Riegl TLS Field Operation Manual and Workflow

UNAVCO
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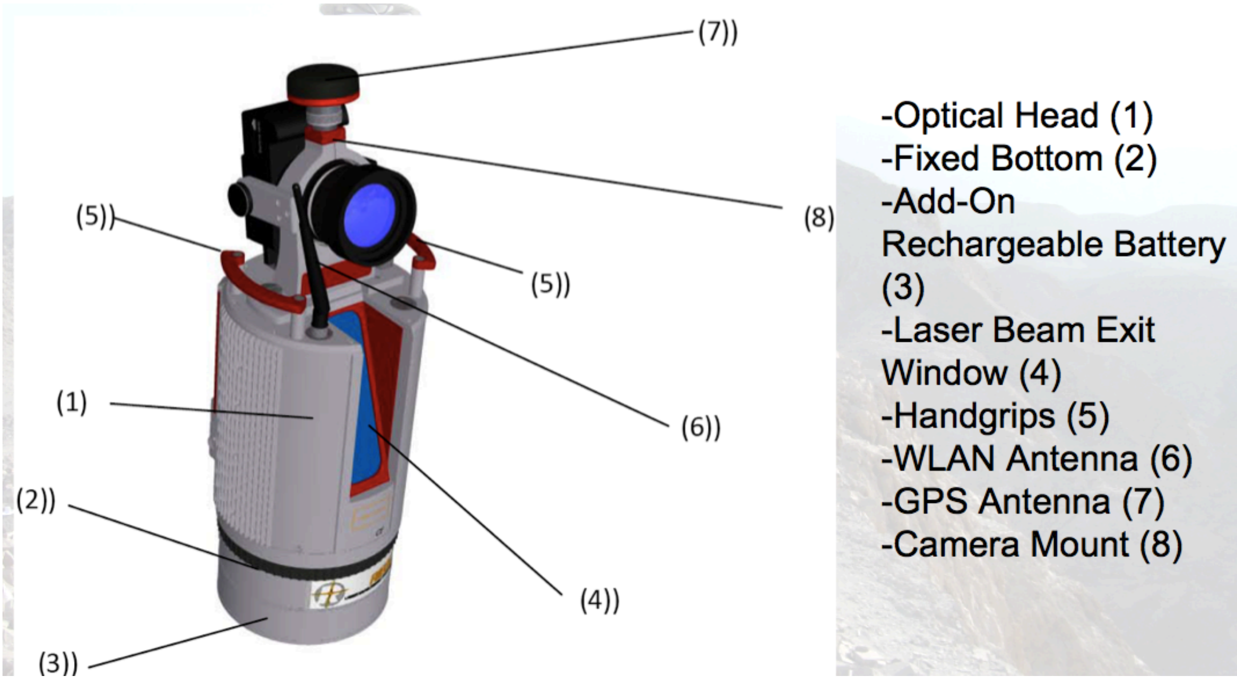
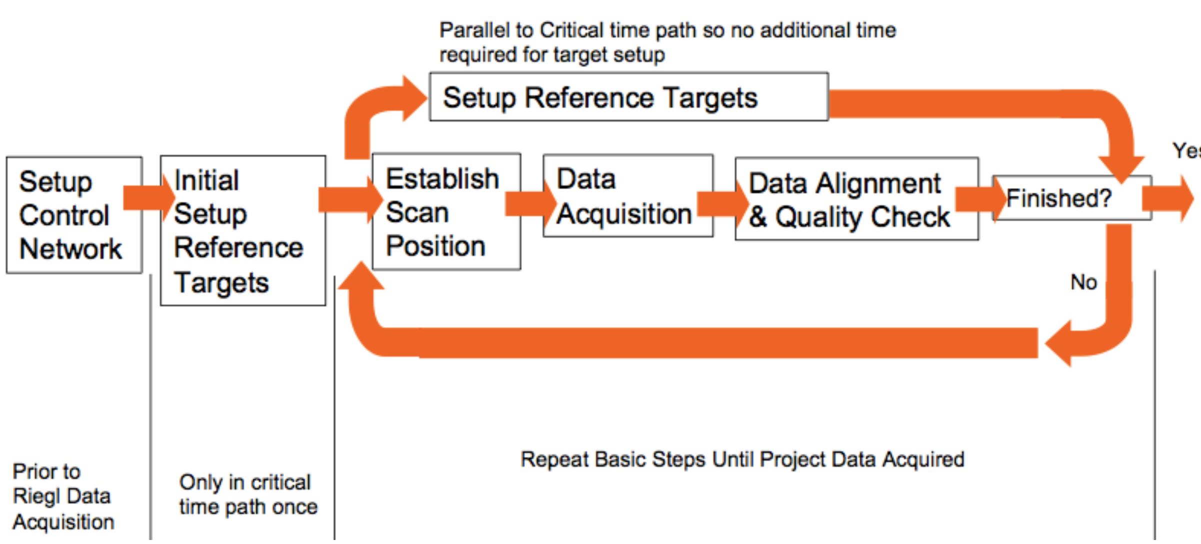
This manual was developed by UNAVCO staff to document our best-practices for Riegl terrestrial laser scanner field operation, data collection, and initial data processing. This document is for a tie-point based workflow, using the Riegl VZ400 (but should also be largely applicable to the Z620 and VZ1000 scanners as well).



Basic components and set up of a Riegl VZ scanner. Image courtesy of Riegl USA.



Basic workflow overview for field operations. Image courtesy of Riegl USA.

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1. Field Set Up

1.1. ***Scanner location(s)*****:** select the best field of view coverage of an area of interest to minimize blind spots.

1.1.1. Decide if multiple scan locations will be needed to obtain maximum coverage with little, if any, blind spots on the area of interest left by any scan position.

1.2. ***Control and Registration Tie points (reflectors)*****:** will be set up in an evenly (as possible) distributed pattern around the scanner. Tie points should not be set up in a linear pattern.

1.2.1. Tie points need to be as perfectly level as possible on their tripods. Use the provided levels to assist you. This is an important step at all times, but becomes particularly important if you have to rotate targets to face another scan position, especially if a GPS antenna is attached as well.

1.2.2. All tie points should be visible to the scanner from multiple scan locations. In the case of uneven topography, a minimum of 5 tie points should always be visible from each scan location.

1.2.3. Tie point distance from scanner should not exceed maximum range of the scanner.

1.3 ***GPS Set Up:*** if georeferencing scans is required by the project, traditionally you will need 3 GPS kits and set them up in conjunction with tie point targets by attaching the antennas atop the targets to collect data for the day (Static Survey). **For further background and equipment needs for 3 methods of GPS surveying, and the pros/cons of each, please refer to Appendix A.**

2. Scanner Set Up

2.1. ***Toughbook*****:** turn on laptop and begin loading RiScan Pro so you are ready to go.

2.2. ***Tripod*****:** should be securely placed in the ground and leveled (level may be provided in case, if not, eye ball it, the RiScan Pro software has a leveling tool (Step 4.1)).

2.3. ***Battery Set Up:*** batteries should **always** be connected in series (refer to Appendix B). A good spot to place them is underneath or to the side of the tripod.

2.4. ***Portable Kestrel Weather Station:*** turn on and hang from tripod to start recording temperature, humidity, and atmospheric pressure

2.5. ***Mount Digital Camera to Scanner*****:** the camera is calibrated to its mount so only grab the camera set up out of the box from its mount. Open scanner box and stand the scanner upright in its box and attach the camera. With respect to the VZ-400

(2) scanner, you must attach the USB cable first (Fig. 1), then mount the camera (in the same direction as the laser) on top of the scanner, securing it in place with two hand screws. **Remember to turn on camera and remove lens cap.**

2.5.1. *VZ-400 (2) Camera:* Connect to scanner via a USB cable (Fig. 1) (can cause issues if not properly connected). Make sure camera battery is operational and charged as well.

2.5.2. *VZ-1000+VZ-400 (CWU) Cameras*: Do not need a battery or a USB cable. The cameras are powered and interfaced directly to scanner head. <u>Make sure interface connectors are clean for proper connection.</u>

Figure 1. Image of VZ-400 from Riegl USA.

2.5.3. *Internal GPS Antenna:* if not using digital camera, remove GPS antenna from camera mount and attach to top of scanner (Fig. 2).

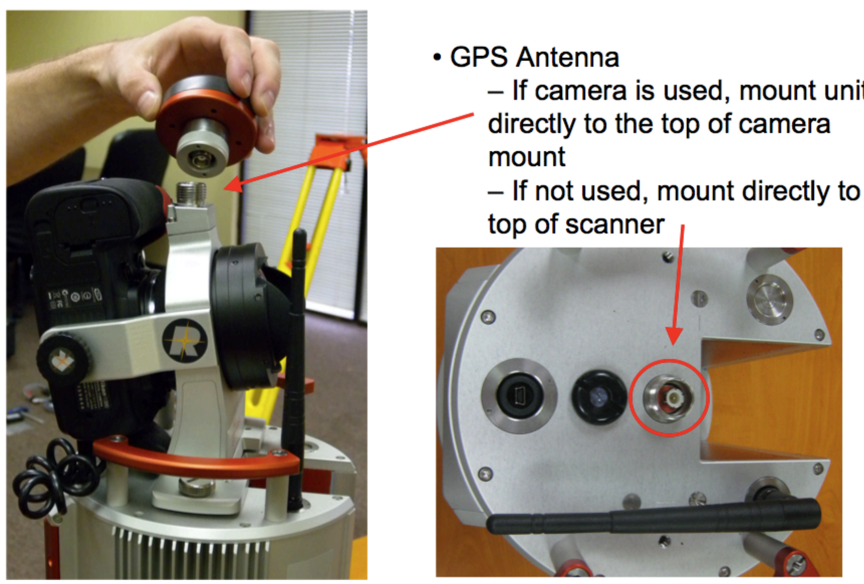


Figure 2. Image from Riegl USA.

2.6. ***Scanner***: should be carefully removed from its case, mounted and secured to a leveled tripod using a mounting bolt at the top of the tripod, below the scanner.

2.7. ***Wifi antenna or Ethernet cables***: decide to use either the Wifi antenna and attach to top of scanner **or** the Ethernet cable and connect the scanner and Toughbook.

2.8. ***Power Cord***: Once all hands are off the scanner, connect the power cord to the batteries then lastly, connect the power cord to the scanner. The scanner will then power up and rotate to its start position. If the scanner does not power up for some reason, press the power button (Fig. 3).

Figure 3. Image from Riegl USA.

3. RiScan Pro – Pre-scan Set Up

The following section only needs to be performed one time, at the beginning of the project, before you start creating scan positions in RiScan Pro; afterwards skip 3.

3.1. ***RiScan Pro***: open file containing pre-set UNAVCO default settings "UNAVCO_Standard_RSP_v177.RiSCAN", then "Save As" new project.

3.2. ***Scanner and computer link:*** Click "Tool" and select "Scanner search (network)". High light scanner and click "Apply". Icons at the top of the menu bar will indicate Scanner and Camera status. If this does not work, refer to 3.3.1.

3.3. ***Project Attributes:***

3.3.1. If step 3.2 is not working, go to "Project Manager" right click *project file name* and select "Attributes". Select the "Instrument" tab, and make sure that the correct IP address is entered for the scanner (192.168.0.125).

3.3.1.1. If problems still persist, makes sure to:

(1) Check that the scanner power is on and the button is illuminated.

(2) Check all that Power, USB, and Ethernet cords are properly connected.

(3) Close out RiScan Pro.
(4) Reboot Scanner by unplugging and re-plugging cords.
(5) Reboot Computer.

3.3.2. Under "Project Manager", right click *project file name* and select "Attributes". Go to "Instruments" tab, check that the camera is set to the correct model (e.g. Nikon D-700). Scanner and Camera Icons on top menu bar should have green check marks when connected. *If camera icon is not green don't worry, this can be confirmed with Step 4.4. If it takes pictures in Step 4.4 then it's connected, if not, make sure the camera is on and check the camera/scanner interface or USB cable connection.*

3.3.3. Still in the "Attributes" window, click "General" tab where you can enter project-wide notes for the day (location, dates, operators, ect.).

3.4. ***Add new Reflectors:*** if necessary, you can add new reflectors by clicking "CALIBRATIONS" then right clicking "REFLECTOR" and selecting "New Reflector". Fill out the descriptors.

3.5. ***RiScan Pro/Scanner Units:*** default units are in "meters", but they can be changed per project requirements if desired. Go to "Tool" on top menu bar, click "Options", expand "General", go to "Units", and select desired units.

4. Scan Position Set Up

4.1. ***Scanner Orientation:*** click "Tool" then "Scanner Orientation" where scanner leveling can be checked. A window with a circular leveling tool will open. Manually correct (carefully) by adjusting tripod legs until the scanner is within at least 1° or less of level.

4.2. ***Create New Scan Position:*** right click on "SCANS", **or use "F6".** Rename scan position or leave default (ScanPos001). Under "Descriptions", enter general field and weather conditions at scan position. You can do this later as well by right clicking the scan position and selecting "Attributes".

4.3. ***Weather Details for Scanner:*** click "Tool" then "V-Line Atmospheric Settings". Enter data from the hand held (Kestrel) weather station for each scan position (barometric pressure, temperature, and humidity).

4.4. ***Camera Configuration:*** click "Tool" then "V-Line Camera Configuration" where you can manually adjust aperture and shutter speed for light conditions on site. Press camera icon to take a test photo. Adjust and repeat as necessary until the picture quality is appropriate. The camera can also be rotated (via "Turn by") to test other viewpoints that may have different lighting conditions. **Closing out the window will save the settings.**

5. Collecting Data

5.1. ***New Single Scan:*** right click on the new scan position you just created (e.g., ScanPos001) and select "New Single Scan" **or, highlight scan position and use "F7".** A window will open with several parameters; select "Panorama". This scan provides a full 360° field of view of the study area and allows you to find and label tie point targets.

5.2. ***Panorama Scan pre-sets:***

5.2.1. *Measurement Program:* Highly dependent on the PI's objectives and desired resolution. Also depends on the range to and reflectance of targets and field conditions. Typically "Long Range" mode is selected.

5.2.2. *Online view:* click "2D view"

5.2.3. *Resolution:* select an appropriate angular resolution, and press the "=" button to apply to both axes. This will adjust scan duration located on the right side of the window. Adjust resolution accordingly for project needs.

5.2.4. *Select:* "Download data to project"

5.2.5. *Select:* "Image Acquisition"

5.2.6. *Deselect:* "Erase data from Scanner" as a precaution.

5.2.7. *Select:* "Ok" to review settings, and make sure all people involved are aware and out of the way before scanning **and** image acquisition starts.

5.2.8. ***Scan!***

5.2.9. ***If scanner or tie point targets are moved or knocked into accidentally during the process, re-level targets and scanner following Steps 1.2.1 and 4.1. Then repeat from Step 5.1.***

6. Finding and Fine-Scanning Tie Points

6.1. ***Locate Tie Points:*** (this step can be started after the panorama scan is complete and while the digital camera is taking photos, if you are in a hurry). A 2D image of the panorama scan should load on RiScan. If not, expand the "Scan Position" and double click on the "panorama" file (pink icon, below "TOL (SOCS)"), select "view type" and 2D, click "reflectance" and "linear scaled", then "black and red color scale".

6.1.1. Set min/max values to -25 and 5 respectively. This should make reflector tie points stand out in red. Pan and zoom in and out so as to make sure you can find all tie points, and that they are tie points, not other highly reflective objects.

6.2. ***Add Tie Points:***

6.2.1. Zoom in and pan view as necessary so you can place your cursor on the tie point (does not need to be perfectly centered). Right click tie point, select "Create new tie point"

6.2.2. In new window, rename tie point if you wish, or just leave default names.

6.2.3. Select "reflector type", ignore "reflector size" and click "Ok".
6.2.4. If a tie point is not showing up clearly, make your best guess and create tie point.
6.2.5. Repeat for all tie points. Tie points are stored in "TPL (SOCS)" (Tie Point List-Scanner Own Coordinates).

6.3. ***Fine Scan Tie Points:***
6.3.1. In "SCANS", select "Scan Position" you are working on and open "TPL (SOCS)"
6.3.2. In window, confirm tie points are the correct type and quantity with at least. Edit if needed.
6.3.3. Select all tie points using Ctrl+A.
6.3.4. **Make sure no one or thing is blocking the laser**, then Click on the "Fine-scan Selected Tie Points" icon in menu bar of the TPL window. The scanner will instantly begin fine-scanning the tie point targets.

6.3.5. **Make sure scanning is finished before moving on.** Sometimes the scanner will pause to recalibrate and then continue scanning the targets. Read the dialogue threads at the bottom of the screen to see that scanning has finished and the scanner is not busy. Scanning is done when message thread reads "Saved and Verified" or "Scanning Finished". Fine scans will now appear in "TPL (SOCS)" under "Fine scan" column.
6.3.6. Under "TIEPOINTSCANS", preview (Pin on bottom left of screen) each individual scan to make sure tie points look good (Fig. 4).
6.3.6.1. Under "TPL SOCS" check that all tie points are at least nearly the correct sizes under the size column. This can be done during the scan process.
6.3.7. If a tie point image is oddly shaped (Fig. 5) or is not close to original size, re-scan by selecting only that tie point and click "Fine-scan tie points" again.

**Depending on what your specific project requires for data collection, or where you are in your workflow during the day, several options exist after you finish Step 6: "Fine scanning Tie Points". The chart below explains the workflow "Steps" to follow after Step 6 for different situations.

After 1st Scan/No Fine-Scan Needed	After 1st Scan/Fine-Scan Needed	After 2nd and subsequent scans/No Fine-Scan Needed	After 2nd and subsequent scans/ Fine-scan Needed
• Step 7 (Shutdown)	• Step 9 (High-Rez Area of Interest Scan) • Step 7 (Shutdown)	• Step 8 (Registration) • Step 7 (Shutdown)	• Step 8 (Registration) • Step 9 (High-Rez Area of Interest Scan) • Step 7 (Shutdown)

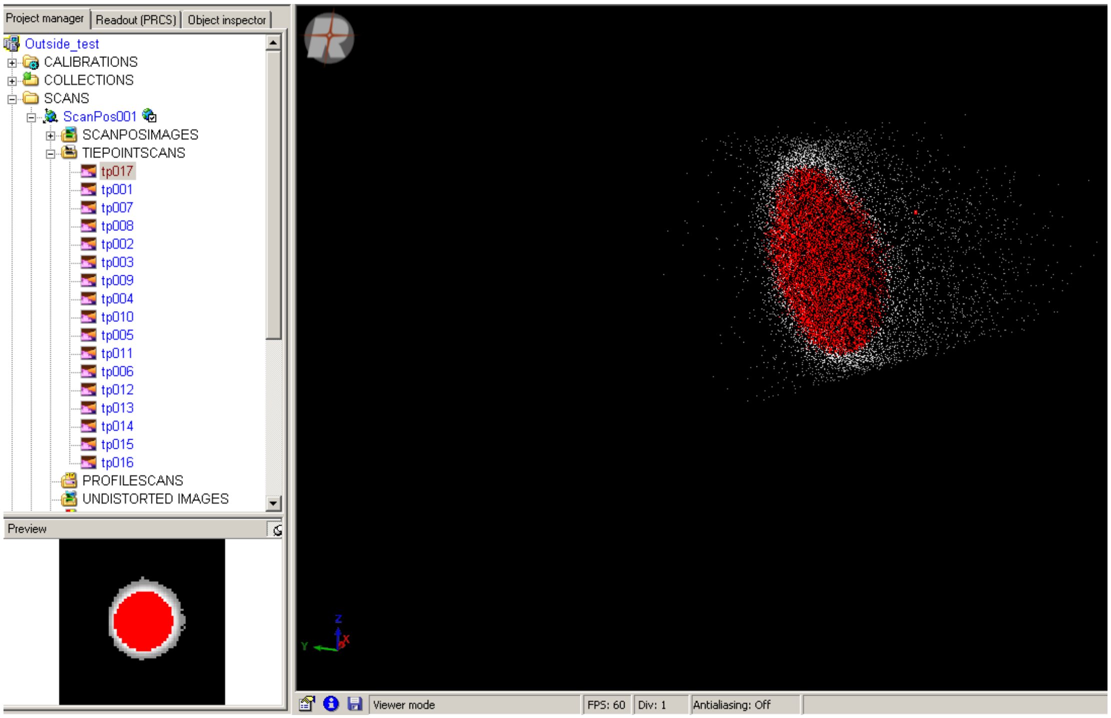


Figure 4. Screen shot of an example of a typical 5cm disc reflector (tie point) in 2D in the preview window, and 3D in the main working window. This is an example of a good image capture.

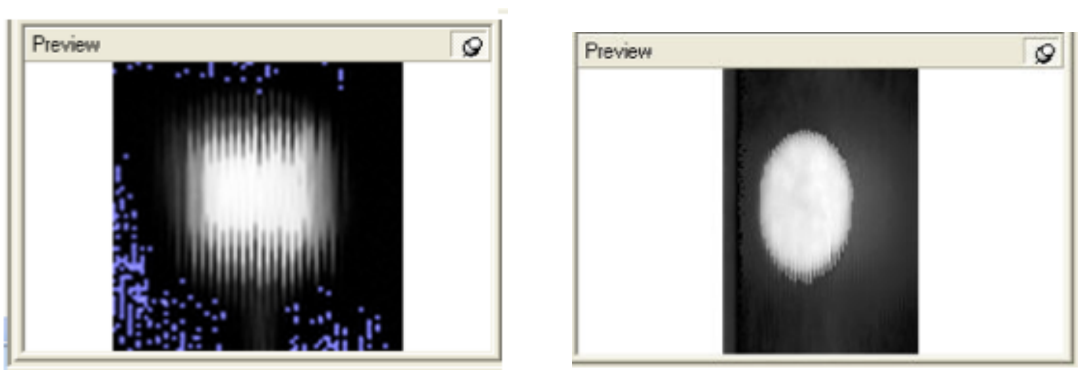


Figure 5. Here is a comparison between a bad tie point image (left) and a good tie point image (right) (Rigel USA, 2007).

7. Shutting Down and Moving Scanner

7.1. ***Park Scanner:*** when moving to the next scan position and returning to carrying case, open "Tool", select "V-line Remote Control", click "Park", followed by "Shutdown". Then:

(1) Don't shut down laptop, just close the lid.

(2) Disconnect the power cord and Ethernet cable from the scanner, then computer. Properly coil cables and place in their carrying case.

(3) Disconnect camera, **turn off power**, replace the lens cap, and place back in its carrying case.

(4) Disconnect scanner from tri-pod and place it properly in the carrying case. **Never transport scanner while still attached to tri-pod.**

7.2. ***Next Scan Position:*** **repeat steps 2 and 4 – 6 for each subsequent scan position followed by step 8-Registration and optional step 9. Then always finish scanning with step 7 - Shutting Down and Moving Scanner.**

8. Scan Registration

This step can only be performed once you have at least 2 scan positions. Typically, you will register your scans one after the other for quality assurance in the field After the second scan position is finished you will go through **Steps 8.1 and 8.2**, which only needs to be done once. From the 3rd scan position on, you will start at **Step 8.3**. Later, during post processing if needed, you can re-register the scans by unregistering all scans (using **Steps 8.1 and 8.2**) and choosing a scan position at or near the center of the project, which can help minimize any propagating error from the previous registration process when aligning your scans.

8.1. ****Unregister:*** this step is only performed once in the field, or if after scanning, you would like to reprocess and choose a different scan position (other than the first) to register all others scans to. Right click **each** scan position and click "unregister" so you can start registration with a clean slate.

8.2. ***Register Reference Scan:*** choose the scan position (e.g. ScanPos001) that you want to register the rest of the scans to (typically the first scan) by right clicking on that scan position and selecting "registered". A green globe will appear to the right of the scan position name.

8.3. ***Non-registered scan positions:*** after a scan position is finished double click on a non-registered scan position (e.g. ScanPos002), then open "TPL (SOCS)"

8.3.1. *Use:* Ctrl+A to select all tie points and click "Find corresponding points" on the window menu bar. There should be a minimum of 3-5 tie points in common.

8.3.2. *Check:* "Project coordinate system (control points only)"

8.3.3. *Check:* the registered scan position(s) (in this example "ScanPos001", but will always include all previous scans).

8.3.4. *Mode:* select "minimize error"

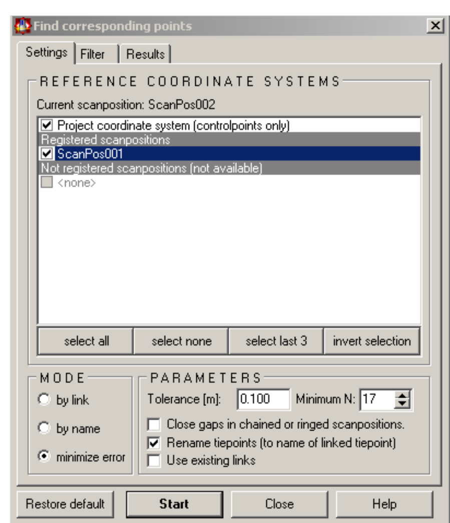
8.3.5. *Parameters:*

(1) Tolerance: 0.1 (for metric units)

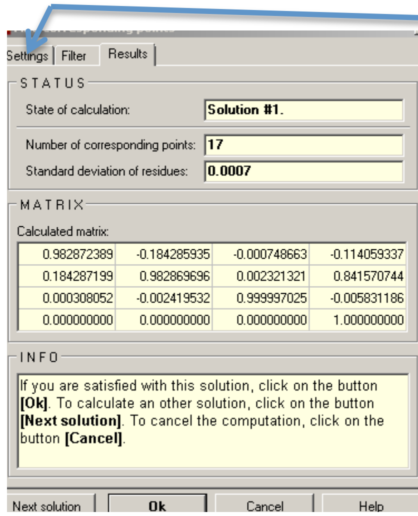
(2) Minimum # of Targets: 3-5

(3) Check: "Rename tie points"

(4) Click "Start"



8.3.6. *Standard Deviation:* should be no greater than 2 cm. If no solution is found or the SD is larger than 2 cm, click "Next Solution" **or** select "Settings" and *increase* the "tolerance" and *decrease* the "minimum # of targets", **but not below 3.**



8.3.7. If an acceptable SD solution is found, click "Ok", and proceed to **Step 8.3.9**

8.3.8. <u>If an acceptable solution still is not found, proceed to **Step 10** to inspect tie points to find if there is one that needs to be thrown out to obtain an acceptable Standard Deviation; thus the importance of having as many tie points as possible.</u>

8.3.9. **Registration is complete. Shutdown the scanner (Step 7) or proceed to Step 9 if you need a higher resolution scan of a specific area.** Repeat for each non-registered scan position. All new registered tie points will be listed in "TPL (PRCS)" under project tree directory**.**

9. High Resolution-Area of Interest Scan

<u>This is an optional step performed after each initial panorama scan and registration, per project requirements. If no fine scan is needed, skip to step 7. This step can be skipped all together if you take a high-resolution panorama scan initially.</u>

9.1. ***<u>Area of interest scan:</u>*** Under "SCANS" select desired "Scan Position", then right click the **panorama** scan and select "new single scan".

9.1.1. A window with a 2D view of the panorama scan will open to select appropriate parameters.

9.1.2. Pan and zoom into area of interest

9.1.3. Hold the "Alt" key while using the mouse; draw a box (from left to right) around the area of interest. Try to minimize the amount of sky included in your chosen area; just include the object you want to scan.

9.2. ***Fine Scan pre-sets:***

9.2.1. *Measurement Program:* depends on target range and reflectance, but adjust for high resolution and long scan duration. Typically "High Speed" mode is selected.

9.2.2. *Online view:* select "2D view"

9.2.3. *Enter Object distance:* use the range finder in the camera box and measure mean distance to the area of interest. This will help decide what resolution to use.

9.2.4. *Resolution:* select smaller point spacing than the previous panorama scans for increased resolution. This should result in longer scan duration. Press the "=" button to apply to both axes.

9.2.5. *Calculate Scan Time:* this will be affected by the resolution desired and time allocated to the field.

9.2.6. *Select:* "Download Data to Project"

9.2.7. *Image Acquisition:* typically you will *deselect* this option as it is not needed unless a significant amount of time has elapsed from when the panorama scan was taken and or lighting conditions have drastically changed.

9.2.8. *Deselect:* "Erase Data from Scanner"

9.2.9. *Select:* "Ok" to scan.

9.3. ***Shut down:*** follow **Step 7.**

10. Tie Point Convergence Inspection (trouble shooting)

10.1 ***Scans:*** open desired scan positions to inspect, then select a single scan (e.g. panorama scan) from each scan position and drag and drop them into the main working window.

10.2 ***Select:*** each time you drop a scan, select "3D View Type", "Reflectance Linear Scaled", and the same "Color" and min/max "Values" as before in step 6.1.1.

10.3 ***View:*** select "Bird's eye view" to start.

10.4 ***Click:*** "Object Inspector" tab.

10.5 ***Shift+Click:*** to select and highlight multiple "Scan Positions" that you want to inspect (under "Positions").

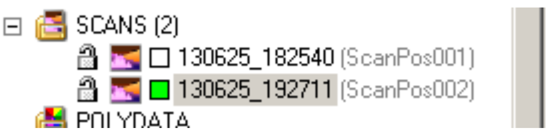
10.5.1. In the properties section open "Tie point Connections" (if you can't see the properties section then click on the "pin icon")

10.5.2. Check "Visible" and open "Mode" drop down menu to "TPL SOCS" not "TPL SOCS linked". The vectors from the scans should be visible.

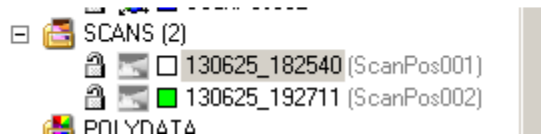
10.6 ***For better visualization:***

(1) Return to “Project Manager” open the reference (registered) scan position and drag and drop “TPL (SOCS) onto the main working window. Discs, labeled “PRCS” as project coordinates, will now appear at tie point locations where the converging accuracies of the vectors can be inspected.

(2) Go back to “Object Inspector” and under “Scans”, click on pink scan icons (screen shot below) to gray them out, which turns off the point clouds, making the discs and vectors easier to see (Fig 6 and 7).



Before



After

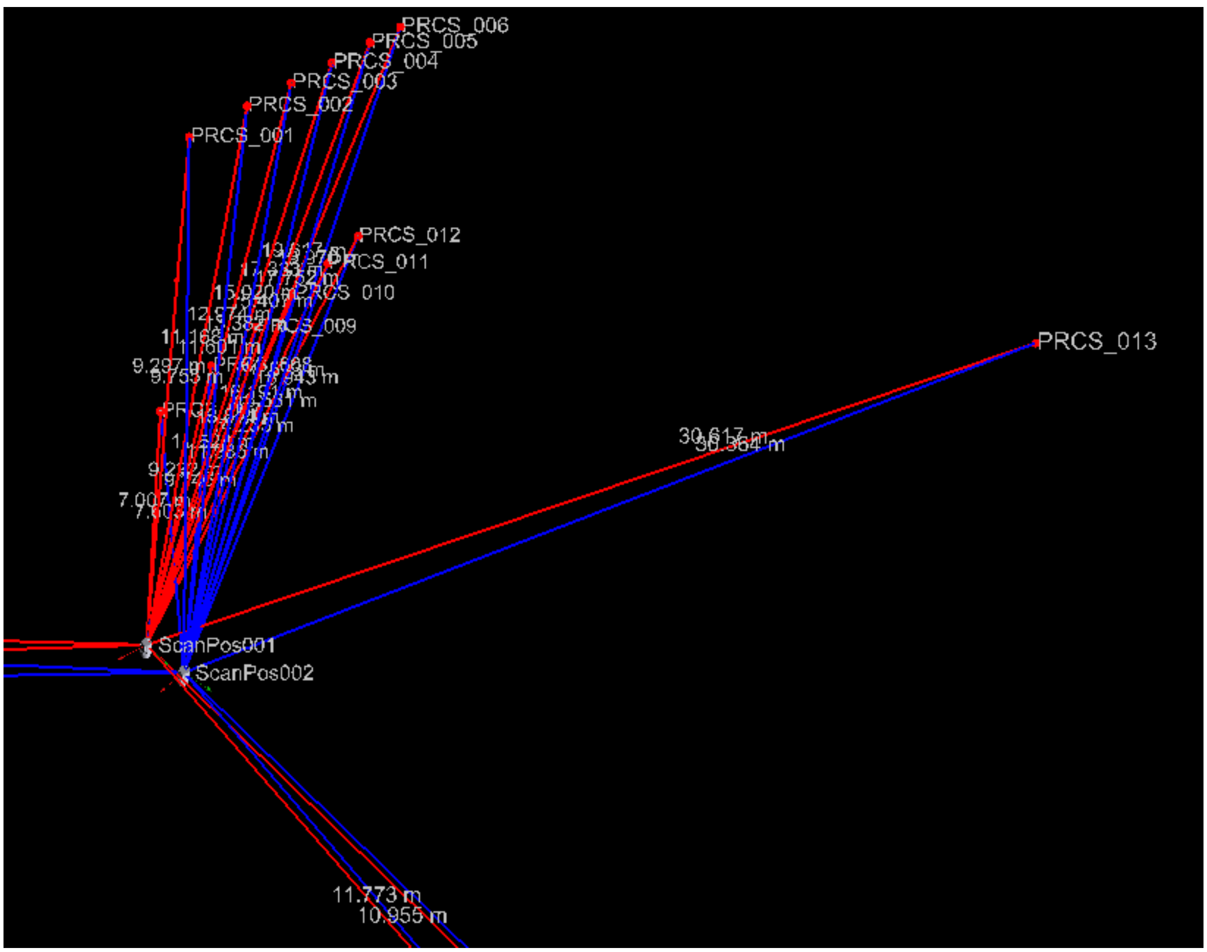
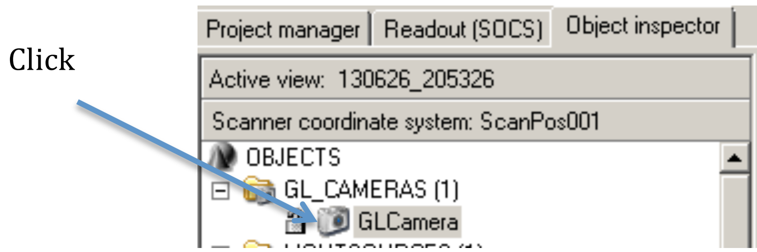
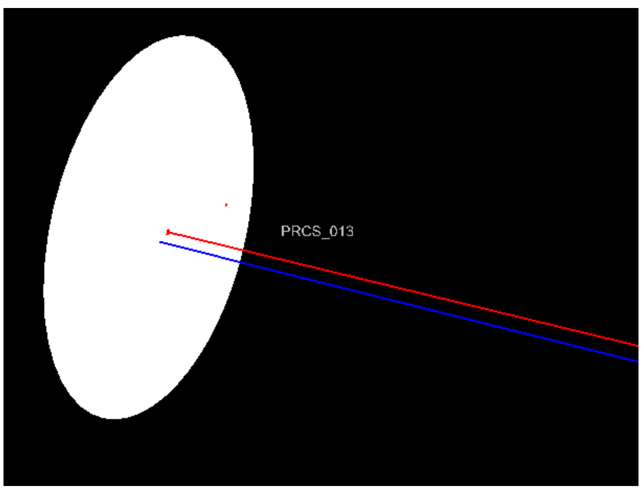


Figure 6. A screen shot of the vectors of Scan Positions 1 and 2 with the point cloud turned off. Note, tie points are now labeled as “PRCS” instead of “SOCS”.

(3) Turn on "Grid Tool" by going to "Object Inspector" and clicking on the "camera icon" (screen shot below) and zoom in to inspect tie points (Fig. 7) to find any problem ones where vectors don't merge within the 2 cm limit. If any are found, then they can be thrown out provided you still have the "bare minimum" of 3 in common between scan positions. **Then repeat Step 8.3.**





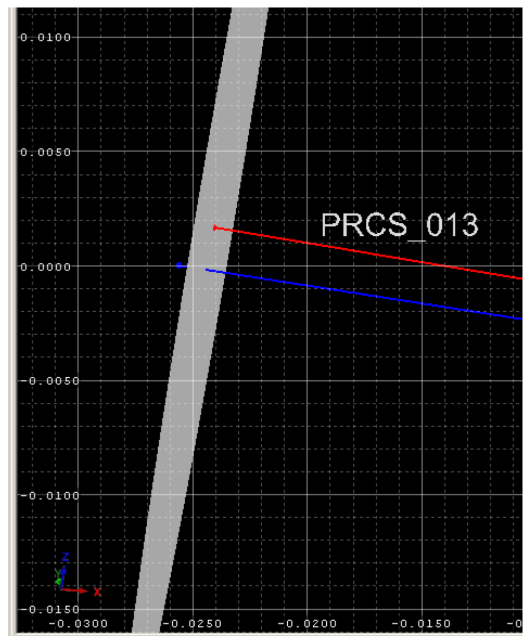


Figure 7. The left image shows two vectors intercepting the disc representing a tie point target with out the grid turned on. In the right image, after turning on the grid (metric units) and zooming in, it can be seen that this tie point has been successfully scanned as they are with in the 2cm tolerance registering only ~2mm apart.

10.9 ***Rescan:*** unfortunately, if all this does not work and you can not maintain at least 3 good tie points, you will need to repeat the scan. Recheck that tie point targets are set up correctly on their tripods and that they and the scanner are level.
Then proceed to **Step 5** and restart the data collection process.

General Trouble Shooting in the Field:

In order for the scanner to work properly, it is very important to follow the above set up sequences, specifically **Steps 2 – 4.** For example, if you power up the scanner before you power up the camera, the camera may not respond during **Step 4.4.** The best solution is to cycle through the system again. Go to "Tool", then "V-line Remote Control" and select "Restart". If this doesn't solve it, then reload RiScan Pro and power down the scanner and camera, and start the set up procedure again from the beginning. Ideally these problems will be discovered at the beginning of each scan position and RiScan Pro automatically saves all previous work, so nothing will be lost.

Other issues could occur if you proceed with another step before the scanner is actually finished processing its work from a previous step. The scanner sometimes pauses for a few minutes to process data and recalibrate before it starts up again to finish its job. <u>It is very important to read the Dialogue Box at the bottom of the screen to see where the scanner is in its workflow. It will tell you when it is finished with a job.</u> Jumping ahead to the next step before the scanner is finished can cause it to freeze up, thus causing you to reload the scanner and start over.

As a general housekeeping tip, a lot of windows will start to accumulate on the computer as you proceed through the workflow, which could bog down the system. We suggest closing out windows through out the workflow that you don't need open. Clicking on the small white "x" in the top right corner of the RiScan Pro screen, below the big red "X" can close these multiple screens out. **Do not click on the big red "X"**, unless you want to shutdown RiScan Pro. This should be reserved for the end of the day.

If any significant technical or software issues arise, contact UNAVCO or Riegl directly.

www.support@unavco.org

www.rieglusa.com/riegl-usa-support-services.html

End of the Day Wrap Up:

Once all data collection is complete, the data is automatically saved on the Tough Book, but it is highly recommended to bring a flash drive or external hard drive to make duplicate copies of your data. After all copies have been made, the last procedure in the workflow will be Step 7: Shutdown, followed by properly packing up all field equipment in their protective cases.

Appendix A
GPS

1. TLS GPS Methods

The most common GPS techniques used in TLS are Static (long occupation) and Fast Static (medium occupation). RTK (Real Time Kinematic) GPS (short occupation) is being developed as another option with newer Riegl Scanner models. The survey method chosen depends on the specific needs of the project and equipment availability. All are forms of differential GPS requiring a Base Station (permanent or temporary) within range and clear sky views for accurate and precise measurements.

GPS Basics: for quality georeferencing of TLS data using Differential GPS, you will need:

(1) Dual Frequency receivers.
(2) To collect data on at least 3 TLS targets in the scan area.
(3) Close proximity (short Base Lines) to a Base Station(s).
(4) A minimum of 4 satellites in the sky to track.
(5) Clear sky views and good satellite geometries to obtain a PDOP (Positional Dilution of Precision) as close to 1 as possible.

1.1. ***Static:*** is the traditional and most precise and accurate survey method used with TLS, capable of achieving centimeter to sub-centimeter vertical and horizontal resolution. It involves at least 3 antenna receivers configured in a triangular geometry on top of specific control targets within the project location. As with all differential GPS, a Base Station or Stations of known coordinates are needed. These can be permanent stations such as the CORS (Continuously Operating Reference Stations) Program, operated by NOAA's National Geodetic Survey; or portable base stations that you set up for the project over a known point. The more base stations involved, and the closer these base stations are to project receivers, a distance called a "Base Line" (a vector), the more accurate and precise the position solution of the receivers. A base line of <10km is ideal, but should not exceed more than 50km for precise and accurate results.

The price you pay for this level of accuracy is long occupation times up to 6-8 hrs. are required to obtain optimal position solutions (the longer the better, and can be for days and months as well depending on the project). Long occupation times allow for some leeway on base lines further away, especially if base stations are scarce in your study location and you did not bring a portable base station.

1.2. ***Fast Static:*** this method is virtually the same as static, but as the name implies, it can be done quicker if you are short on time. You can use one rover receiver and collect different positional points as you can move the rover around from tie point target to tie point target. Occupation times range from 20-30 minutes and improves work efficiency over Static surveys. Adding multiple rovers will increase work efficiency as well.

The down side is you will loose precision, as results will range from 1-2cm in the horizontal and 2-4cm in the vertical. Base lines are limited as well as you can be no more than 20km away from a base station for best results. Ideally you'd want to have a base line within 50m for better precision and accuracy, and that would most likely require the set up of a portable base station in the project area. If base lines are longer than 20km, the general rule is to collect one minute of data for every kilometer the base station is away. The longer data is collected, the better.

Both the Static and Fast Static methods require post processing of GPS data later, when you return from the field, before you can georeference your point clouds. In the United States, OPUS (Online Positioning User Service), provided free by NOAA's National Geodetic Survey (NGS), can be used to process Static and Fast Static GPS data. You need to upload your GPS (RINEX) files to OPUS that then references the data with the high-accuracy National Spatial Reference System (NSRS). In short duration, OPUS will email back accurate and consistent position solutions for your project. The website can found at: http://www.ngs.noaa.gov/OPUS/index.jsp

1.3. ***<u>RTK (Real Time Kinematic):</u>*** **R**eal **T**ime **K**inematic GPS is useful as it is quick and requires less equipment to carry to the field site than Static Surveys; but has been less common and practical in TLS surveys, until recently. It involves a (stationary) base station set up on site at the beginning of the project that collects data through out the day, which then provides a "real-time" correction via a radio link to a mobile receiver called a "rover unit". Therefore, occupation times can be seconds to minutes with no need for post processing. For the purposes of TLS, newer scanner models will be employing internal GPS, making the scanner itself the rover (section 1.3.1.).

Unlike post-processing surveys, RTK surveys need to be assigned to a specific type of datum and projection. RTK only transmits using a single L1 frequency that limits its baseline to within 10km. Precision and accuracy will not be like that of Static surveys, RTK will give a horizontal resolution of 1.5-5cm and a vertical of 2.5-10cm. The benefit of real time corrections via a radio link is also its limitation. RTK surveys need to have a clear line of site for radio communication between the base station and rover that can be limited by complex topography and dense vegetation. Proper planning before hand can limit these problems by placing the base station on the highest possible topographic feature in the area with a clear sky view, as well as clear lines of sight to tie point targets. Radio repeater towers have also been used to help with complex topography.

1.3.1. ***VZ-1000 and VZ-400 (CWU):*** if using either of these two machines from UNAVCO, they come stocked with an internal GPS, inclinometer, and compass, virtually eliminating the need for other GPS receivers, except a base station to provide differential corrections. They can be used in RTK survey or Fast Static Survey methods if desired, but are equally capable to operate using Static Survey Methods.

2. Basic GPS Set Up

2.1. Decide on you survey method from the above choices, but having a minimum of 3 GPS locations collecting data through out the day is needed.

2.2. Obtain the correct amount of equipment:

2.2.1. *Static:*

(1) Base station campaign kit, *if permanent stations are not available or within an acceptable range.*
(2) Three antenna/receiver kits.
(3) Power supplies for each GPS unit (Battery and Solar Panel Kits).
(4) Mounting hardware to attach antennas to tie point targets

2.2.2. *Fast Static:*

(1) Base station campaign kit, *if permanent stations are not available or within an acceptable range.*
(2) One antenna/receiver kit (multiple kits can speed up collection times, but not necessary).
(3) Power supplies for each GPS unit (Batter and Solar Panel Kits).
(4) Mounting hardware to attach antennas to tie point targets.

2.2.3. *RTK:*

(1) Base station campaign kit.
(2) RTK rover kit.
(3) Radio Antennas.
(4) Power supplies for each GPS unit

2.3. ***Tripod Set Up:*** It is very important that the tripod be as absolutely level as possible to provide a level target, to which, a level GPS antenna can be attached. The same goes for a portable base station tripod and antenna unit.

2.4. ***Antenna Set Up:*** Measure the vertical height of the base station *antenna reference point* (ARP) against the monuments, which they are recording upon. The ARP refers to the base of the antenna (Fig. 1). For GPS antennas atop tie point targets, measure the vertical offsets between the ARP and the tie point target center as well. The ARP vertical offsets will vary between different targets, so it should be carefully documented in your notes or sketch maps what types of targets are being used and their various offsets, as well as vertical heights from the ground. This information is needed for georeferencing your data later. A common target used by UNAVCO for TLS scanning is the "CNU" target (Fig. 2) and it has its offset stamped on the outer frame.

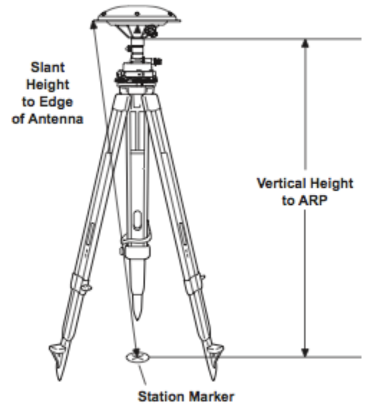


Figure 1. A diagram of a Base Station mounted over a benchmark of known coordinates. The vertical height difference between the ARP and the benchmark (station marker) is depicted on the right side. The top horizontal line represents the ARP (base of the antenna).

Figure 2. The UNACO "CNU" target pictured to the right contains a reflective surface that rotates within a machined aluminum frame. On the frame toward the bottom, the vertical offset can be seen as 11cm.

2.5. ***Power Source:*** properly connect GPS units to the battery source contained in their respective campaign kits. If two batteries are required, **always** connect in series. Many kits contain solar panels for extended campaign surveys.

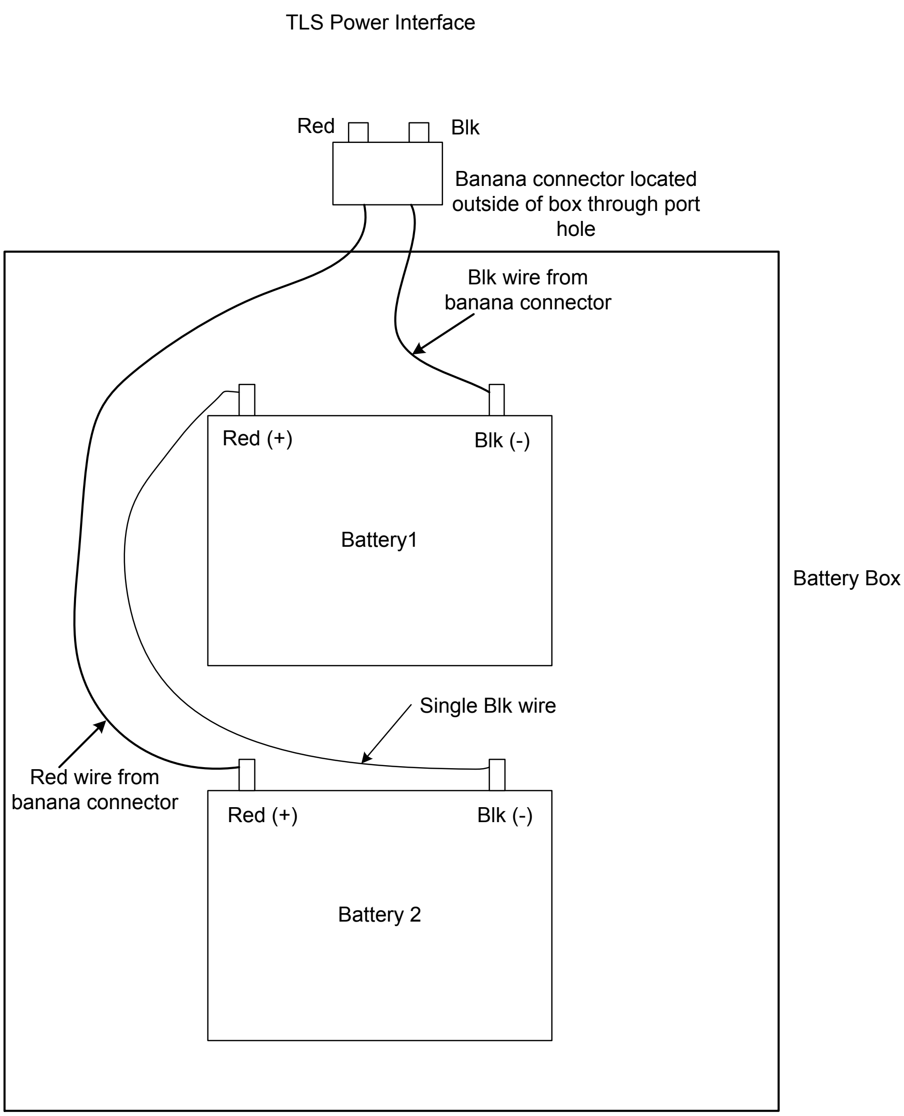
For more in depth workflows and manuals for individual GPS units, UNAVCO has comprehensive coverage on their "Knowledge Base" website:

Start your search here: http://facility.unavco.org/kb/

Specific helpful articles such as the "UNAVCO Campaign GPS/ GNSS Handbook":
http://facility.unavco.org/kb/categories/GNSS+Campaigns/

Typing in searches for "Topcon" and "Trimble Static Surveys" will pull up specific "How-to" manuals for these respective GPS instruments. Pre-reading and downloading this material to bring to the field is recommended as a reference.

Appendix B
Schematic for Battery Connection in Series



Appendix C
Visualizing Merged Scans

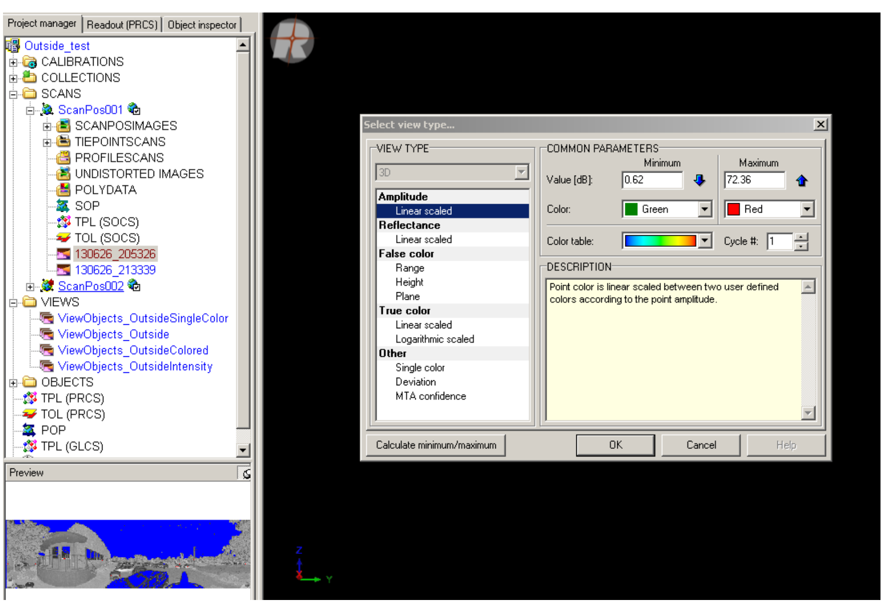
This step is merely a spot check to see if you covered everything you needed to scan and is optional if time allows. Sometimes it is not possible or practical in the field if you have a large project with a lot of data.

1. Once scans have been registered, they can be merged to form one unified point cloud in object view.

2. ***Create Object View:*** right click "View" and select "New Object View". Rename it or leave the default.

3. ***Scans:*** open "SCANS" and select the registered "scan position". Double click the single scan (e.g. panorama scan).

4. ***Select View Type:*** view type dialog box will open and make sure 3D view is selected. You will then have at least 3 choices to view the scan depending on your preference or situation:
   (1) *Intensity:*
      a) For "Z – series Scanners, select "Reflectance – Linear Scaled"
      b) For "VZ – series Scanners, select "Amplitude – Linear Scaled"
         i) *Select:* color range from "Color Table" (gray scale tends to work best).
         ii) *Select:* "Calculate minimum/maximum and click "Ok".
   (2) *Colored scan:* select "True Color – Linear Scaled" and click "Ok".
   (3) *Single Color scan:* select "Other – Single Color" and choose a color from "Data Color" drop down box.



5. The point cloud should be visible on screen. Now drag and drop any and all other necessary scans into the window selecting the same attributes. You now have a unified point cloud.

6. ***Save Data:*** Once you are done, you can save the "Object View" and it will be stored in "Views".

Appendix D
Georeferencing Point Clouds

1. Download Data from GPS Units

1.1. ***UNAVCO Knowledge Base:*** if you are not familiar with Topcon or Trimble GPS units and their download procedures, refer to UNAVCO's "Knowledge Base" website for manuals. Below is an abbreviated overview of the procedures for transferring between a Topcon GPS receiver and the Toughbook.

It is advised to take note of the vertical off-set from the GPS antenna ARP to the tie point target center in case errors arise with OPUS in **Step 2.

1.2. ***Connect GPS and Laptop:*** connect both units via an Ethernet cord that should be supplied with the equipment.

1.3. ***IP Address:*** if not already set up, enter IP Address: 192.168.1.3 and Subnet Mask: 255.255.255.0 to set up your communications between the GPS and the Toughbook.

1.4. ***Topcon software:*** using the **PC-CDU software** on the Toughbook, transfer files from the GPS to the Toughbook.

1.4.1. *IP Address:* 192.168.1.2
1.4.2. *Password:* TOPCON
1.4.3. *Create New File:* go to the file manager and create a new folder to download data.
1.4.4. *Highlight:* file(s) and click "Download".
1.4.5. *Finished:* select "Exit" and go to "File" and select "Disconnect".

1.5. ***Convert raw data files into RINEX files***: open **Topcon Link software** to begin the process. Note the file date/file name (contains the serial # of the GPS and date).

1.5.1. *Select*: "File", then select "Convert File". A two-sided window will appear.

1.5.1.1. *From:* under the left window you will browse for a singular GPS file and the "File Format" should be a "TPS" file.

1.5.1.2. *To:* under the right window, choose the destination for your converted file (we suggest the same file as the TPS format). Change "File Format" to a RINEX format.

1.5.2. *Select:* "Convert" to create the RINEX file. Open the file it was saved to and rename it to something distinguishable.

2. Loading to OPUS

2.1. ***OPUS Website:*** Online Positioning User Service
www.ngs.noaa.gov/OPUS/index.jsp

2.2. ***Loading Data:***

2.2.1. Upload a RINEX file (one at a time).
2.2.2. Enter vertical offset between the GPS and a reference point.
2.2.3. Select antenna type that was used
2.2.4. Enter your email address.

2.3. ***Return Email:*** when you receive the return file back from OPUS, save it in your emails and make an extra copy as a PDF so you have a duplicate.

3. Create a Control File

3.1. ***Text Editor:*** using any text editor, take the coordinates and elevations from each GPS OPUS solution and enter in the text file. OPUS provides a position in several coordinates systems. Which you choose is project specific, but in general, UNAVCO uses "Earth-centered Earth-fixed" coordinates. Start with a header titling the project, then lines indicating target #, X, Y, and Z (orthometric/elliptical height) on the same line for each GPS position (Fig 1). Then save the file in same folder as the rest of your project.

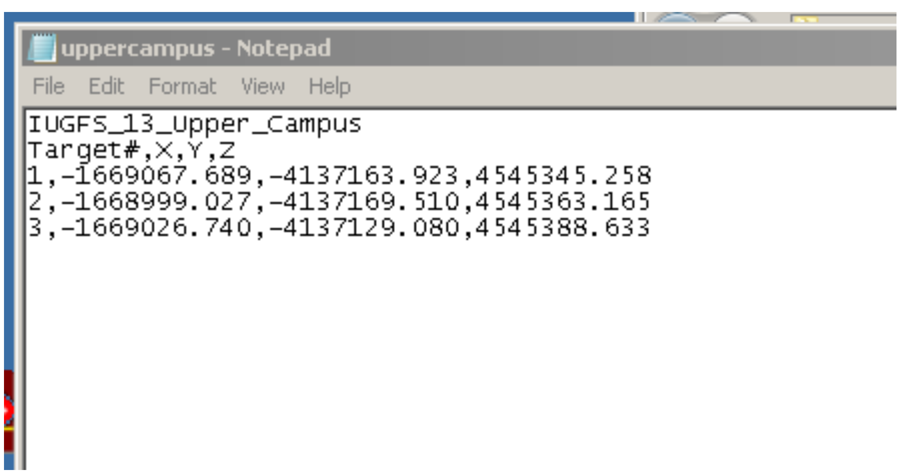
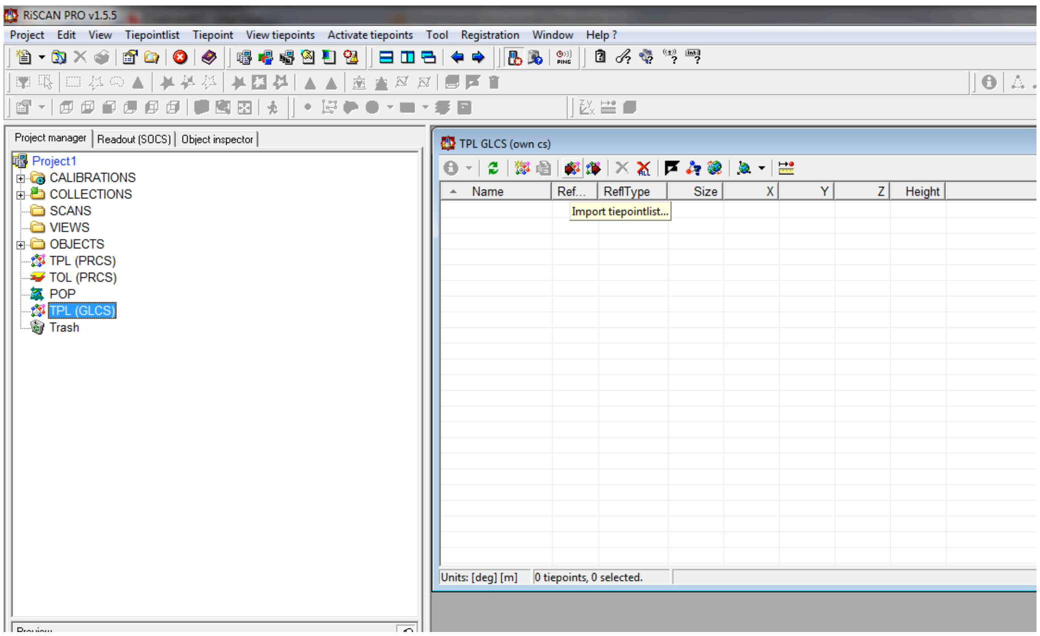


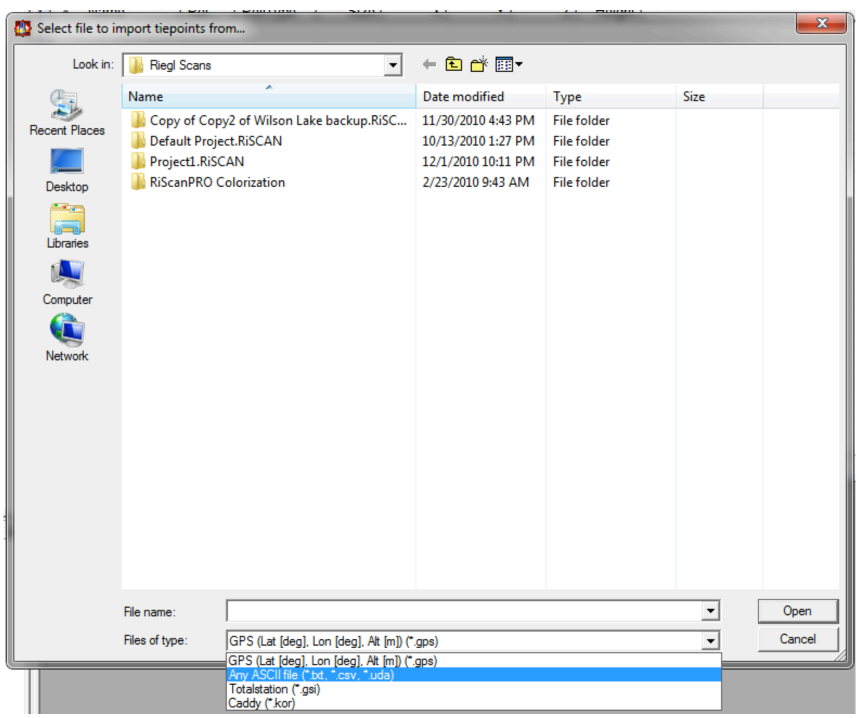
Figure 1. An example of how a control file should be formatted.

4. RiScan Pro

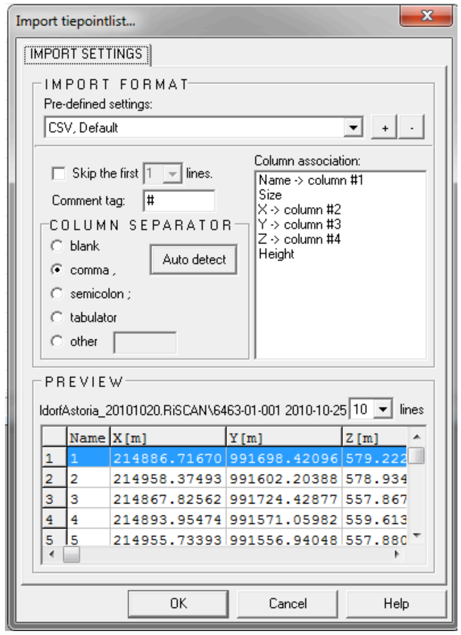
4.1. ***Open TPL GLCS:*** import the created "control file" using the "Import" icon.



4.2. ***Browse Control File:*** make sure you choose file type as an "ASCll" and navigate to the appropriate control file and click "Open".

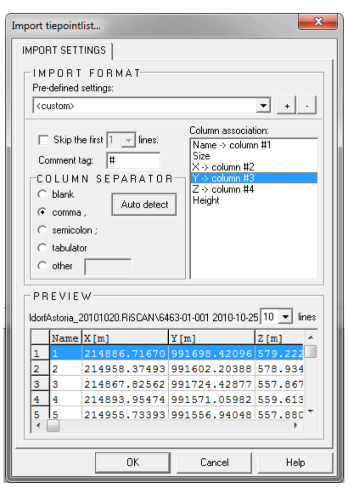


4.3. ***Define Units and Organization of Control Points:*** the following screen will open where you can organize the information from the control file. You can rearrange columns according to specific coordinate systems.

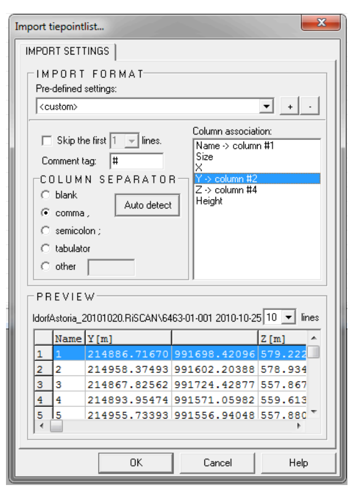


4.3.1. As you can see in the above image, RiScan Pro has assumed the column organization and units (meters), when looking at the associated "Column association" window and "Preview" window. These can be changed manually depending on the type of survey control you are using.

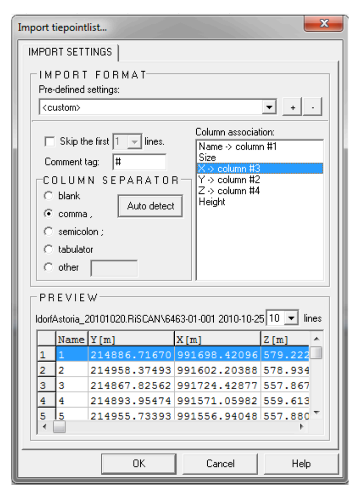
4.4. ***Reorganize Column Headers:*** to reorganize columns in the "Preview", simply click the attribute you want in the "Column Association" window, and drag it down to the appropriate header in the "Preview" window. The images below should help illustrate this.



"Y" is highlighted in "Column Association" window, and ready to be dragged down to the "Preview" window.

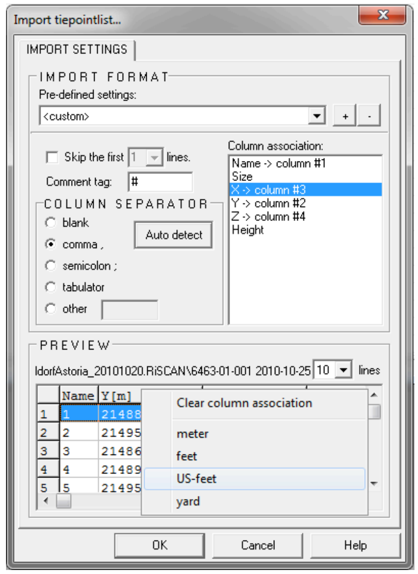


After "Y" is dropped into its new header, "X" disappears.

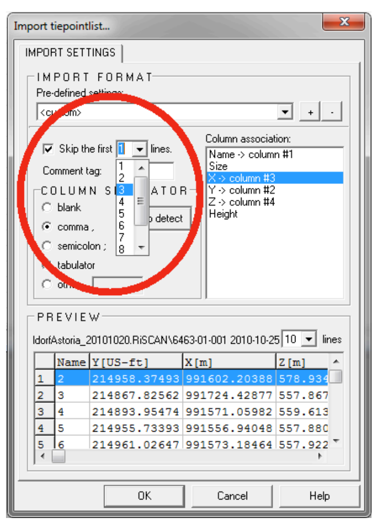


Next, highlight the empty "X" row and drag down to its new column and it will be reassigned.

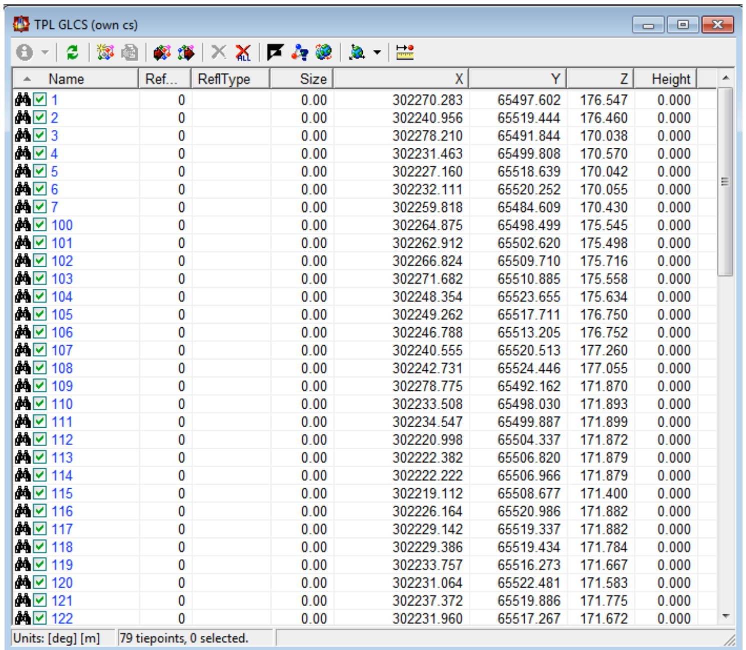
4.4.1. Define Units: in the "Preview" window, just right click on the column headers and chose the appropriate units.



4.4.2. Eliminate Headers: if your control file contains headers, they must be eliminated for the file to properly import. Use the "Skip the first xx# line" drop down and select the appropriate number of lines to skip without skipping your control points.



4.5. ***Import Control Points to GLCS:*** if everything is selected and adjusted correctly, click "OK" to import your control points. As the image below illustrates, you should have a nice table in your "GLCS" of your imported control points.

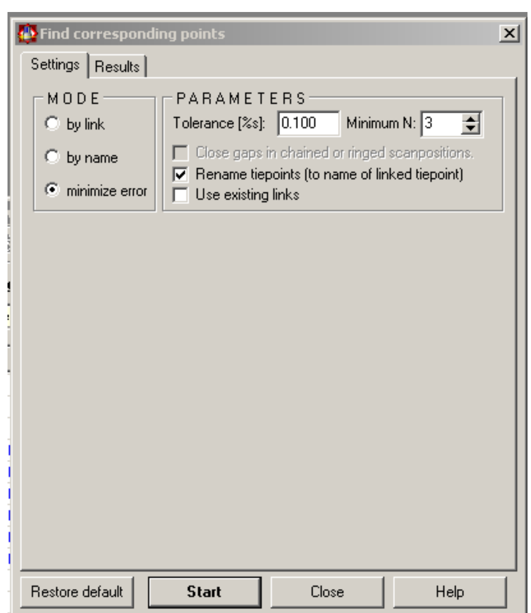

TPL GLCS (own cs)

Name	Ref...	ReflType	Size	X	Y	Z	Height
1	0		0.00	302270.283	65497.602	176.547	0.000
2	0		0.00	302240.956	65519.444	176.460	0.000
3	0		0.00	302278.210	65491.844	170.038	0.000
4	0		0.00	302231.463	65499.808	170.570	0.000
5	0		0.00	302227.160	65518.639	170.042	0.000
6	0		0.00	302232.111	65520.252	170.055	0.000
7	0		0.00	302259.818	65484.609	170.430	0.000
100	0		0.00	302264.875	65498.499	175.545	0.000
101	0		0.00	302262.912	65502.620	175.498	0.000
102	0		0.00	302266.824	65509.710	175.716	0.000
103	0		0.00	302271.682	65510.885	175.558	0.000
104	0		0.00	302248.354	65523.655	175.634	0.000
105	0		0.00	302249.262	65517.711	176.750	0.000
106	0		0.00	302246.788	65513.205	176.752	0.000
107	0		0.00	302240.555	65520.513	177.260	0.000
108	0		0.00	302242.731	65524.446	177.055	0.000
109	0		0.00	302278.775	65492.162	171.870	0.000
110	0		0.00	302233.508	65498.030	171.893	0.000
111	0		0.00	302234.547	65499.887	171.899	0.000
112	0		0.00	302220.998	65504.337	171.872	0.000
113	0		0.00	302222.382	65506.820	171.879	0.000
114	0		0.00	302222.222	65506.966	171.879	0.000
115	0		0.00	302219.112	65508.677	171.400	0.000
116	0		0.00	302226.164	65520.986	171.882	0.000
117	0		0.00	302229.142	65519.337	171.882	0.000
118	0		0.00	302229.386	65519.434	171.784	0.000
119	0		0.00	302233.757	65516.273	171.667	0.000
120	0		0.00	302231.064	65522.481	171.583	0.000
121	0		0.00	302237.372	65519.886	171.775	0.000
122	0		0.00	302231.960	65517.267	171.672	0.000

Units: [deg] [m] 79 tiepoints, 0 selected.

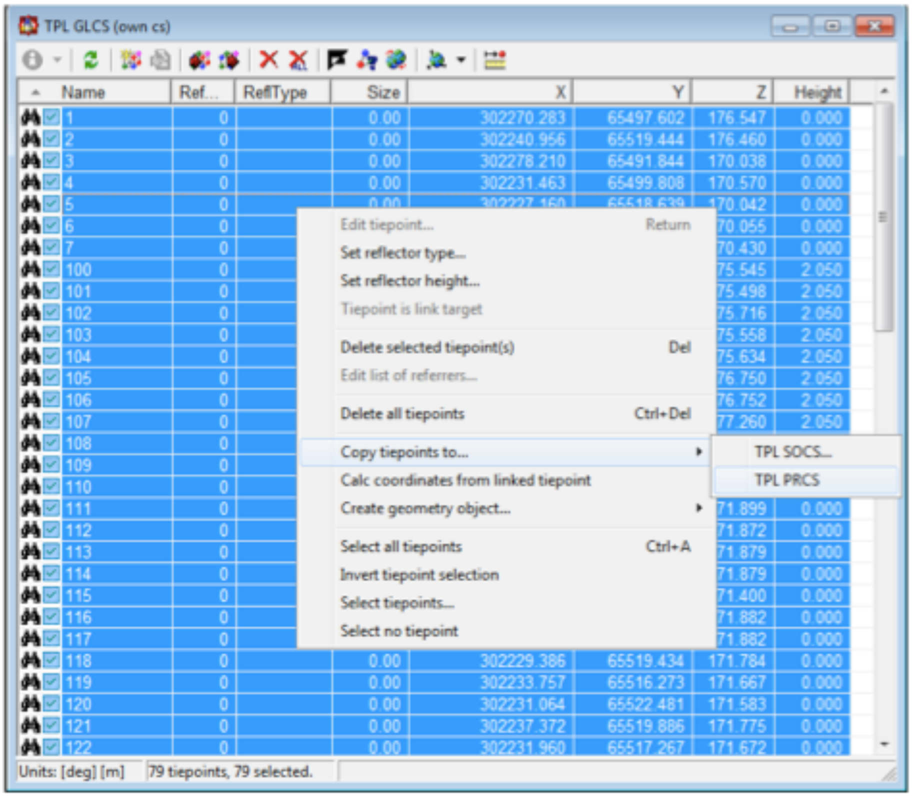
4.6. ***Registration of Scan Data:*** two options exist for registration: if the <u>total size of the project area</u> is within the scanner range, use "Small Area", or if outside of the maximum range of the scanner, use "Large Area".

4.6.1. *Small Area:* if the scans have already been acquired and registered relatively, a simple registration of the "PRCS" to the "GLCS" is all that is needed to fully georeference these scans. To do so, open "TPL PRCS" and select the "Find Corresponding Points" button. A similar dialogue box as in **Step 8.3** in the Field Operation Manual will appear (screen shot below). Only chose the number of targets that contain GPS antennas for the "Minimum N". Click "Start" and the entire project will be registered 'en masse' using "PRCS" points (accumulated by common reference between two scan positions). You are now finished.

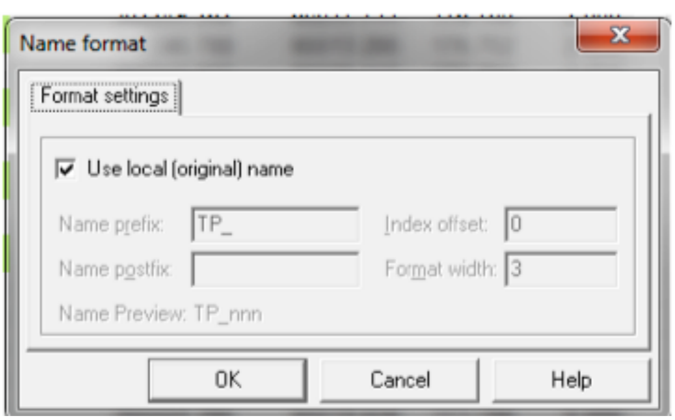


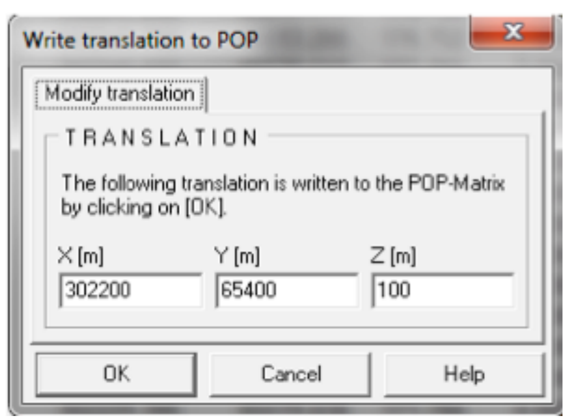
4.6.2. *Large Area:*

4.6.2.1. <u>Copy all GLCS to PRCS:</u> open “TPL GLCS” and select all (Ctrl+A), next right click on table and scroll to “Copy Tie points to…” and select “TPL PRCS” (screen shot below).



4.6.2.2. <u>Name Format and Write Translation to POP</u>: you should be prompted with the following windows in sequential order…



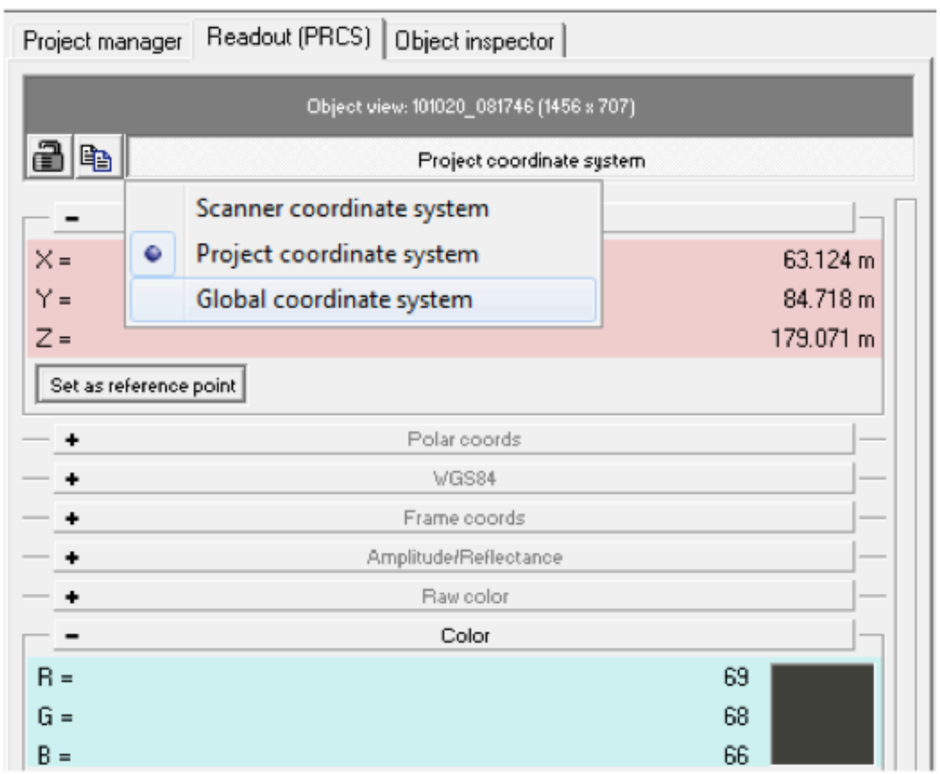


The first window allows you to rename all the control points as they are copied into "PRCS", but this is not necessary.

The second window displays the truncation matrix, which will be applied to every coordinate. This means that every point "entering" into the project will be reduced by these values. No need to worry, as these exact values will be added to every single point that is exported from the project as well, such as LAS files, ASCll files, ect.

4.6.2.3. Registration: you can now register any scan position directly to the "PRCS" by using "Find Corresponding Points" at each scan position. Once the scan position has been registered to the "PRCS", it is, by the link, registered to the "GLCS" and therefore tied to real-world coordinates.

4.6.2.4. View Coordinates in 3D: pull up the "Read Out" tool next to "Project Manager" and change the coordinate system to "GLCS" by clicking on the current coordinate system at the top. Click "Project Coordinate System" and a drop down menu will be displayed. Select "Global coordinate system" and run your mouse over the scan data in the 3D or 2D window. All applicable values for a point, which the mouse hovers over, will be populated in this "Readout" view.



Appendix E
Colorizing and Aligning Scans with Digital Photos

1. ***For Each Scan Position:*** expand "SCANPOSIMAGES" and start by double clicking on the first scan image. You will repeat these steps for every scan image in each scan position file. But only work on one Scan Position at a time.

2. ***Image Navigator:*** click on the "Image Navigator" icon on the top menu bar to reveal arrows on the perimeter of the image to allow easy navigation from one image to the next.

3. ***Revealing Image Tie Points and PRCS:*** this can be done by pressing Ctrl+1 and Ctrl+2 respectively. Cross hairs with the PRCS labels should appear near your tie point targets. They will most likely not be centered on you targets…yet. This is because of the parallax between the scanner and the camera.

Figure 1. Screen shot of a scan image displaying the PRCS that should be floating near tie point targets.

4. ***Label Targets with Tie Points:*** zoom in on the center of the target or control point, and click as close to perfect center as possible. A blue cross-hair marker will appear. Without moving the mouse, right-click and select "Add point to TPL". A window will appear, and click "OK". You do not need to name or define the type of target in the image (Fig. 2). Proceed with this process for every target in each scan image of one scan position.

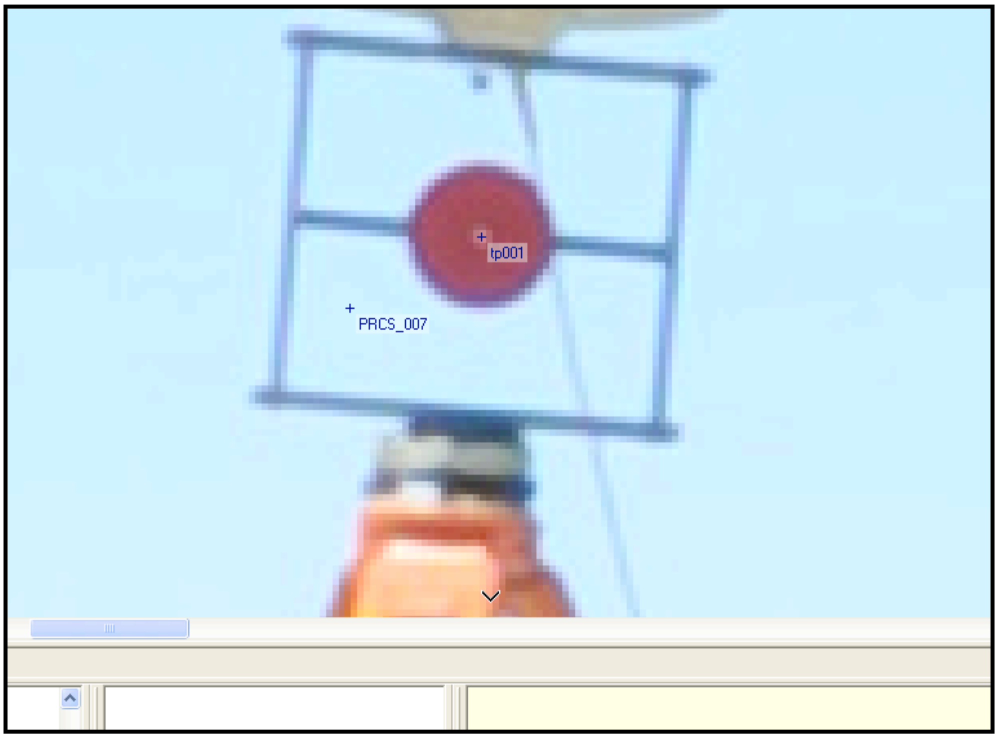


Figure 2. Each target in all images should have a project-defined point (PRCS) and a user-defined point (tp001).

5. ***Auto Link:*** next, link the two points once all tie points have been labeled in the image. Right click anywhere on the image and select "Auto Linker". You will then be prompted to choose a pixel search radius for the software (Fig. 3). If the range is too small, the points will not link. A good search range is between 10-120 pixels. There may be cases where you'll need to enlarge the search radius to link the points. When linked, the two points will turn from blue to red (Fig. 3).

Figure 3. Linking two points using Auto Linker. Select an appropriate search radius and the points should turn from blue to red when linked.

6. Continue on to the next image by clicking on the right or left arrow keys on the perimeter of the image and repeat Steps 4 and 5. If for some reason, you loose the PRCS crosshairs, just press "Ctrl+2" again, but pressing it the first time should apply the PRCS to all images. As a reminder, "Ctrl+1" will reveal the tie points you create.

7. ***New Camera Mounting Calibration:*** after tie points have been created and linked for every image, a new camera mounting calibration for each Scan Position must be created.

   7.1. *Export:* expand the "CALIBRATIONS" folder at the top of "Project Manager". Next expand the "MOUNTING" folder. Double click on the existing camera calibration file that will open a window displaying the current camera calibration matrix (Fig. 4). Right click in the matrix window and click "Export". Save to the project file. This will only need to be completed once per project. Use the file for all scan positions.

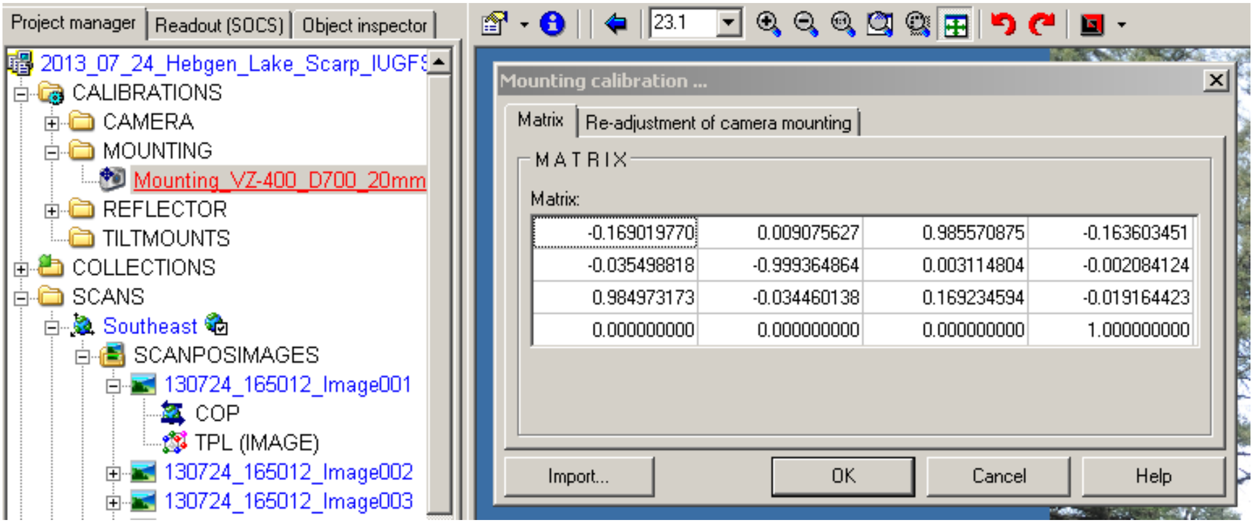


Figure 4. Image showing the Mounting Calibration Matrix to export.

7.2. *New Mounting:* right click on the "MOUNTING" folder and select "New Mounting". A new matrix window will appear, and <u>then right click on the window</u> and select "Import". Navigate to the saved original calibration matrix and load the file and click "OK". It will serve as a staring point for the new calibration.

7.3. *Rename:* right click and rename the new mounting file you just created, preferably to match the Scan Position that it belongs to.

7.4. *Assign to Scan Images:* right click on the renamed mounting file and select "Assign to Scan Images". A window will appear (Fig 5), select "Filter By Scan Position" and only select the Scan Position that you are working on. Click "OK" and the window will disappear.

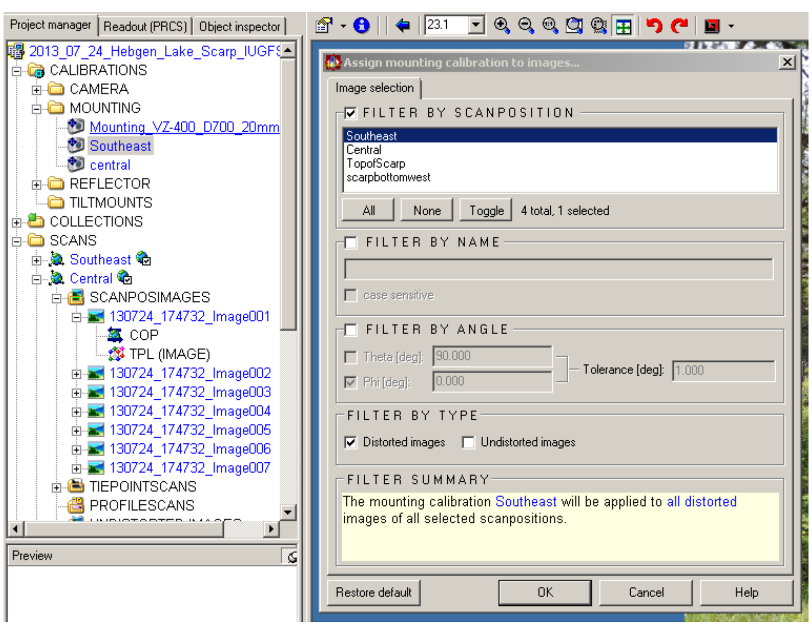


Figure 5. Choose the one scan position you are working on.

7.5. *Re-adjustment of Camera Mounting:* double click on the new camera-mounting file just created (and renamed) and the matrix window will reappear. Click on "Re-adjustment of Camera Mounting". Under "Setting" → "Calculation mode", select "modify rotation and translation" in the drop-down menu (Fig. 6).

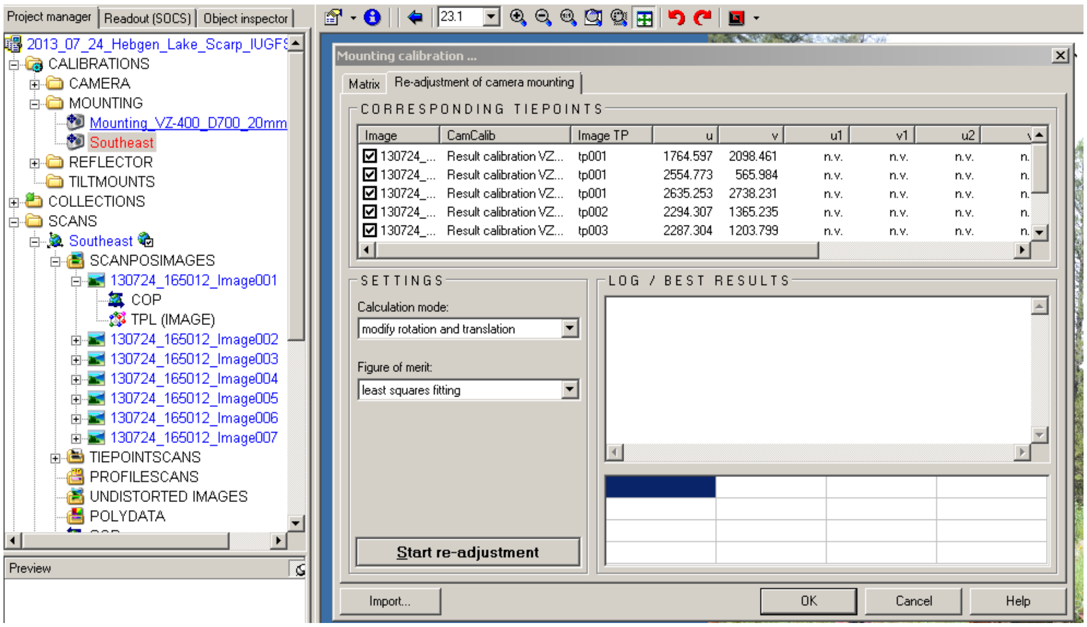


Figure 6. Window displaying the camera mounting re-adjustment parameters.

7.6. *Click:* "Start re-adjustment" and the software will calculate the new calibration. In the "Log/Best Results" window, it will display the current and now new adjusted pixel distances between the "PRCS" and tie points. Click "OK" to close window.

7.7. *New Calibration:* the "PRCS" will now be much closer to center then previously before and you must toggle "Ctrl+2" and zoom in on targets to see the adjustments (Fig. 6).

7.8. ***Repeat Step 7 for every Scan Position.***

Figure 6. PRCS and tie points are now closer together.

8. ***<u>Colorize Scans:</u>*** The scans in each Scan Position can now be colorized. Right click on a scan (e.g. a panorama scan you took) and select “Color from images”. The software will automatically select all the images from that scan position. Click “OK” to start colorizing; it will take a few minutes.

8.1. *View Colorized Scan:* double click, or drag and drop scan into work window. Click “3D” under “View Type” and select “True color” → “Linear Scaled”. Click “OK” to view a 3D, photo-realistic scan.

8.2. *Merge Colorized Scans:* if you desire, you can now create a new “Object View” of all colorized scans for a full colorized 3D image by following the steps in Appendix C and picking chose (2) in Step 4.