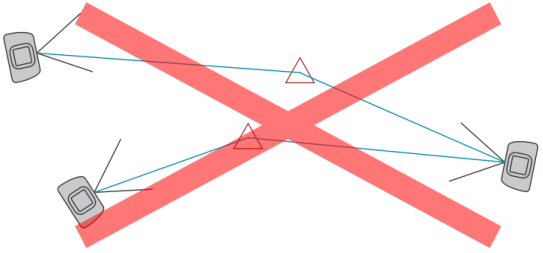


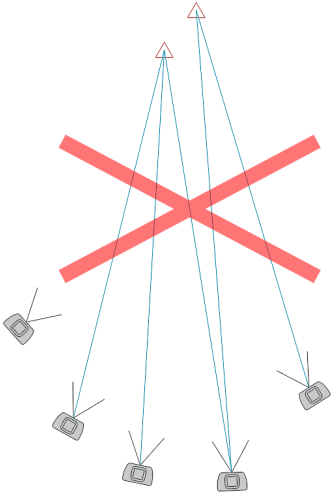
◆ In addition to the points of the object being investigated (target), it is necessary to provide a sufficient number of tie points. It will be perfect to have 4-5 points visible on all images. If it is unachievable, it is necessary that on each image there are minimum 3 common points, visible at least on three shots each. The minimum condition for obtaining solutions is to have on every shot three points each visible on at least one shot more.

◆ The tie and target points are the points which can be recognized on the picture with approximate accuracy of about 1 pixel. These can be either contrast points (corners of the objects on terrain, buildings windows, fence graffiti, etc.), or symmetrical objects. In the latter case their centers are used as tie points. Take into account the image noise level of the TRIUMPH-LS sensor.

◆ For accurate coordinates determination provide for each point the intersection angle close to 90°. I. e. for each investigated point, and for tie points as well, there should be a couple of shots, where the rays from given point to the vantage points form an angle close to 90 °.







- Be sure the device during shooting is stationary. The low speed of reading image from the sensor causes significant geometrical image distortion, if the picture is taken at the moment of pressing hardware buttons (it is taken care for when taking image from the Camera Offset Survey module, which makes small delay before taking an image). For small movements the upper and lower parts of frame are somewhat shifted relative one another. It causes the errors in measurement, but is poorly detected visually.
- Note that vantage points should be measured as carefully and precise as possible, even when known control points are used. Vantage point coordinates are primary reference data.
- For unbiased accuracy assessment it is desirable to measure 1-2 check points (i. e. points, which are not used as source data in bundle adjustment, only for verifying the result), visible at least on 2 images each with intersection angle close to 90°.
- To improve the accuracy, use control points. Control point, generally, does not have to be visible on more than one shot, although the more pictures it is visible on – the better.

Processing Images

All data (images and points) for a specific scene is organized as a photogrammetric project, and can be reviewed on a single screen.

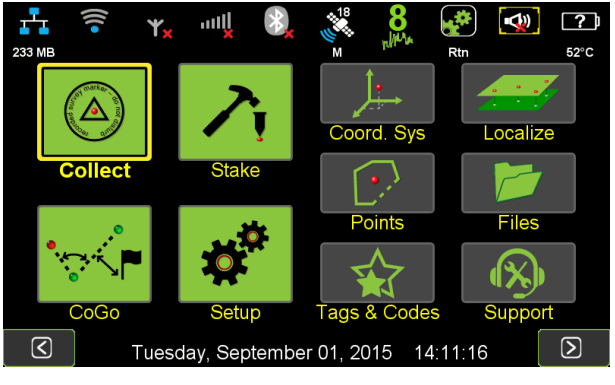
You can use either images attached to already surveyed points or take new images with surveying points via special viewfinder screen (recommended)

The Camera Offset Survey module provides capability of measuring coordinates of points which are impossible to measure with GNSS directly. You need to take photos of the point or points of interest from several locations (minimum 3

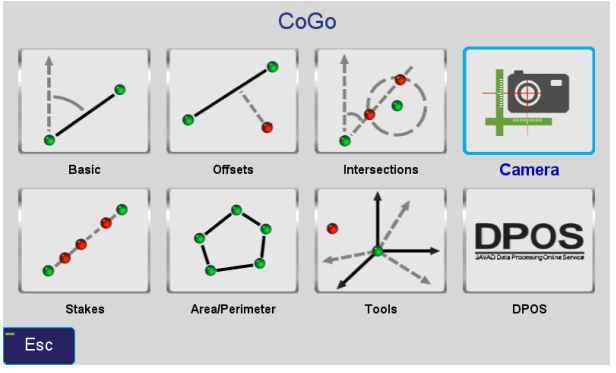
if using control points; without control points at least 5 recommended) not on one straight line. When images are taken, corresponding (***tie***) points must be measured on images in order to compute precise camera orientation. Reference points (points with known coordinates, which are visible on images) can be used to enhance precision (as ***control*** points) or provide unbiased checking for results (as ***check*** points). Without control points, each tie point should be marked on 3-4 images, and on each images there should be at least 5 points marked. Minimum is 3 point marks per image and 2 marks on images per point. If control points are used, there can be less tie points – concrete numbers depend on scene configuration, sufficiency can be checked via estimated errors on the Adjustment Result screen. Points of interest should be also marked at 3 or more images.

Reference

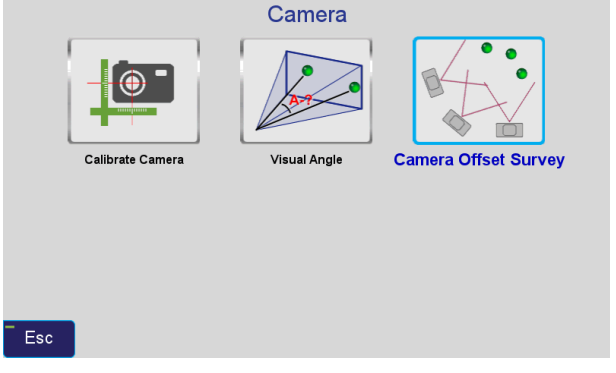
To perform ***Camera Offset Survey***, from the ***Home*** screen tap ***CoGo***.



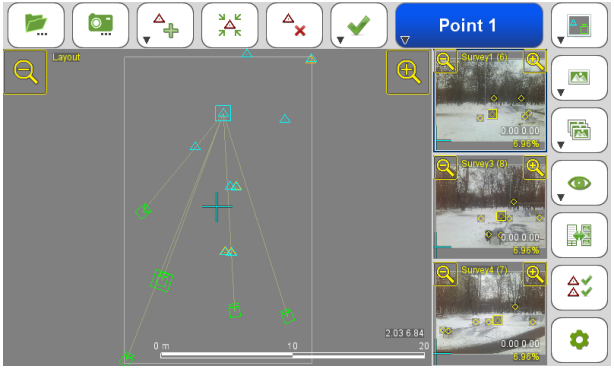
Tap ***Camera***.



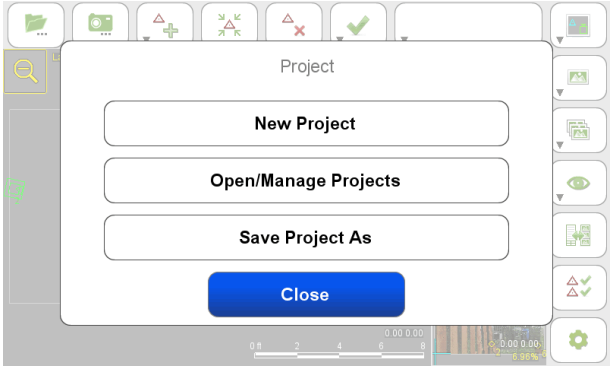
Tap ***Camera Offset Survey***.



Main Screen

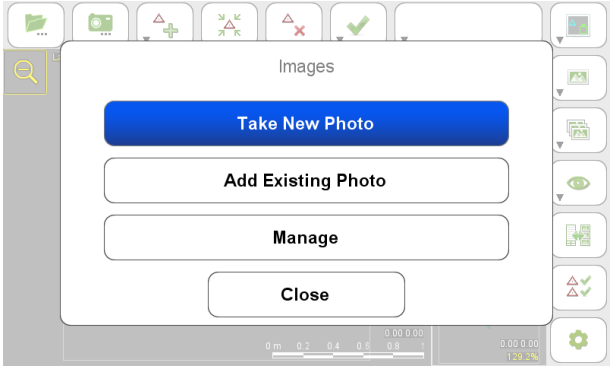


All scene data is grouped into a camera offset survey project file inside a ***J-Field*** project. Note that the project file does not contain copies of images, so if you delete image files from ***J-Field*** project, they will be also lost from the camera offset survey project. Project files are managed via commands in the menu invoked by the ***Projects*** button:



- ***New Project*** – create new empty project
- ***Open/Manage Projects*** – switch to projects management screen, where you can select project to open, as well as rename or delete projects
- ***Save Project As*** – save currently loaded project under a different name

To manipulate project images, use the menu invoked by the ***Images*** button:



- ***Take New Photo*** – switch to viewfinder screen for surveying viewpoint and taking photo
- ***Add Existing Photo*** – select already surveyed point from ***J-Field*** project with attached photo to add the image to camera offset survey project
- ***Manage*** – switch to images screen where you can review the images list and delete these you do not need

To add a tie point, tap the ***Add Point*** button

and then the ***Mark Point*** button

to place it. Tap ***Mark Point*** once more to remove point measurement (without removing the point itself) and once more to add again to current marker position. The ***Delete Point*** button

deletes current point (its name is displayed at the right part of the top toolbar) with all its measurements on all images.
Tap and hold the ***Add Point*** button to add reference (control or check) point.
After marking necessary amount of points on all images, tap the ***Adjust*** button

to pass to adjustment.
Use the right toolbar to navigate between project images and manage points:

- ***Show Layout*** window (tap and hold to switch and zoom all windows to fit)

- ***Show One Image*** in central window (the image from the most recently focused window is shown; tap and hold to switch and zoom all windows to fit)

- ***Show All Images*** in central window (tap and hold to switch and zoom all windows to fit)

- Change display ***Detail Level*** (tap and hold to toggle text labels display)

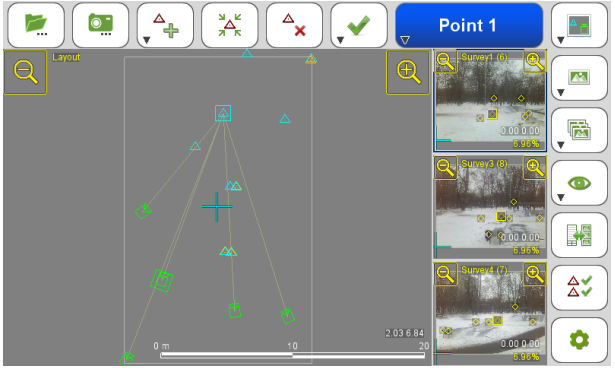
- Toggle ***Right Panel*** between image previews and points list

- Go to the ***Project Points*** screen

- Go to the ***Setup*** screen

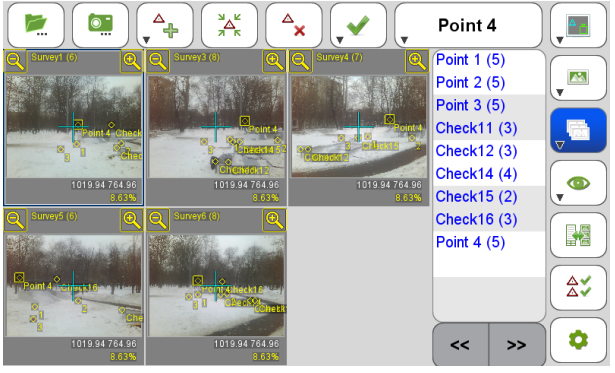
Central window of the main screen supports three display modes activated by respective buttons of the right toolbar:

- In ***Layout*** mode, it displays project layout in local topocentric coordinate system



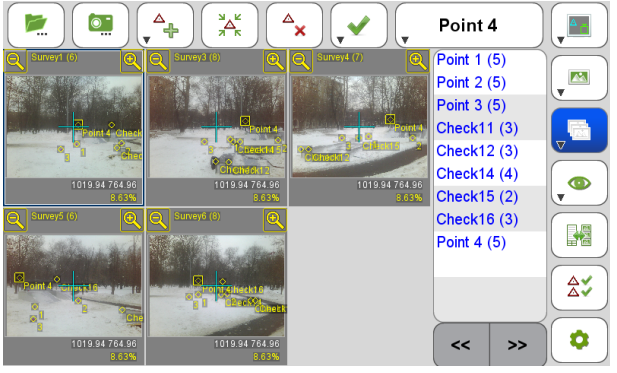
- In ***Show One Image*** mode, one image is shown for measuring points

- In ***Show All Images*** mode, all project images are shown tiled



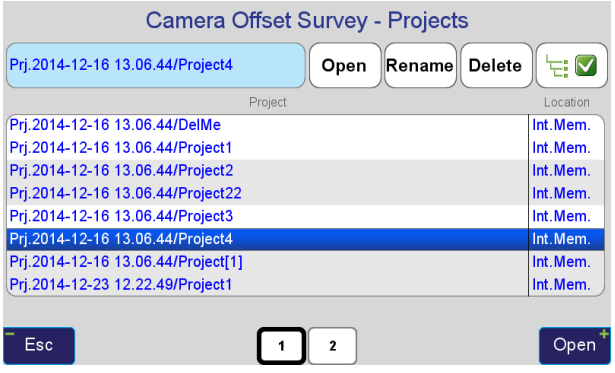
This mode can be used to review all project images, or position of a point on all images. Editing is possible but less comfortable due to window size. Tap an image and use ***Show One Image*** button to open the image in the central window. Right Panel can be toggled between two modes by respective button in the right toolbar:

- Points mode. Number of images where the point is measured – in parentheses



- 3 images mode. Tap an image and use ***Show One Image*** button to open the image in the central window

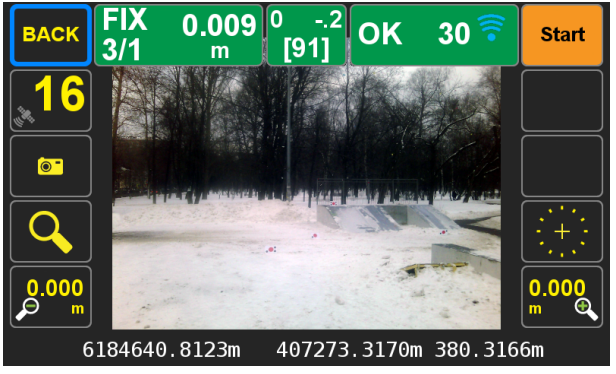
Projects Management Screen



This screen contains list of all camera offset survey project files within current ***J-Field*** project. Use the ***Show All*** check-box

to show project files from all ***J-Field*** projects.
Use ***Open*** to load the selected project and return to the main camera offset survey screen; ***Rename*** to change project name (without changing its location) or ***Delete*** to delete the project (in this case, only project working data is deleted – images and/or points already saved to ***J-Field*** project are not influenced).

Viewfinder Screen



Make sure the device is stationary and use normal ***Start-Stop-Accept*** sequence to measure position. Photo is taken when you press ***Start***, after a short delay (indicated by circular countdown), so that shaking caused by pressing the button does not influence the photo. After ***Accept***, you will automatically return to main camera offset survey screen.
You can use the ***Camera*** button

to temporarily hide the viewfinder window and show map.

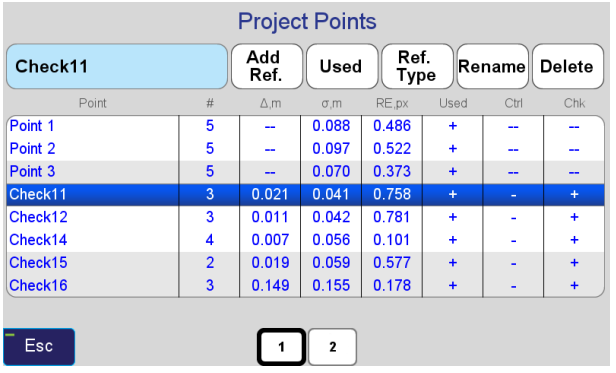
Images Screen

This screen lists images in the current camera offset survey project.

If you need to remove one or more images, select the images in the list (tick the corresponding checkboxes) and tap the ***Remove selected*** button.

Use ***Add images*** button to add images associated with points of the current ***J-Field*** project.

Points Screen



This screen contains list of all points in current camera offset survey project – both tie and reference points. The following fields are shown for each point:

- ***Point*** name
- ***#*** – number of images the point is measured on
- ***Δ*** – reference point error, available for reference points only: distance between actual (input) and calculated (adjusted) point position
- ***σ*** – estimated adjusted position RMS
- ***RE*** – mean reprojection error in pixels: mean distance between point mark and projection of computed point on each image where the point is measured
- ***Used*** – "+" if point is used in adjustment and "-" otherwise
- ***Ctrl*** – "+" if reference point is used as control point (reference point coordinates are used in adjustment)
- ***Chk*** – "+" if reference point is used as check point (reference point coordinates are used only for accuracy assess-

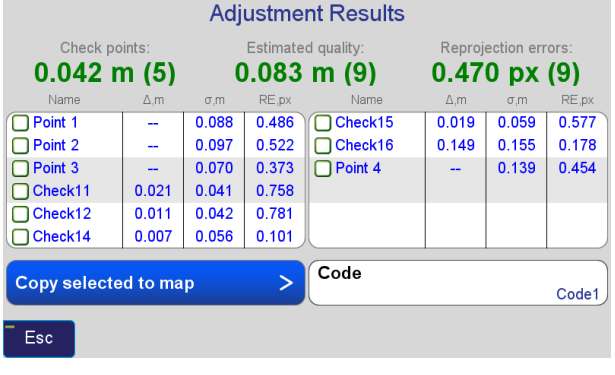
ment, but not as input data for adjustment)

The following actions are available:

- ***Add Ref.*** – add reference point from list of points already existing in the ***J-Field*** project. The added point will be ***control*** by default – use the ***Ref. Type*** button to change its type to ***check*** if necessary
- ***Used*** – toggle whether the point is used as tie point in adjustment (i.e. its marked positions on images are used to tie images)
- ***Ref. Type*** – toggle reference point role: control (use coordinates in adjustment), check (use coordinates for accuracy control) or tie only (coordinates are not used at all)
- ***Rename*** point
- ***Delete*** point

All editing is applied and saved immediately.

Adjustment



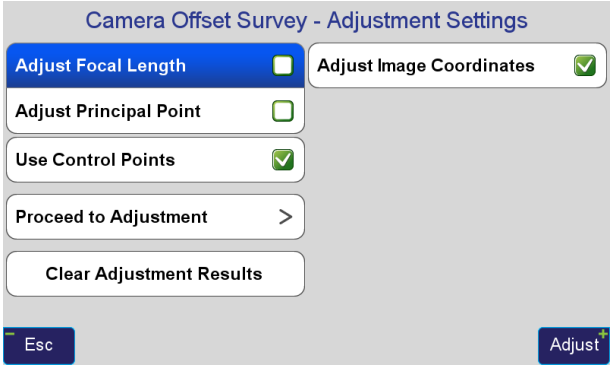
This screen displays results of the project bundle adjustment with accuracy assessment. Also it allows copying computed point coordinates to the current ***J-Field*** project.

Top line contains overall quality estimation consisting of 3 parameters:

- ***Check points*** – mean error on check points (reference points coordinates of which were not used in adjustment, for unbiased assessment), if any
- ***Estimated quality*** – mean estimated RMS of all computed points' positions
- ***Reprojection errors*** – mean reprojection errors of all points (mean distance between point mark and projection of computed point on each image where the point is measured)

Next the list of all points with calculated positions is given (if for some reason point coordinates could not be computed – e. g. for points measured on a single image only – such points are not shown in the list) with estimated position RMS for each point. These points are the output data of the Camera Offset Survey module. Select points you wish to copy to the ***J-Field*** project (tick the checkboxes) and tap ***Copy selected to map***. New points are created in current ***Page*** with specified ***Code***.

Adjustment Settings



Here you can change some bundle adjustment settings, as well as clear adjustment results (computed point positions and image orientation).

When you have reliable control points visible on images, you may turn on ***Adjust Focal Length*** and ***Adjust Principal Point*** options to check calibration quality. If after enabling this options, RMS and errors on check points become significantly lower, it means that either camera needs to be recalibrated or there are some problems with input data. In general these two options should be left off.

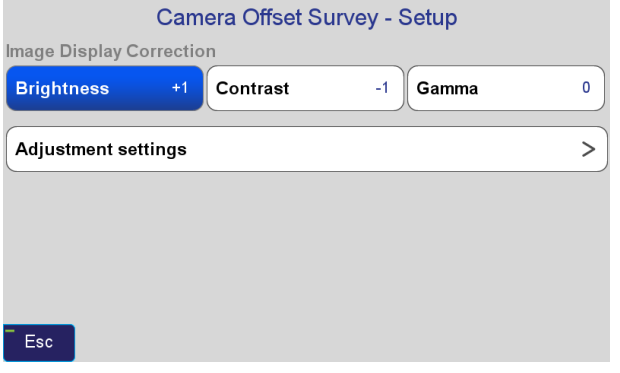
The ***Use Control Points*** option allows temporary forcing all control points to be used as check points – e. g. if you wish to quickly see the overall effect of using the control points in the scene. This options should be generally left on.

The ***Adjust Image Coordinates*** option enables slight adjustment to GNSS coordinates of viewpoints, which, given there are more than 4 images, can enhance overall accuracy. If you use only 3 images (which is generally not recommended), turn this option off. Otherwise, it should be left on.

Tap ***Clear Adjustment Results*** to delete all computed (output) coordinates. Input data (coordinates and measurements on images) is left intact.

Tap ***Proceed to Adjustment*** to adjust the project and switch to the ***Adjustment Results*** screen.

Setup



Here you can adjust ***Brightness***, ***Contrast*** and ***Gamma*** of displayed photos (only display is affected; image files stay intact).

Use ***Adjustment settings*** button to switch to bundle adjustment settings screen.