Ground-Based Geomatic Surveys at the BGS - A Manual for Basic Data Collection & Processing (2015)

GSF & LUPD Programme

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BRITISH GEOLOGICAL SURVEY

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Front cover

Riegl VZ-1000 & Leica Viva GNSS, Virkisjokull, Iceland.

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Contents

1 Introduction

Geomatics is the discipline of electronically gathering, storing, processing and delivering spatially related digital information. This broad term applies both to science and technology, and integrates the more specific disciplines and technologies of geodesy, surveying, mapping, positioning, navigation, cartography, remote sensing, photogrammetry and geographic information systems.

The British Geological Survey (**BGS**) has been using ground-based geomatics techniques for a variety of geoscientific applications since 2000. The importance of geomatics data acquisition and monitoring capabilities to the BGS has been highlighted in particular, but not exclusively, with respect to geoscience priorities linked to Integrated Environmental Modelling (BGS–Emerging strategy 2014-2020, Peach, 2012) and the need for enabling technologies to improve capability in 3D data capture, analysis, modelling and visualisation (BGS Top Geoscience Priorities, Peach, *et. al.*, 2012). BGS will continue to harness new technology to instrument the earth (Gateway to the Earth, Patterson & Ludden, 2014).

The discipline of geomatics continues to be one of the fastest expanding global markets. Ground-based geomatics is driven by technology and, at present, there is a huge demand for land, hydrographic and engineering surveyors who are able to fully utilise this technology. This is due to a high media profile, the changing nature of mapping and spatial data management worldwide and the growth in EU and national governments' spatial data agendas and legislation. As the underpinning information provider of the land and property lifecycle, geomatics is of fundamental importance to society.

The most common geomatics application in BGS uses a mobile Light Detection and Ranging (**LiDAR**) scanner, a Global Navigation Satellite System (**GNSS**) and a Geographic Information System (**GIS**) in order to obtain a terrestrial version of an airborne LiDAR survey and create a 3D model. Combining a terrestrial LiDAR scanner with a high-resolution digital camera and a high-precision differential GNSS enables coloured point-clouds, textured triangulated surfaces, or orthophotos with depth information to be accurately geo-referenced and captured. The relative distance, elevation angle and azimuthal angle between the laser and the subject are measured in each scan and, once processed, a 3D surface model can be generated. From the 3D models created a variety of products have been derived including digital elevation models (**DEM**), virtual outcrop models (**VOM**), cross-sections, area and volume calculations, 3D photo-realistic video 'fly-throughs', discontinuity maps, stratigraphic facies profiles, attributed 3D reservoir models, fossil assemblage maps, surface deformation feature recognition layers, soil erosion maps, cave surveys and change models. BGS also has the ability to produce high-resolution 3D photo-realistic scans of fossils in order to preserve the fossil record. Terrestrial LiDAR Scanning (TLS) allows geological outcrops to be digitally captured with unprecedented resolution and accuracy (Buckley *et. al.*, 2007).

The BGS geomatics capabilities have been utilised in a variety of scientific studies such as the monitoring of actively growing volcanic lava domes and rapidly retreating glaciers; coastal erosion and platform evolution; inland and coastal landslide modelling; mapping of geological structures and fault boundaries; rock stability and subsidence feature analysis; and geo-conservation (Jones, 2014b). These capabilities can be utilised alongside airborne LiDAR and other Remote Sensing techniques in order to provide a range of complimentary applications.

Outside the BGS Terrestrial LiDAR Systems are used for close-range, high-accuracy applications such as bridge and dam monitoring, architectural restoration, crime and accident scene analysis, landslide and erosion mapping, forest canopy and biomass measurements, mobile mapping systems, adaptive cruise control systems, manufacturing, and military applications.

Utilisation of the BGS geomatics capability has steadily increased since its initial introduction in 2000. However, operational and data-handling procedures are still undertaken on a relatively ‘informal’ or unstructured basis, and staff expertise in these techniques remains limited. In addition, developments in modern laser technology have hugely increased the amount of spatial data acquisition. This has repercussions for increased computing power and state-of-the-art software for processing this data, and the need to address the important issues of storage, archiving, access and delivery with respect to these important and unique digital datasets on a corporate basis.

This manual has been produced in order to enhance the ‘Ground-based Geomatics’ basic training course, for staff that require the use of Terrestrial Laser Scanning (TLS) and Global Navigation Satellite System (GNSS) equipment in order to carry out ground-based geomatic surveys. It gives an overview of the equipment used in these techniques, a brief outline into the basic principles of GNSS and TLS techniques, and provides a basic step-by-step guide to their initial set-up procedures.

This manual also provides an in-depth, comprehensive, guide in dealing with the data that is generated by these systems. Step-by-step procedures are given for downloading the data from all the systems, including any peripherals required, a basic guide to the processing of this downloaded data is also provided, along with a discussion about the various software programmes available in BGS for data visualisation and interrogation.

NOTE: This is a Guide to the most commonly used applications only.

2 Overview of Equipment

The BGS uses Riegl and Faro terrestrial LiDAR scanners because of their flexibility, range and portability. Each scanner also has a rugged-style laptop associated with it.

- Riegl LPM-2K LiDAR system comprising:
  Long-Range scanner, scanning up to 2500m with an accuracy of ±50mm and a measurement rate of 4 meas./sec.
  Panasonic CF-29 Toughbook (No Camera)
  2 x 12 volt Batteries (Black) & Charger, Tripod and Tribrach
- Riegl LPM-i800HA LiDAR system comprising:
  Medium-Range scanner, scanning up to 800m with an accuracy of ±15mm and a measurement rate of 1000 meas./sec.
  Panasonic CF-19 Toughbook and Canon 450D Camera
  2 x 12 volt Batteries (Yellow) & Charger, Tripod and Tribrach
- Riegl VZ-1000 LiDAR system comprising:
  Medium to Long-Range scanner, scanning up to 1400m with an accuracy of ±8mm and a measurement rate of 122000 meas./sec.
  Getac V200 Laptop and Nikon D700 Camera
  Internal and external 12 volt Battery & Charger, Tripod and Tribrach
- Faro Focus 3D X-330 LiDAR system comprising:
  Short-Range scanner, scanning up to 300m with an accuracy of ±2mm and a measurement rate of 997000 meas./sec.
  Internal Camera, Battery and Charger, Tripod and Tribrach

The BGS has a range of Leica GNSS which can be utilised for a range of applications; acting as base-station for airborne surveys, differential positioning of boreholes, kinematic surveys.

- GS50 GIS system comprising:
  12-channel L1 GPS/GIS receiver, with 30cm 'post-processed' accuracy
  Camcorder-style Batteries and Charger
- 2 x System 500 each comprising:
  12-channel L1, L2 GNSS receiver, with 20mm 'RTK' and 10mm 'post-processed' accuracy
  Tripod and Tribrach, Camcorder-style Batteries and Charger
- 2 x System 1200 (SmartRover) each comprising:
  12-channel L1, L2, SBAS GNSS receiver, with 20mm 'RTK' and 10mm 'post-processed' accuracy
  Tripod and Tribrach, Camcorder-style Batteries and Charger
- 2 x GS15 (Viva) systems each comprising:
  120-channel L1, L2, L2C, L5, GLONASS, Galileo, Beidou, SBAS GNSS receiver, with 10mm 'RTK' and 3.5mm 'post-processed' accuracy
  Tripod and Tribrach, Camcorder-style Batteries and Charger
- GS08 Plus system comprising:
  120-channel L1, L2, L2C, L5, GLONASS, Galileo, Beidou, SBAS GNSS receiver, with 20mm 'RTK' and 10mm 'post-processed' accuracy
  Tripod and Tribrach, Camcorder-style Batteries and Charger
- 2 x GS14 systems each comprising:
  120-channel L1, L2, L2C, L5, GLONASS, Galileo, Beidou, SBAS GNSS receiver, with 8mm 'RTK' and 3mm 'post-processed' accuracy and SmartCheck
  Tripod and Tribrach, Camcorder-style Batteries and Charger
- 2 x GR10 (Base Station) systems comprising:
  500-channel L1, L2, L2C, L5, GLONASS, Galileo, Beidou, SBAS GNSS receiver, with 15mm 'Fixed RTK' accuracy
- 6 x GS10 (Single Frequency)systems each comprising:
  120-channel L1, L2, L2C, L5, GLONASS, Galileo, Beidou, SBAS GNSS receiver, with 15mm 'Single Baseline' accuracy (Red = avilable to add-on)

The BGS also has a range of other survey equipment available.

- Leica TCR1205 Theodolite Positioning System (TPS)
  Total station with 1800m range and 5" (1.5 mgon) accuracy
- 3 x Leica Electronic Level
  Electronic Distance Measurement (EDM) device with 50m range and 2mm accuracy
- 2 x Leica Disto Laser Distance Measure
  Digital laser distance measurement device with 60m range and 1.5mm accuracy
- Laser Technology Inc. TruPulse 200L Laser Range Finder with 1750 m (1000 m non-reflective) range and ±1 m accuracy
- Tape Measures (various lengths)
- Safety Equipment:
  Mobile Phones, 2-Way Radios, High Visibility Vests & Hard Hats, Steel Toe-capped Boots/Wellingtons & Waterproofs, Trolley

The BGS has a number of high-specification PC's capable of handling the acquired digital data, including a dedicated data processing PC (WSB, Upper Ground Floor – N). Software to process and output the acquired survey data is listed below. With the exception of Virtalis GeoVisionary and Esri ArcGIS, all these proprietary processing and visualisation software packages fall under single user license restrictions, and as such are either loaded onto dedicated PC's or controlled by 'dongle' technology.

- Riegl RiScanPro (Acquisition & processing VZ scanner data)
- Riegl RiProfile (Acquisition & processing LPM scanner data)
- Faro Scene (Acquisition & processing X-330 scanner data)
- Leica Geo-Office (Post-processing GNSS data)
- Maptek I-Site Studio (Point-cloud processing)
- Golden Software Surfer (Gridding scanner data)
- Innovmetric Polyworks (Change models & cross-sections)
- Bentley Pointools (Visualisation of point-cloud data)
- Paradigm GOCAD (Integration with other surfaces e.g. GPR)
- Applied Imagery Quick Terrain Modeler (3D model creation)
- Esri ArcGIS (2D mapping and visualisation)
- Virtalis GeoVisionary (3D mapping and visualisation)
- Split-FX (Rock-fracture analysis)

3 Principles of Laser Range Finding

Riegl Terrestrial Laser Measuring Systems are designed for the automatic and manual medium-to-long range capture of digital data for terrain modeling. The LPM scanning system (Figure 1) comprises a laser distance-measuring device mounted on a Pan and Tilt mechanism that rotates 360 degrees around the mounting axis and scans 150 degrees vertically to provide almost total coverage. The VZ scanning system (Figure 2) is a single-axis device that rotates 360 degrees but is limited to 100 degrees scanning arc.

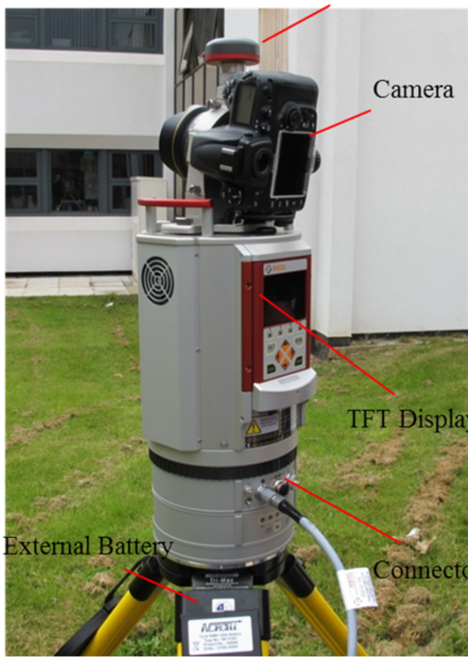


Figure 1 – LPM-i800HA **Figure 2 – VZ-1000**

Both scanning systems are pulse range-finding lasers, incorporating a signal processing unit, a transmitter and a receiver (Figure 3). The scanners are easily attached to a standard survey tribrach and tripod for field usage. The scanning systems are linked via a serial (LMP-2K) or ethernet (LPM-i800HA, VZ-1000) cable to a laptop to enable capture of the digital data.

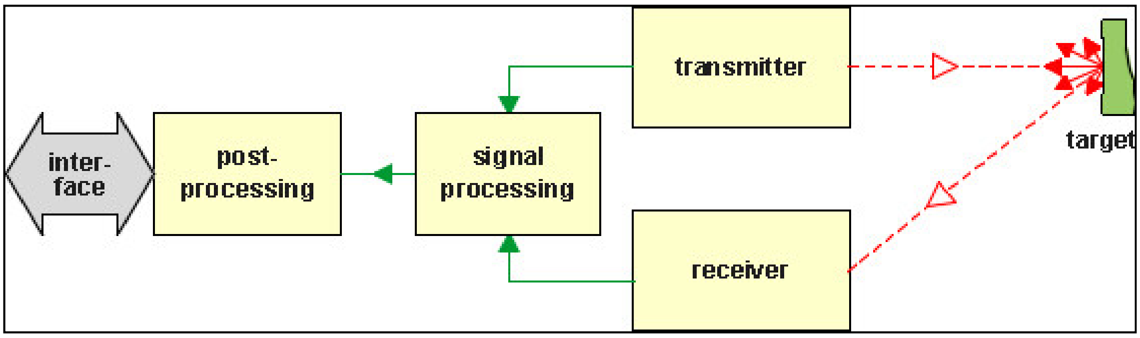


Figure 3 – Laser Scanning system

3.1 CONCEPT

- "Time-of-flight" method
- Near-infrared wavelength
- Pulsed diode laser transmitter
- Sensitive narrow-band optical receiver
- Single pulse or multiple pulse signal detection
- Microprocessor-based post-processing and interfacing

3.2 ADVANTAGES

- Small size
- High reliability
- High interference immunity
- High accuracy
- Long range
- Quick data acquisition
- Highly collimated measuring beam

3.3 REDUCTION OF THE MAXIMUM RANGE

- Very bright daylight
- Bad visibility
- Dirty or dusty front lenses

4 Principles of GPS

The Global Navigation Satellite System (GNSS) is a worldwide, space-based, navigation system consisting of 4 global navigation systems (GPS – United States, GLONASS – Russia, COMPASS – China, Galileo – European Union) with a combined constellation of over 90 satellites (by 2020) orbiting the earth, twice a day, at a height of between 19130 and 23220km on precisely determined orbital paths. These paths are defined so that at least 5 satellites are visible anywhere on the earth at any time. Each satellite transmits signals which allow the distance between a receiver and the satellite to be calculated. By calculating the distance from at least four satellites whose positions are precisely known then an accurate position for the receiver can be established (Figure 4).

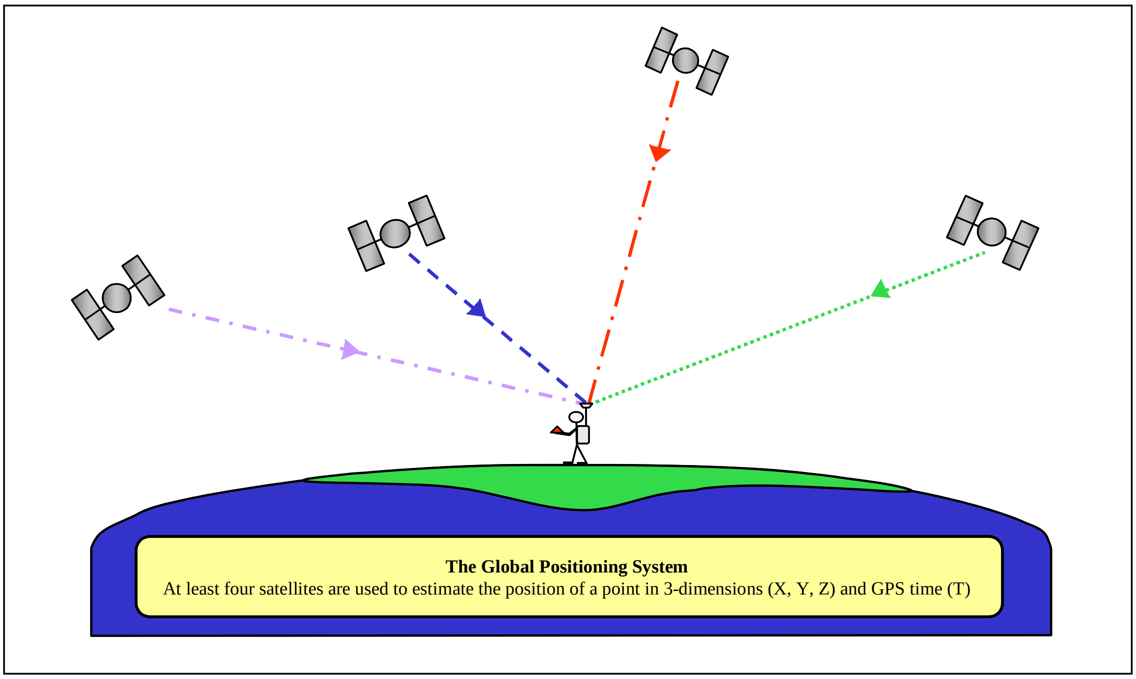


Figure 4 - Measurement of position from four satellites

Positional accuracy with a single receiver, for civilian use, approximately equals 2 to 5m horizontally and height accuracy is generally 5 to 10m, for 95% of the time. The positional accuracy is affected by GPS satellite orbit errors, the atmosphere and receiver clock errors. To give better accuracy the known errors must be accounted for. The GPS satellite orbit errors and other errors introduced into the signal travel time due to it travelling through the atmosphere, cannot be computed by a single receiver in real time. The real-time positional accuracy of a single receiver can be greatly improved by using a more accurate technique known as Differential GPS (dGPS).

Initially, dGPS involved the use of twin receivers; the base receiver being installed at an accurately known position and the apparent location error used to correct the remote receiver which was tracking the same satellites (Figure 5). Thus any error which was common to both receivers was accounted for. This can be done in real time with corrections being transmitted from the base to the remote receiver or it can be done by post-processing data from each receiver.

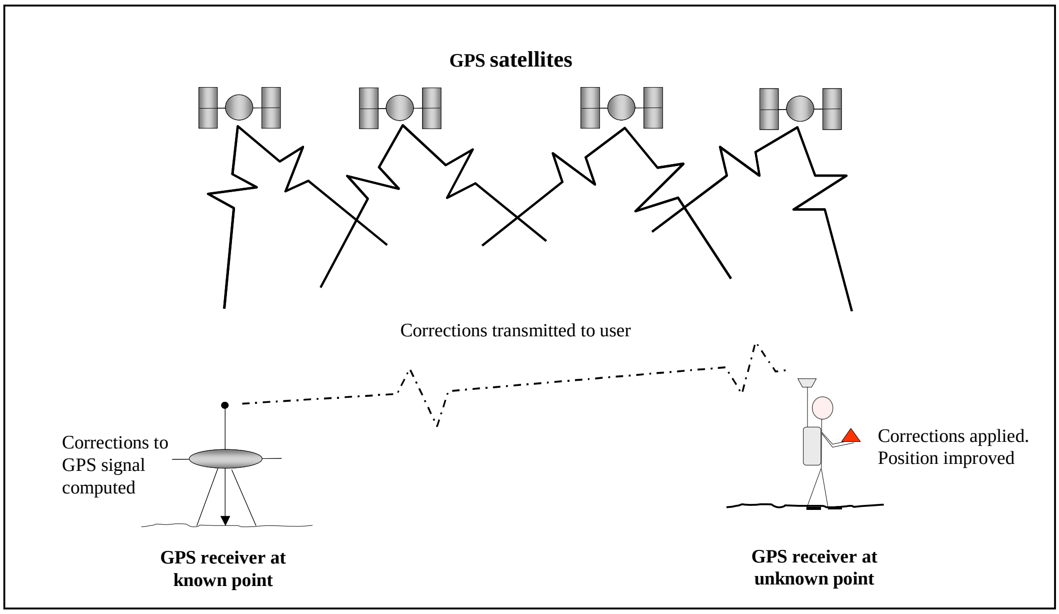


Figure 5 - Improved accuracy using dGPS

Networks of permanent Differential GPS stations have been installed all over the globe with data often available free of charge. Data is available in standard format called the Receiver Independent Exchange (RINEX) Format. This allows for the differential processing of data from a range of different receivers. The great disadvantage of GPS is that as the satellite signal is quite weak, line of sight from the receiver to the satellite is essential. Therefore GPS cannot be used indoors or in areas where a clear view of the sky is not possible such as in forests, next to tall buildings or in deep valleys. Great care should always be taken in positioning GPS receivers and when using twin receivers ensuring each receiver can track the same satellites (Figure 6).

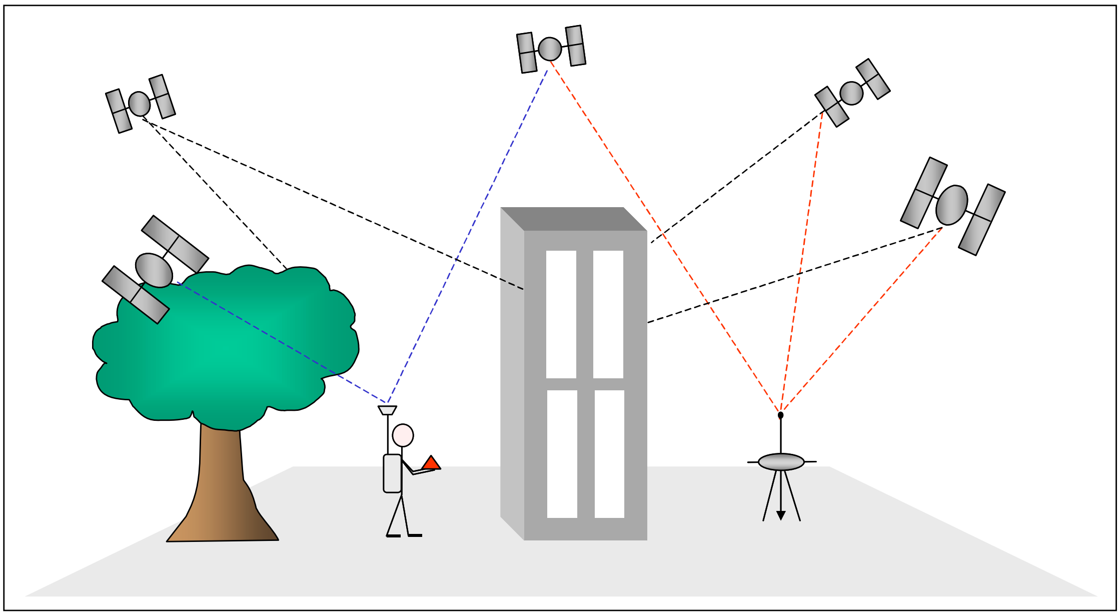


Figure 6 - Poor/lack of satellite signal, leading to loss of accuracy

A Real Time Kinematic (RTK) network is a network of permanent GPS and/or GNSS receivers whose combined data is used to generate RTK corrections for a rover – these network generated RTK corrections are called Network RTK.

RTK Networks can vary in size, from small local networks consisting of only a few reference stations, to dozens of reference stations covering a whole country. A user subscribes to a Network RTK Service to receive RTK corrections with their rover (instead of setting up their own reference/base station). The server generates and sends RTK corrections directly to the rover, which uses these to compute an RTK solution (Figure 7).

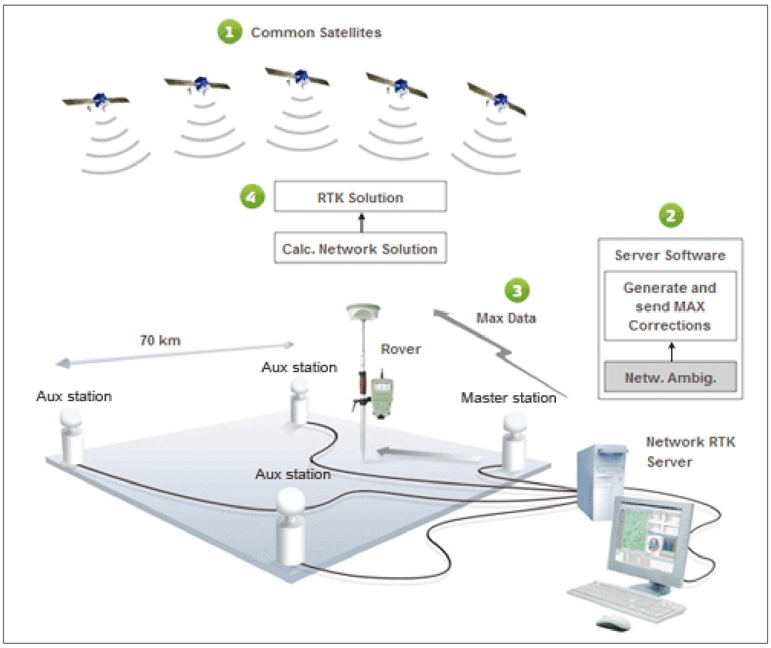


Figure 7 – Relationship between server and rover in Network RTK

5 TLS Set-up Procedures

5.1 LPM SCANNING SYSTEM (FIGURE 1)

The location and orientation of the co-ordinate system of the scanner is fixed internally. In general, this scanner co-ordinate system will need to be converted to a known terrain co-ordinate system. In order to minimise the number of parameters involved in the co-ordinate transformation from the scanner system to the known terrain system, it is advised that a baseline be established and the instrument leveled. To do this:

- Set up the instrument, on a tripod, at the first scanning position and locate it with a GNSS receiver. The antenna of the receiver can be mounted on a leveled Tribrach.
- Locate a second tripod at the second scanning position so that once the scanner has completed the scanning from the first position, the scanner and the GNSS receiver may be swapped with each other.
- Place the high-reflectance target on the second tripod after the GNSS observations have been recorded, in order for the laser scanner to take an accurate backsight reading on it. Repeat this cycle as required.

The above procedure allows for the capture of GNSS observation data while the instrument is scanning. At a later stage, the baseline method facilitates the comparison of the GNSS measurements with the observations made with the scanner. The scanner should be setup in the following way:

- Set-up large tripod (splay legs if very windy) and fix the tribrach (3-footed levelling plate) centrally on it, with the leveling screws in the middle of their runs.
- The target bubble of the tribrach should then be leveled using the tribrach foot screws and the adjustable legs of the tripod. Once level, check that the tripod adjustment screws are tightly screwed in.
- Mount the scanner on the Tribrach, so that the three pins are engaged and the instrument is locked in place.
- Ensure that the horizontal angular/azimuth zero mark (short vertical line) is pointing towards the centre of the scan area.
- Attach camera (LPM-i800HA only), telescope, battery, cables, and joystick.
- Turn on in the following order:
    - Switch on the Laser Scanner, by pressing the switch once. The laser performs a rotation/elevation check.
    - Switch on laptop.
- Level the scanner bubble using the joystick (more accurate).
- Measure the scanner height using the measuring device.

The Laser Scanner is now ready to perform the scan. The software is designed to allow the taking of tiepoints, or backsights, and for taking scan data. To perform the scan carry out the following:

- Start RiProfile. Communications with the scanner will be checked.
- Create a new project. Right-click on SCANS and choose ‘New Scan Position’. Record station name and instrument height.
- Right-click on ‘Scan Position’ and choose ‘New Single Scan’. The scanner will check communications and then open the Scan Window.
- Choose *Top, Right, Bottom, Left* extents of the scan. This is defined using the joystick and then pressing the corresponding button.
- Choose a scan increment, the smaller the interval, the tighter the scan and the more time needed. The display will show the estimated time and number of points for the scan. Press OK when happy.
- Confirm by pressing OK. The scan will begin automatically.

When the scan is finished it will be automatically saved. To take tiepoints to points with known coordinates, in order to properly orient the scan, you should do the following:

- Right-click on TIEPOINTSCANS and choose ‘New Tiepoint Scan’. Record name.
- Choose *Top, Right, Bottom, Left* extents of the scan. Press OK when happy.
- Confirm by pressing OK. The scan will begin automatically.

In order to colour the scans, photographs are required (LPM-i800HA only) by doing the following:

- Turn on the Camera and wait for the laptop to register the connection.
- Right-click on the Scan and choose ‘Image Acquisition’. Check angles, overlap and number of images. Click OK. The camera will automatically take the required number of photographs.

When all the Scans and tiepoints are completed the Laser Scanner can be switched off, packed away and moved. This is done as follows:

- Select Tools, Scanner Control. Choose Park.
- Turn the Scanner off by pressing the switch once. It will make an audible tone and switch itself off.
- Turn off the Camera and laptop. Disconnect the telescope and all cables. Dismantle the scanner and place back in the box before moving.

5.2 VZ SCANNING SYSTEM (FIGURE 2)

The location and orientation of the co-ordinate system of the scanner is fixed internally. It can either be done via an internal GNSS or the Leica Viva GNSS system (better accuracy). This can be done via the ‘baseline’ (previously stated) or ‘scan and move’ techniques. The latter is carried out as follows:

- Set up the high-reflective tiepoint on a ranging-pole, or tripod, in a central area observable from ***all*** scan positions.
- Set-up the scanner on a tripod and level using the Tribrach.
- Establish the co-ordinates of both using the GNSS receiver. This can be done on-the-pole for the tiepoint and then mounted on the top of the scanner, which can then be moved independently as required.

The scanner should be setup in the following way:

- Set-up large tripod (splay legs if very windy) and fix the tribrach (no always required) centrally on it, with the leveling screws in the middle of their runs.
- The target bubble of the tribrach should then be leveled using the tribrach foot screws and the adjustable legs of the tripod. Once level, check that the tripod adjustment screws are tightly screwed in.
- Mount the scanner on the Tribrach, so that the three pins are engaged and the instrument is locked in place.
- Attach camera, GNSS, external battery (if required) and laptop (if required).
- Turn on in the following order:
    - Switch on the Laser Scanner, it performs a rotation check.
    - Switch on laptop.
    - Switch on Camera.
- Level the scanner using the internal bubble (more accurate).
- Measure the scanner and GNSS height.

The Laser Scanner is now ready to perform the scans. To perform the preview scan carry out the following:

- Start RiScanPro. Communications with the scanner will be checked.
- Create a new project. Right-click on SCANS and choose ‘New Scan Position’. Record station name and instrument height.
- Right-click on ‘Scan Position’ and choose ‘New Single Scan’. The scanner will check communications and then open the Scan Window.
- Choose ‘Panorama Scan’, 0.1 deg. as ‘Increment’ and press OK.
- Confirm by pressing OK. The scan will begin automatically.

When complete the scan will save automatically. To perform the precise scan:

- Right-click on 'Scan Position' and choose 'New Single Scan'. The scanner will check communications and then open the Scan Window.
- Choose 'Scan', 0.05 deg. as 'Increment' and press OK.
- Make sure 'Image Acquisition' is turned on.
- Press OK.
- Confirm by pressing OK. The scan and photographs will begin automatically.

When complete the scan will save automatically To take tiepoints, do the following:

- In the 2D Scan Window, mark the tiepoints. Click the 'fine scan all targets' icon. The scanner will carry out an ultra-fine scan and automatically locate the centre of each tiepoint.

When all the Scans and tiepoints are completed the Laser Scanner can be switched off, packed away and moved.

6 GNSS System Set-up Procedures

Whether you use the Leica System 1200 (SmartRover) dGPS unit (Figure 8) or the Leica Viva RTK GNSS unit (Figure 9) the same basic principles of operation apply. However, there are some differences with the initial set-up procedures and also how the icons/menus appear on the controller unit display screen.

Figure 8 – System 1200 (SmartRover)

Figure 9 – Viva

6.1 SYSTEM 1200 (SMARTROVER)

The initial set-up procedure for the SmartRover is as follows:

- Put Battery into Antenna, Controller and Holder. Make sure CF Card is inserted into Controller before inserting Battery.
- Attach Sleeve to Pole and screw both parts together.
- Attach Holder to Pole via Clamp, using Clamp Bolt. Adjust as required.
- Attach Controller to Holder by applying downward pressure on bottom part of Holder, whilst lowering top part of Controller unit it ‘clicks’ in place.
- Ensure Locking Pin is pushed into position.
- Attach Aerial to Radio.
- Attach Antenna to top of Pole.
- Turn on the Antenna followed by the Controller.

Once everything is on and connected, unit displays the SmartWorx Main Menu (Figure 10) and will say “Connected to GS Sensor” and “GSM initialised”.

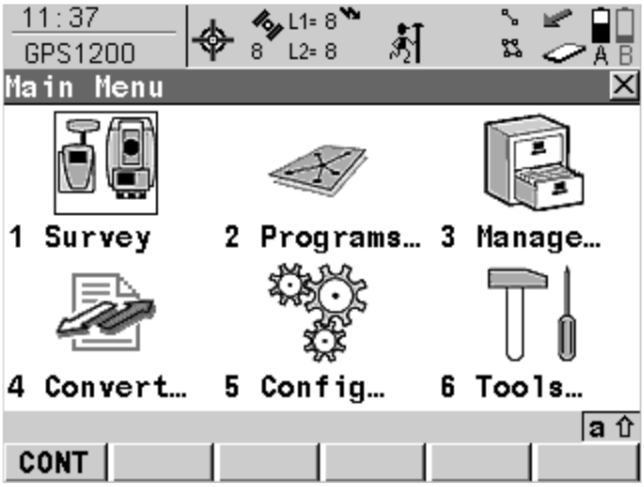


Figure 10 – SmartWorx Main Menu

In order to record GPS data you need to create and select a job, check the configuration set and antenna, and choose a codelist (if required). From the Main Menu:

- Tap 1 SURVEY to take you to the SURVEY Begin screen.
- Tap the Job field to take you to the MANAGE Jobs (CF Card) screen.
- Press F2 NEW to take you to the MANAGE New Job screen. Enter the Job name (max. 16 characters) in the Name field. Make sure CF Card is displayed in the Device field. Press F1 (STORE) to return to the MANAGE Jobs (CF Card) screen.
- Highlight the Job and press F1 (CONT) to return to the SURVEY Begin screen.
- Make sure the correct Config Set (BGS SMART) and Antenna (AX1202 Pole) are chosen. Choose a Codelist if required.
- Press F1 (CONT) to take you to the SURVEY Survey screen.
- Press SHIFT followed by F3 (CONECT) to connect to the NTripCastor – this is the RTK network that sends out the RTK corrections directly to the SmartRover.

We need to verify that the unit is receiving RTK transmissions. To do this look at the Top Menu Bar (Figure 11) and note the following:

- Make sure there are a minimum of 5 Satellites shown on both L1 and L2.
- Check for a pulsing down arrow – this indicates that RTK corrections are being received.
- Look for the 'fixed' icon, and notice the two 'tick' marks – this indicates that all ambiguity checks have been completed and solved.

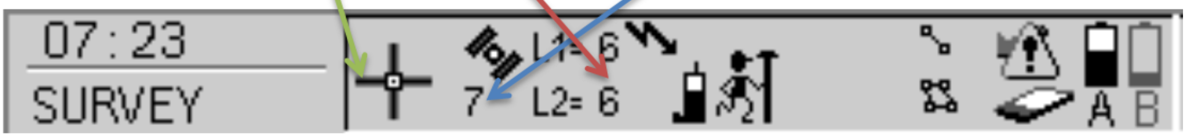


Figure 11 – Top Menu Bar

Before recording the position of a point you need to enter the Point ID and check the following:

- Antenna Height – this should read 2.000m.
- Coordinate Quality (3D CQ).
- Initialisation Status icon – this should be 'fixed' (as above).
- Hold the Pole level and steady and press F1 (OCUPY) to automatically record the point position.
- Move to next position and repeat.

When all the points of the survey have been stored the SmartRover can be switched off and packed away. Please do so in the following order:

- Turn off the NTripCastor by pressing SHIFT followed by F3 (DISCO).
- Press ESC to exit the SURVEY Survey screen and return to the Main Menu.
- Press USER and PROG together in order to turn off the Controller.
- Turn off the Antenna by holding the ON/OFF Button for 5 seconds.

The unit can now be taken apart and packed away.

6.2 VIVA

The initial set-up procedure for the SmartRover is as follows:

- Put Battery into the Controller and two into the Antenna. Make sure CF Card and SD Card are inserted into the Controller and Antenna respectively.
- Attach Controller to Pole using Clamp Bolt and Holder. Adjust as required.
- Attach Antenna to top of Pole and connect RTK Aerial via Arm.
- Turn on the Antenna followed by the Controller.

Once everything is on and connected, the unit will first ask if you would like to 'continue with last job', 'choose existing job' or 'create new job'. Select the appropriate button and press OK.

[See below for how to set-up a new job]

The Viva will now display the SmartWorx Viva Main Menu (Figure 12) and will say "Connected to GS Sensor" and "GSM initialised".

Figure 12 – SmartWork Viva Main Menu

In order to record GPS data you need to check the configuration set and antenna height, and choose a codelist (if required). From the Main Menu:

- Tap 2 Jobs & Data.
- Select Existing or New Job and press OK.
- *If New:* Enter the Job name (max. 16 characters) in the Name field. Make sure CF Card is displayed in the Device field.
- Press F1 (STORE) to return to the Main Menu.
- Tap 3 Instrument.
- Select 'Other Connections' then Check Antenna is set to 'Pole' and height is 2.000m. Press Ok
- Tap 1 Go to Work!
- In Survey screen, check pole height etc. and enter point name.
- Press * button and select Start RTK Stream. Unit will say "Connected to NTRIP CASTOR". You're now ready to begin logging points.

We need to verify that the unit is receiving RTK transmissions. To do this look at the Top Menu Bar (Same as Figure 11) and note the following:

- Make sure there are a minimum of 5 Satellites shown on both L1 and L2.
- Check for a pulsing down arrow – this indicates that RTK corrections are being received.
- Look for the 'fixed' icon, and notice the two 'tick' marks – this indicates that all ambiguity checks have been completed and solved.

Before recording the position of a point you need to enter the Point ID and check the following:

- Antenna Height – this should read 2.000m.
- Coordinate Quality (3D CQ).
- Initialisation Status icon – this should be 'fixed' (as above).
- Hold the Pole level and steady and press F1 (OCUPY) to automatically record the point position.
- Move to next position and repeat.

When all the points of the survey have been stored the Viva can be switched off and packed away. Please do so in the following order:

- Turn off the NTripCastor by pressing * Stop RTK Stream.
- Press ESC to exit the SURVEY screen and return to the Main Menu.
- Press and hold ON/OFF Button on the Controller for 5 seconds. This will turn of the Controller and ask if you want to power off the Antenna. Choose ‘Yes’.

The unit can now be taken apart and packed away.

6.3 *VIVA ATTACHED TO VZ-1000

There is one slight differences to the set-up when using the Viva on-top of the VZ-100, namely the Antenna Height should read 0.000m (zero) rather than 2.000m.

7 Data Processing

7.1 WORKFLOW PROCEDURE

7.1.1 Superceeded Workflow

There are currently no Quality Assured documented standard procedures for field data acquisition, data processing/visualisation, or the storage/retrieval of raw data, photographs and processed 3D models. The current work-flow is fragmented, complex and time consuming (Figure 13). Scan data and GNSS positioning data collected in the field varies with respect to accuracy and precision, depending on the individual operator collecting it and also on the type of survey being carried out. Back in the office the scans are oriented using the GNSS data, attributed with their RGB colour and correctly aligned. The data are exported from RiProfile (or RiScan if VZ data) and imported into one of ***nine*** software packages in order to grid, map, model or visualise it – no single package is able to carry out all the tasks required at present.

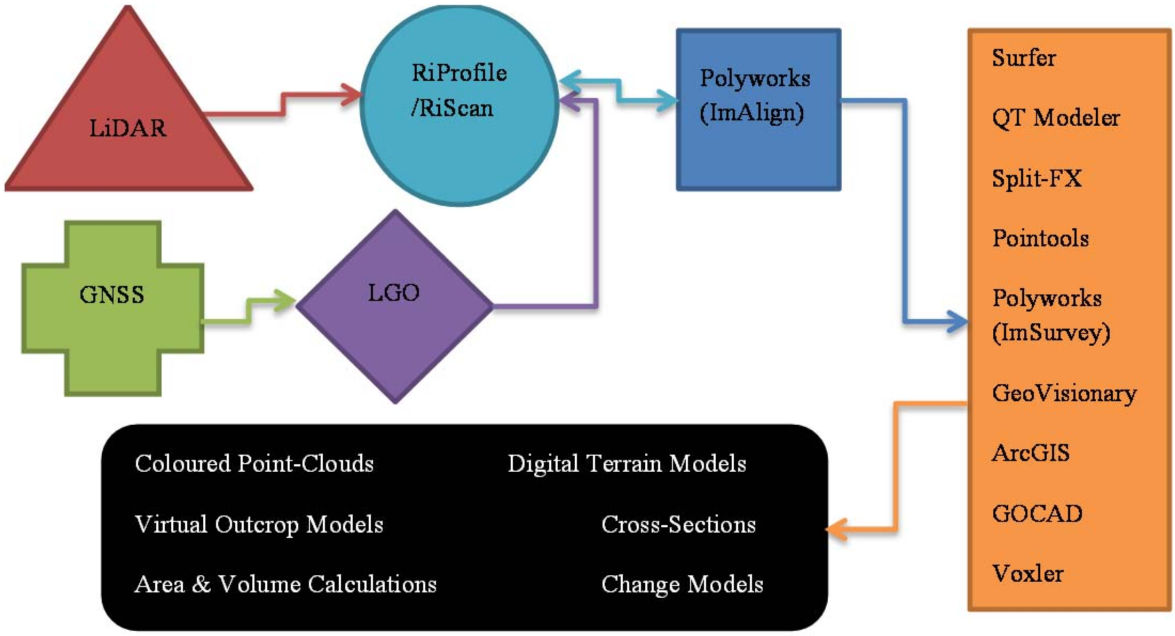


Figure 13 – Work-flow

7.1.2 Curent Workflow

The ‘new’ work-flow is much more simplified and less time consuming than the superseded work-flow (Figure 14). Scan data is now collected in the field in a much more rigorous manner, with users aware that resolution and accuracy are of equal importance. GNSS data is also collected in a more measured and precise manner, with users aware of issues that might arise and the ways in which to deal with them. The scans are geo-rectified using the corresponding GNSS data, properly aligned using multi-station adjustment algorithms, and attributed with RGB and Amplitude (intensity) values. This work is now carried out entirely in RiscanPro (for the Riegl scanners) or Scene (for the Faro scanner) and the data are exported as ASCII files. These data are then imported into one of *six* software packages in order to grid, map or model the data and one of *two* software packages in order to visualise it.

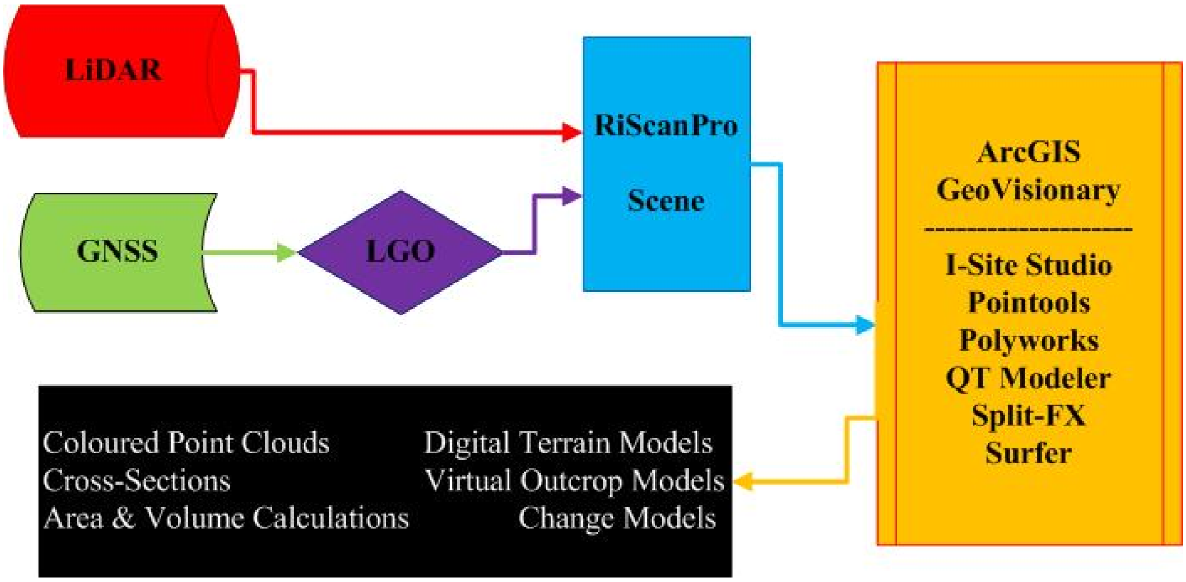


Figure 14 – Current work-flow

7.1.3 Data Issues

Modern laser scanners have significantly increased the level of resolution, accuracy and speed of data acquisition. However, the extremely large data files produced by the latest terrestrial LiDAR surveys (typically 40-50 GB raw and 80-100 GB processed) are making them difficult to deal with. Although the processing power of a typical desktop PC has increased significantly over the past few years the modelling software's ability to deal with these increasingly large datasets has not.

A further major issue associated with the large datasets produced by terrestrial LiDAR surveys is the difficulty of storing and archiving the data. This has recently been addressed with the implementation of a corporate TLS Data Plan:

- TLS data collected for many projects in BGS by trained TLS users
- Raw TLS data stored on W:\Teams\SGR\Geomatics\Data under Project folder
- Data checked, geo-referenced and trimmed (if required) in this folder
- Copy of Raw and Processed data kept on this drive
- Data exported as ASCII point clouds to S:\Geomatics\Terrestrial where it is stored under Project folder (same name as W:drive)
- Data cleaned and filtered, multiple files combined and .dat files created for GeoVisionary
- Completed processed data now available for access by all BGS users, not just commissioning project

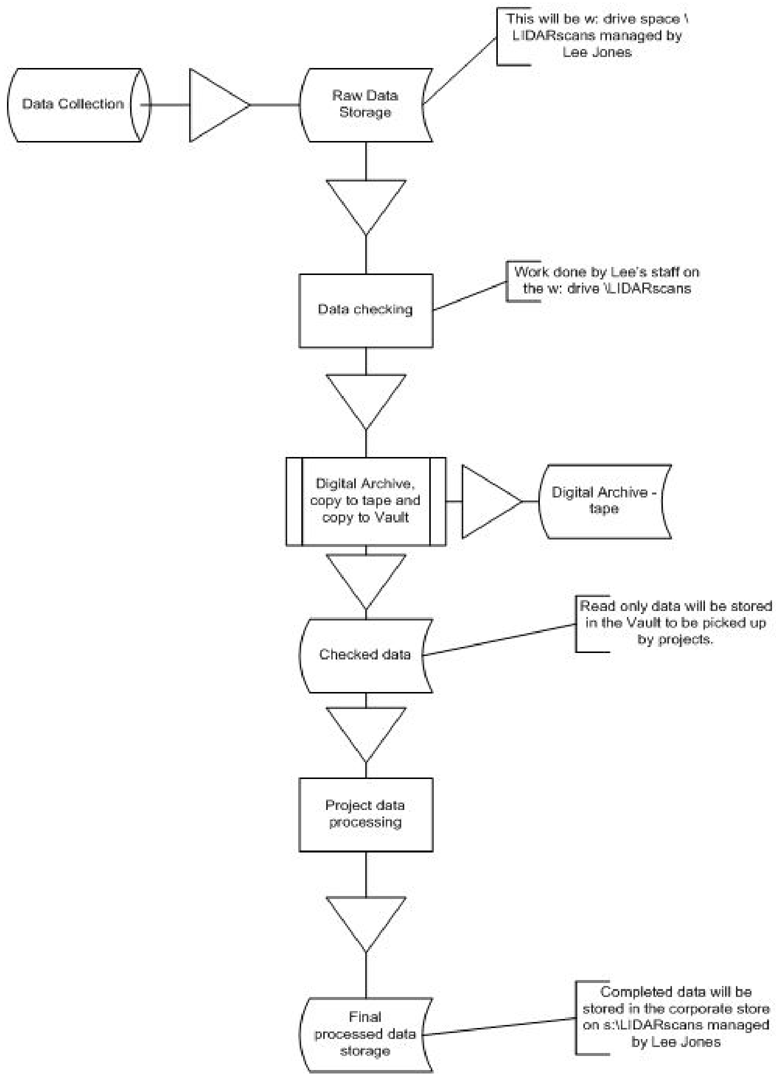


Figure 15 – Corporate Data Work-Flow

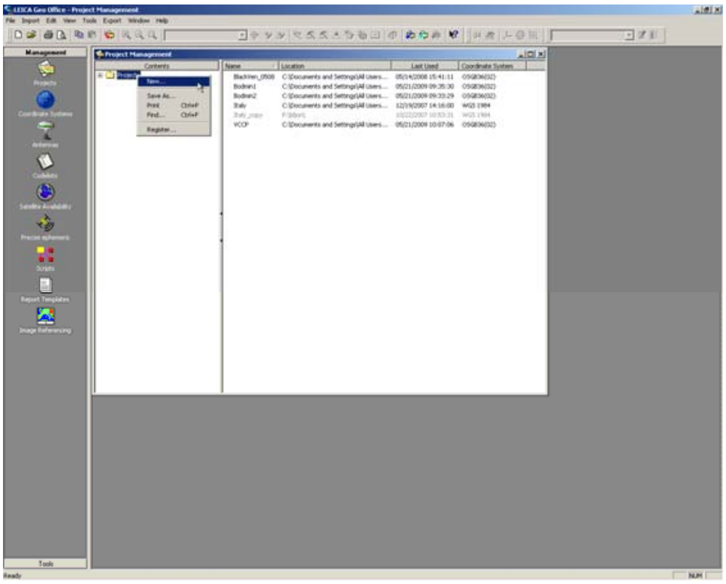
7.2 PROCESSING WALK-THROUGH

Once the survey is completed the data needs downloading from the various pieces of equipment; GNSS positional data from the Compact Flash cards in the Leica SmartRover Controller and Viva Controller and SD cards in the Viva Antenna. LiDAR data from the HDD on the Toughbook associated with the LPM scanners and from the HDD on the Getac associated with the VZ scanner.

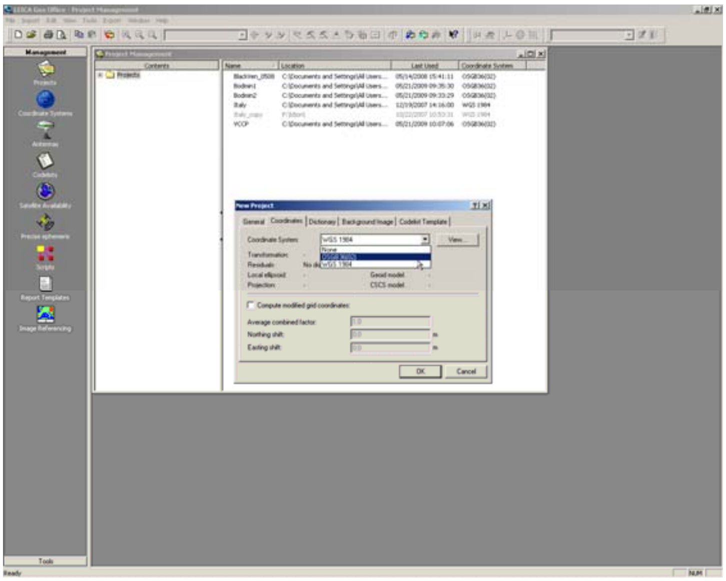
7.2.1 Leica Geo Office

The GNSS positional data is stored on Compact Flash cards located inside the Smart Rover and Viva Controllers, and on SD cards located inside the Viva Antenna. The data can easily be copied from the 'DBX' folder on the card to a PC using a card reader. Start LGO.

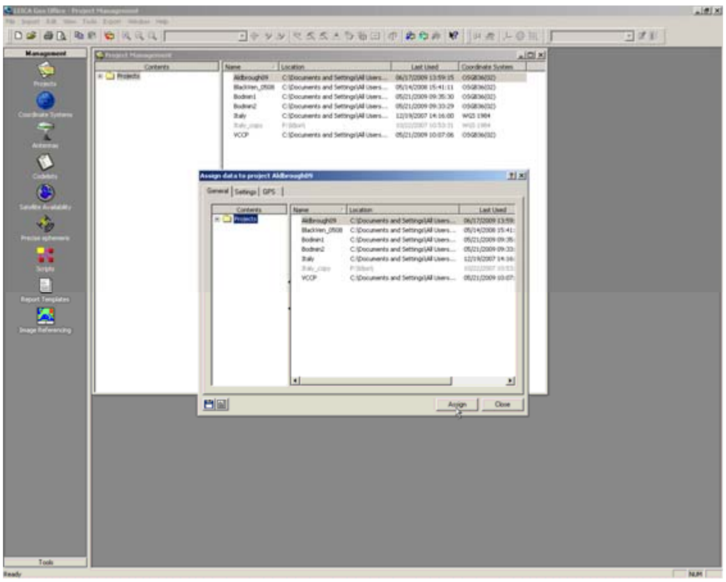
- Choose 'Projects'
- Right-Click <Project> folder then <New>



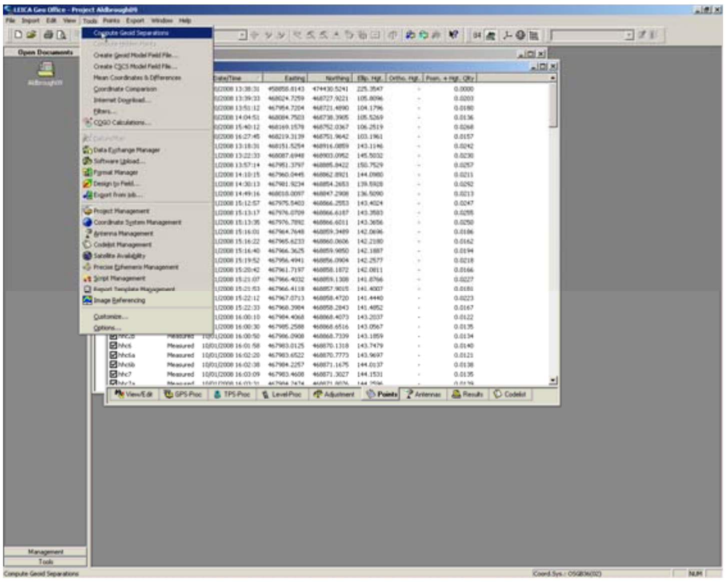
- Type in the name of the survey and click <Coordinates> Tab. Change the Coordinate System to OSGB36 <OK>



- <Import> <Raw Data>
- Browse to 'DBX' folder and select the data and 'Assign' it to the required survey



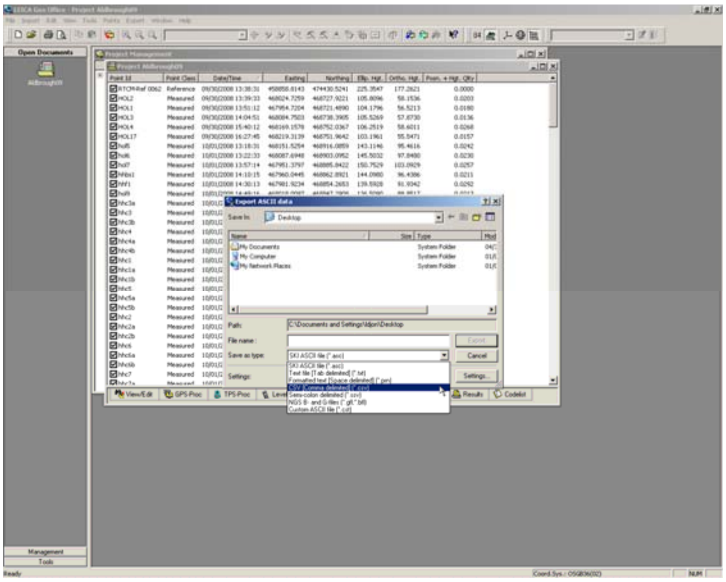
- Select ‘Points’ tab to view imported data
- In View change Coordinate System to ‘Local' and Coordinate Type to 'Grid'. <Tools> <Compute Geoid Separations>



- If RTK link was down during acquisition, RINEX corrections are required. Download from OS (www.gps.ordnancesurvey.co.uk) , Leica (www.leica-geosystems.com) or, if later than 30 days, from BIGF (www.bigf.ac.uk)

Note: Processing RINEX data is not covered in this manual.

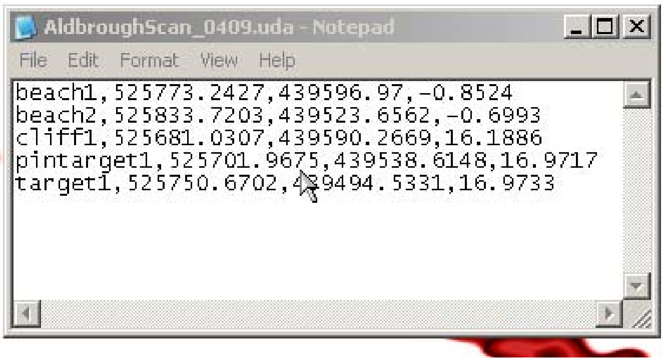
- If you are dealing with RINEX data you will need the Dongle (No. 27) in order to import and post-process it in LGO
- <Export> <ASCII Data> Choose location to save to and 'Save As' *.csv format



This can now be 'cleaned-up' in Excel and saved as a (comma-delimited) *.csv file.

Note: 'Orthometric height' is correct value to use, not 'Ellipsoid height'.

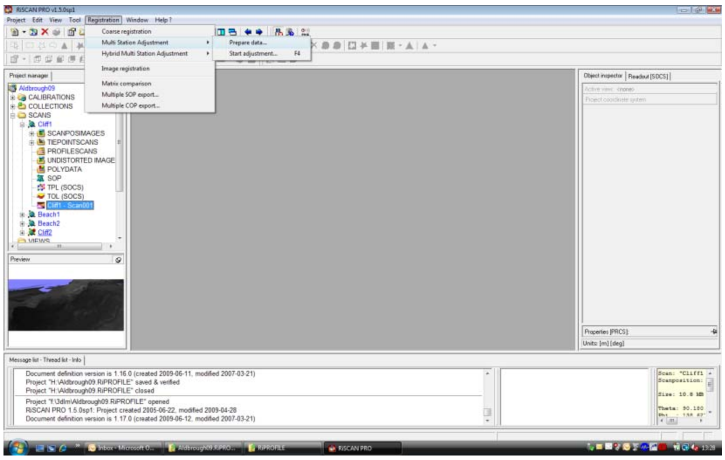
Open the *.csv file with Notepad and save it with no headings in the form {Name, X, Y, Z} and save as a *.uda file. It is useful to also create a 'space delimited' *.txt file in the form {Name, X, Y, H}, where H is Z + Scanner Height - This "Height" file will be used in Polyworks later.



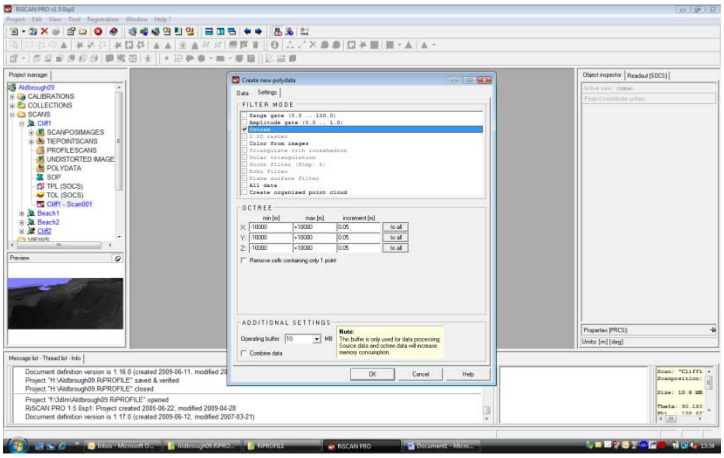
7.2.2 Riegl RiProfile

RiProfile is the LPM scanner operating and visualisation software. It allows the user to run the laser scanner and also to orient, join and view the scans. The data is stored on the Panasonic Toughbook laptop in a folder named after the survey and can be opened using the 'Project.rsp' file.

- The first step, once the project is loaded, is to check that all the scans are there, and appropriately named
- Next, create a coloured point cloud of the images. To do this they must firstly be undistorted. Open 'SCANPOSIMAGES', highlight all images and select ‘Undistort’
- 'Right-click' on a Scan and select 'Colour From Images'. Change to 'Undistorted Images' and highlight all images (for Scan 1 only). <OK>
- To view the data properly in RiProfile use 'True Colour', 'Linearscaled', 'Type = Amplitude', 'Sub = Histogram'
- In order to view *all* the scans together then it is a good idea to filter the data. <Registration> <Multi Station Adjustment> <Prepare Data>



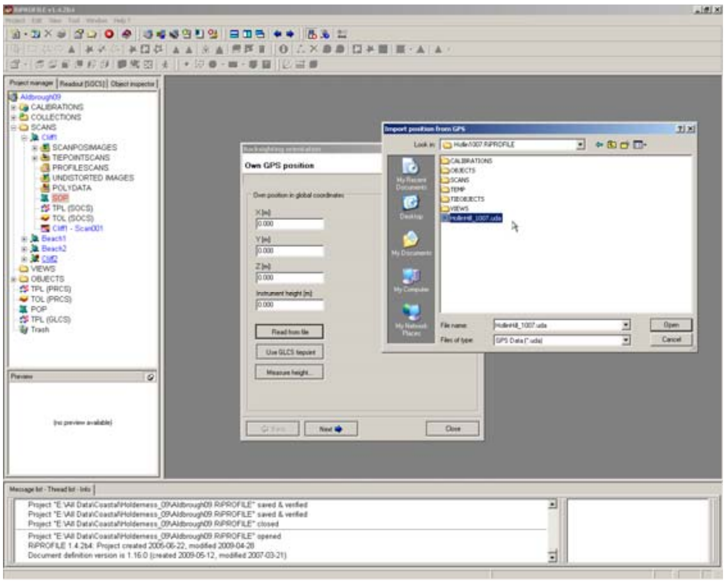
- Select all the scans required and then run an 'Octree' filter with the following settings:



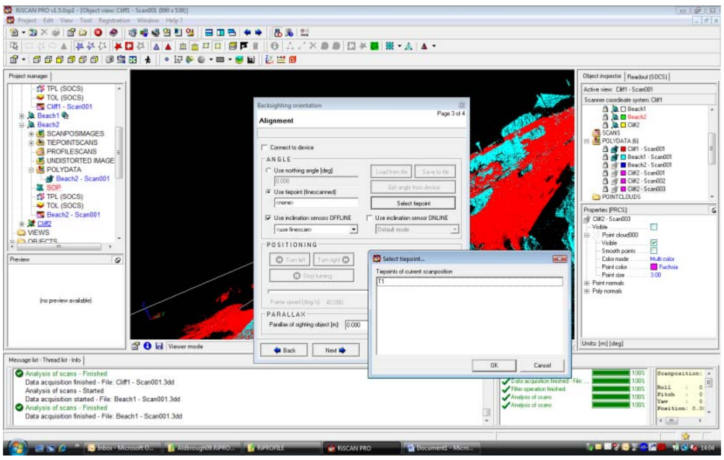
- Alternatively you can run a '2.5D' filter, which may help in finding the ground level on a vegetated survey, or an 'All' filter, which keeps more detail.

Note: These filters will create Polydata in the OBJECTS folder.

- In order to correctly align the scans to National Grid, and to each other, they must be oriented. Right-Click on 'SOP' and choose 'Backsighting Orientation'. Put in the scanner position (use the *.uda file) and instrument height (recorded in field notebook). Click <Next> and enter the backsight target position



- And Alignment



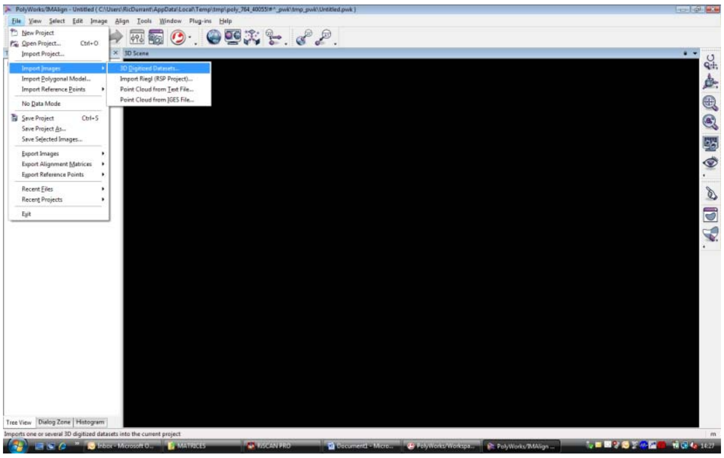
- Click <Next>. Select <Set SOP>. SOP icon will go blue and star will appear next to POP. Close ‘Backsighting Orientation’

- In the survey folder (*.RiProfile) create a new folder named 'MATRICES' and save ALL the SOP positions <Registration> <Multi SOP export> to this new folder
- To create a Panorama image, open 'SCANPOSIMAGES', highlight all images (for Scan 1 only). 'Right-click' and select 'Create Panorama Image' <OK>. Choose 'Name' and 'Location'
- If this doesn't work it could be because you have too many photos. Try splitting them in half and generating 2 coloured scans
- SAVE the Project. Don't shut it down yet!

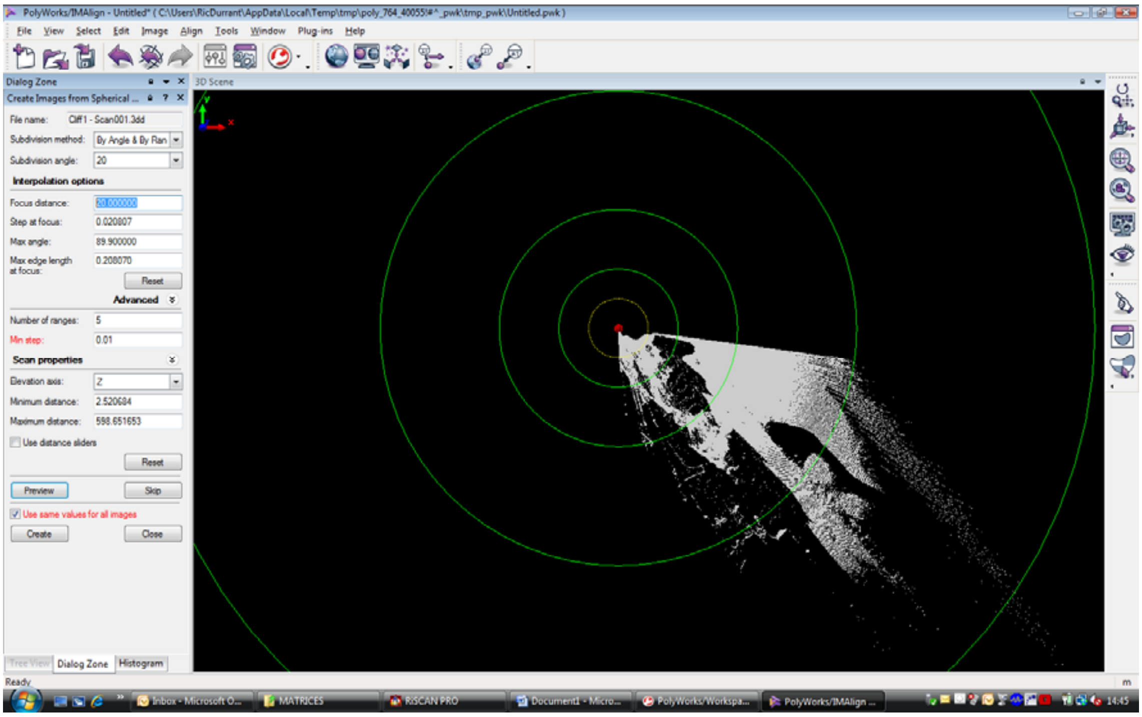
7.2.3 Innovmetrics Polyworks (IMAlign)

Polyworks is a 3-D point cloud software platform designed for surveying applications. IMAlign allows for re-alignment and visualisation of multiple scans.

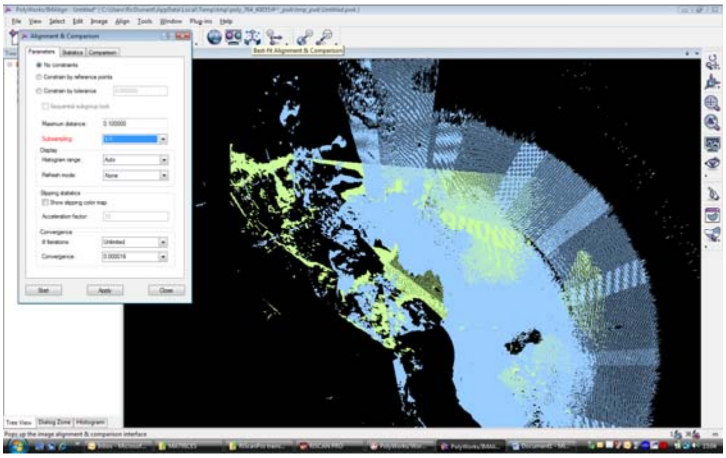
- Run Polyworks and open 'IMAlign'. Import the oriented RiProfile data. <File> <Import Images> <3D Digitized Datasets> <Spherical Grids> and choose RSP Project (Riegl)



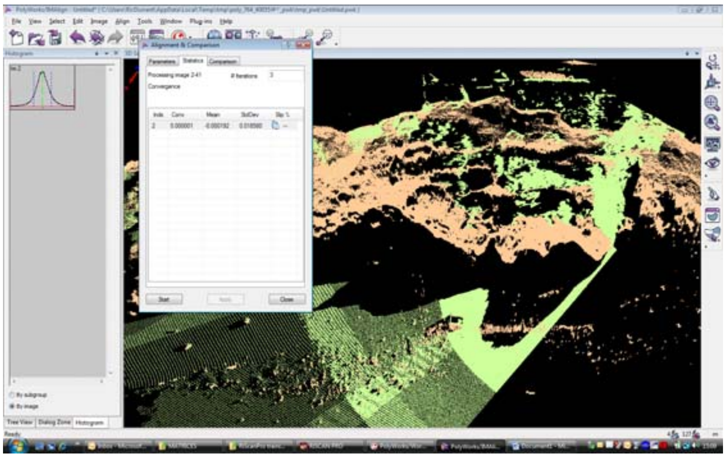
- Browse to the RiProfile folder and select all the required scans. <OK>
- Choose Metres and Colour
- The 'Create Image' window will open. Change the 'Focus distance' to 20 and make sure that 'Use same values for all images' box is ticked. <Create>



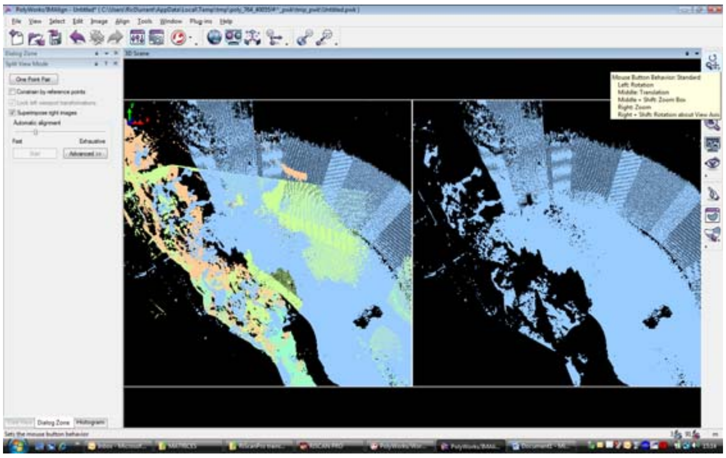
- Group scans from the same scanner location. Highlight them, right-click <Edit> <Group>
- Choose the 'best' scan and lock it. Right-click <Edit> <Lock> and 'Ignore' all the scans but one (other than the locked scan) Right-click <Edit> <Ignore>
- Carry out a 'Best-fit Alignment' by clicking the shortcut and changing the 'Parameters' to the following:



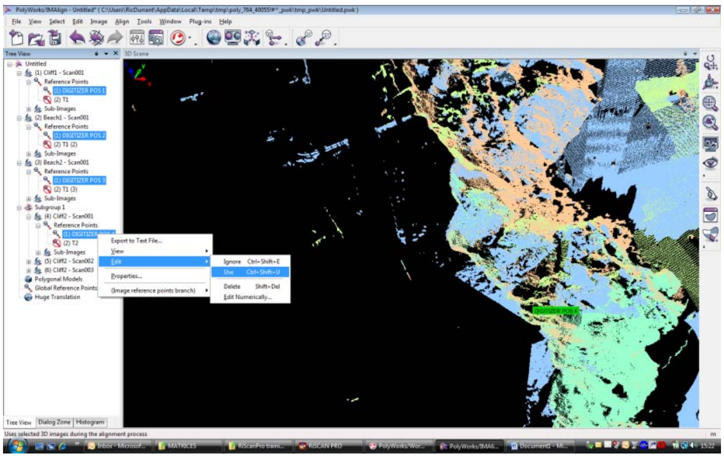
- Click <Start>
- Check the 'Statistics', look at the shape of the 'Histogram' and run a 'Comparison' check on the two scans



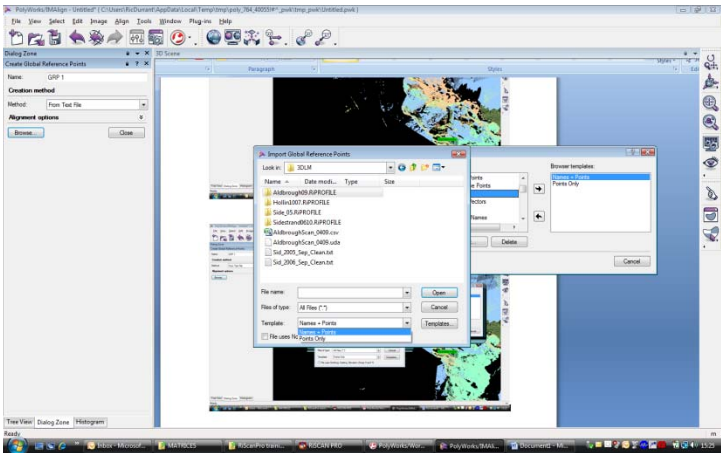
- Lock the second scan (keeping first locked) and carry out the method again with a third scan etc
- If the scans are too far out (misaligned, bad backsight etc.) they can be manually adjusted using the 'Split-view Alignment' tool. Zoom in to the area and ***only*** use [Shift+R] to rotate around the axis of the screen and [Middle Mouse] to translate the image



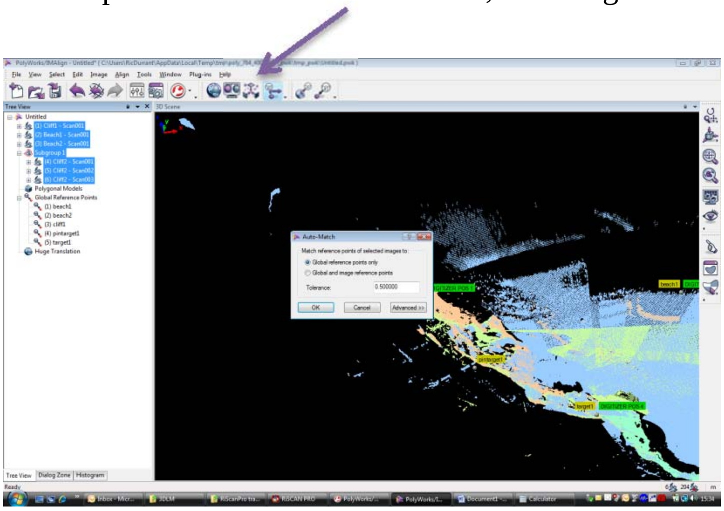
- Then carry out the 'Best-fit Alignment' as before
- Once ***all*** the scans have been re-aligned the survey needs adjusting to its correct base level. To do this highlight ***all*** the digitiser positions, right-click <Edit> <Use>



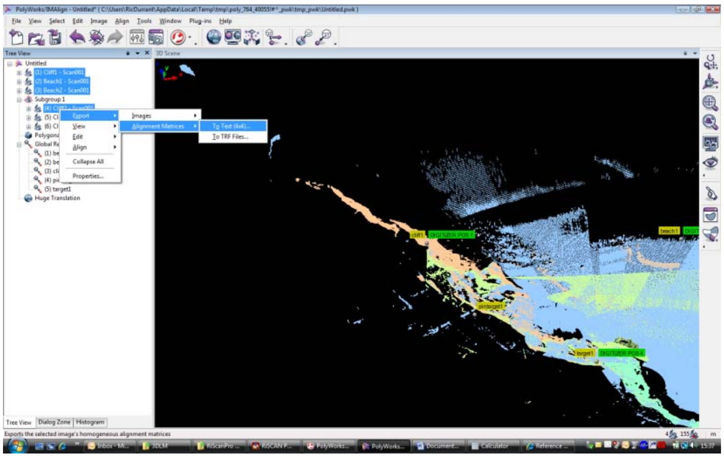
- Make sure all the scans are visible and unlocked. Highlight them, right-click <Edit> <Unlock>
- Right-click on 'Global reference Points' <Create> and change method to 'From Text File' and browse to the "Height" file (created earlier) under the 'Names + Points' Template (need to create this for first time of use)



- Select ***all*** the scans and press the 'Auto-Match' button, choosing 'Global reference points only'.



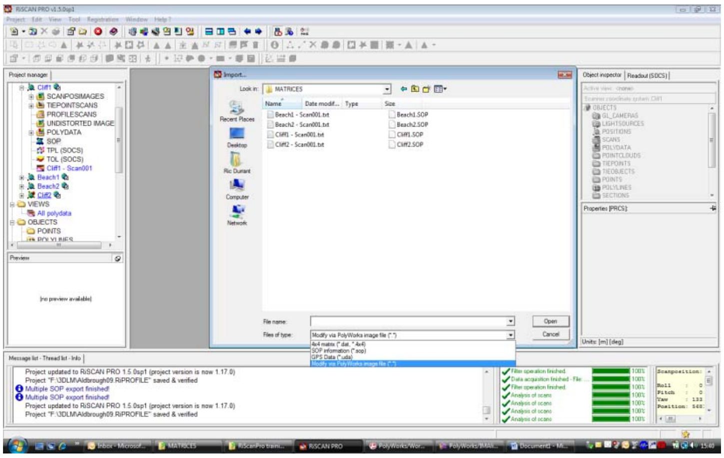
- Select the scans (only require one from each Group). Right-click <Export> <Alignment Matrices> <To Text (4x4)>



- Export these *.txt files to the 'MATRICES' folder under the surveys *.RiProfile project.

7.2.4 Back to RiProfile

- For each scanner position, right-click the SOP <Import> and choose 'Modify via Polyworks image file (*.*)' and adjust each one

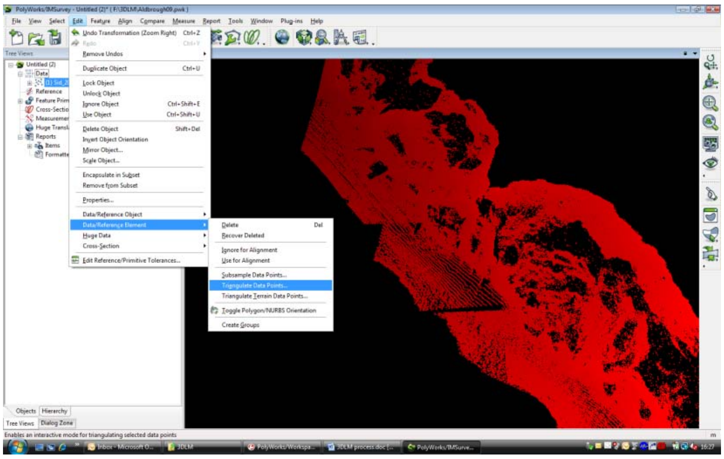


- In the survey folder (*.RiProfile) create a new folder named 'DATA'. Right-click each scan (colour or intensity) <Export> and 'Save as' “xyzRGB” (colour) or “xyzi” (intensity) *.csv format to this folder. Make sure you use the GLCS coordinates
- SAVE the Project

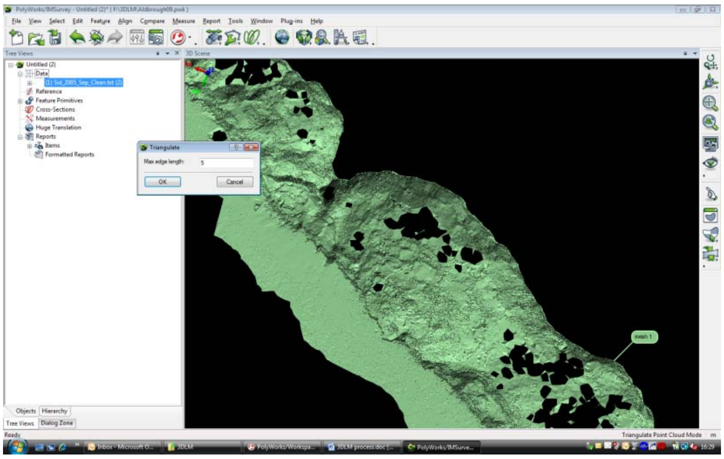
7.2.5 Innovmetrics Polyworks (IMSurvey)

IMSurvey is the visualisation tool, that allows the 3-D viewing of single and multiple scans and the creation and viewing of change models etc.

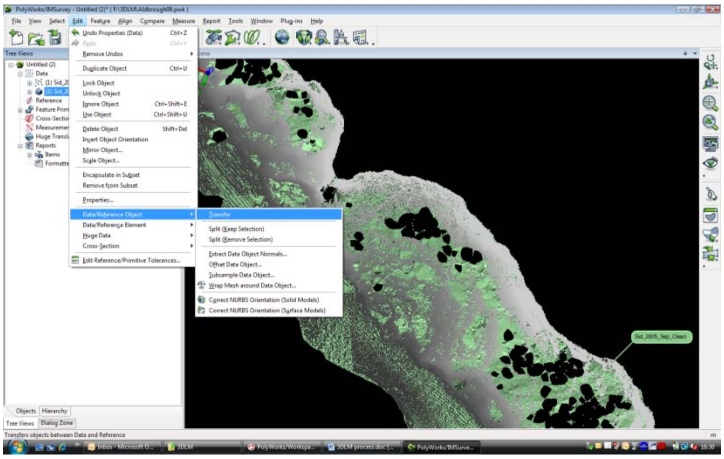
- In Polyworks, open 'IMSurvey'. Right-click 'Data' <Import> <ASCII Point Cloud> and bring in the scans
- 'Ignore' all scans but one (usually oldest). Highlight this scan and <Select> <All Elements>
- To create a mesh use <Edit> <Data Reference Element> <Triangulate Data Points> and then re-name it



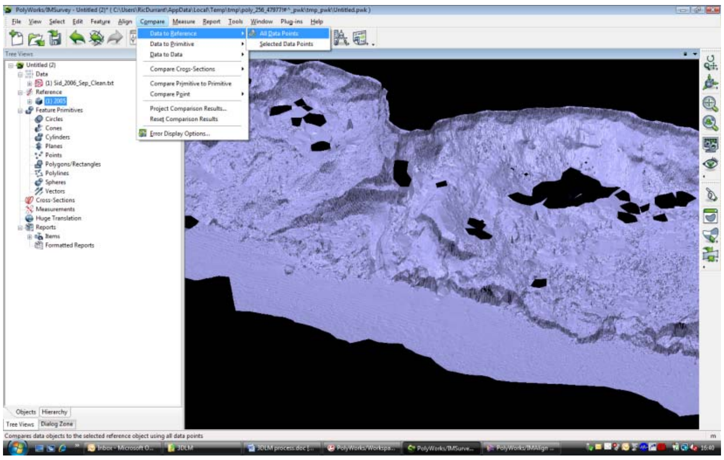
- Initially try the XY 'Triangulation plane' and set the 'Max edge length' to 5m (ish)



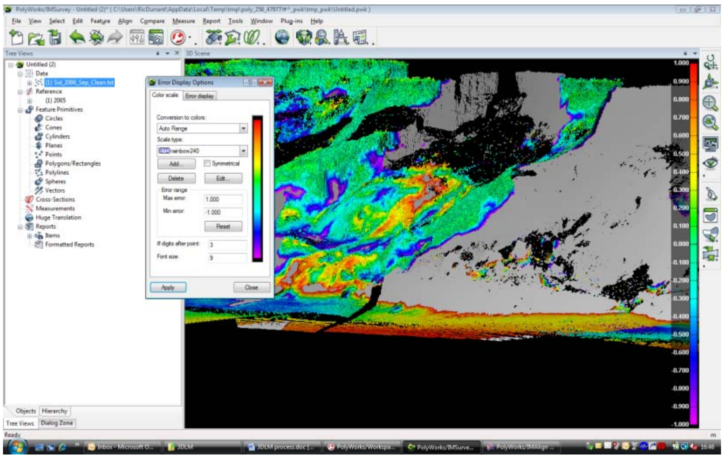
- This triangulated model needs to be converted from a 'Data' object into a 'Reference' object. The initial data object can be 'Ignored' (or even 'Deleted'). 'Select' the triangulated model <Edit> <Data/Reference Object> <Transfer> to turn it into a 'Reference' object



- To compare models (and create a change map), 'Use' the new 'Data' object (what your model is being compared to). 'Select' the triangulated model <Compare> <Data to Reference> <All Data Points> and change the 'Max distance' to 1m (or greater), turn the 'Max angle' off and initially try 'Direction' as shortest distance



- Use <Compare> <Error Display Options> to bring up the options box and make any changes to the display required



- SAVE the project

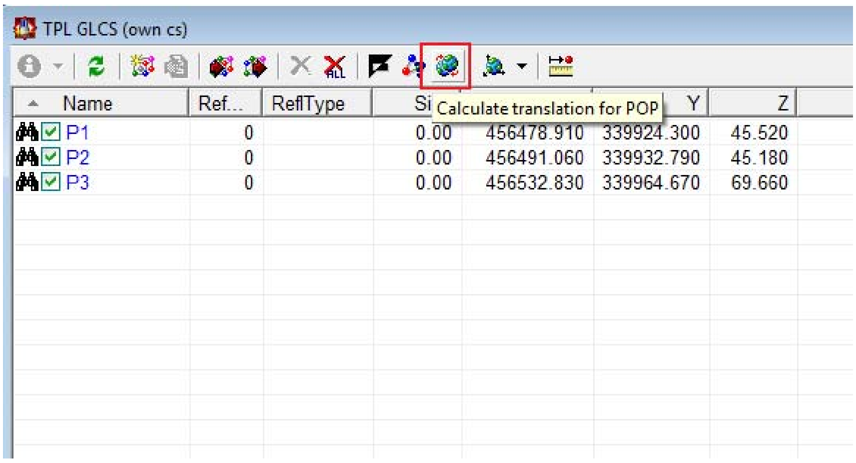
7.2.6 Riegl RiScanPro

RiScanPro is the VZ scanner operating and visualisation software. It allows the user to run the laser scanner and also to orient, join and view the scans. The data is stored on the Getac laptop in a folder named after the survey and can be opened using the 'Project.rsp' file.

- The first step, once the project is loaded, is to check that all the scans are there, and appropriately named
- Next, right-click on TPL (GLCS), change the Files of type to ‘Any ASCII file’ and navigate to the GPS (*.uda) file created earlier. Click Open. Check the settings in the Preview window <OK>
- Set the height for all Scanner Positions as -0.295m (Scanner Origin Offset) and for any tiepoints as ‘say’ +2.000m (if using Pole Targets).

Note: Height from top of battery to scanner axis is 0.233m (needed if GPS NOT on scanner).

- Select the ‘Calculate translation for POP’ button to set the POP (Project Orientation and Position) to the ideal value for all GPS positions in the project.

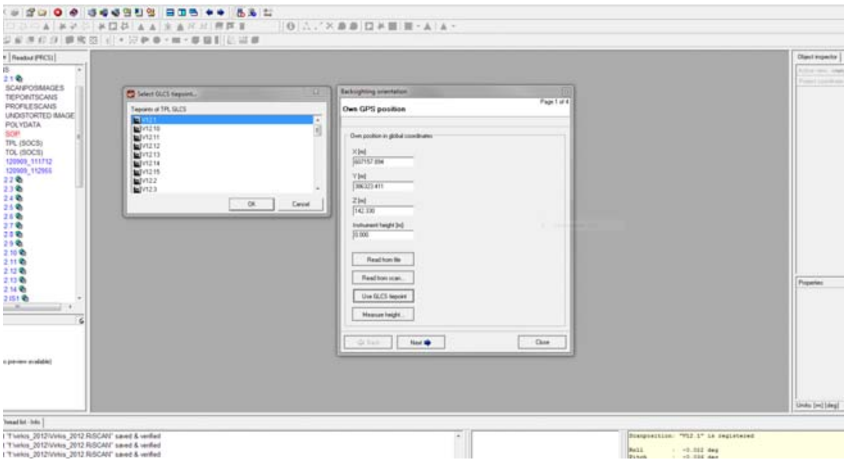


- Select all values. Right-click and select Copy tiepoints to ‘TPL PRCS’. Close window.
- Right-click on POP and select ‘Freeze’
- TPL (PRCS) will automatically select points as Control points.
- Note the change made to the Z value. Close window.

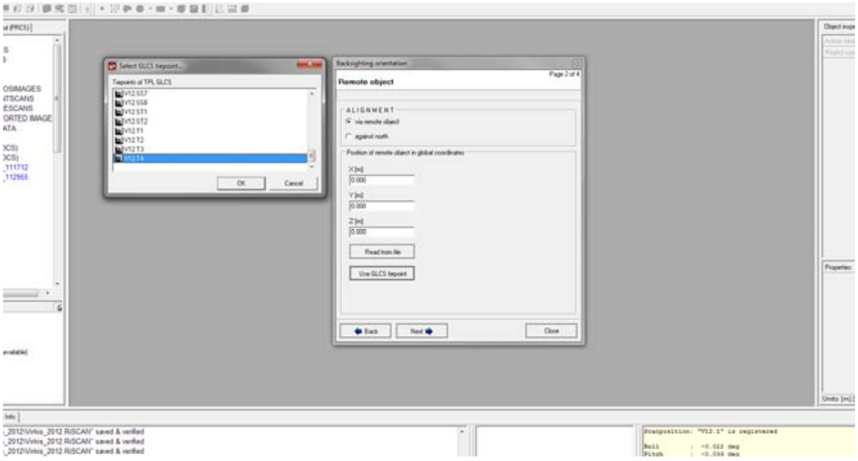
- Next, create a coloured point cloud of the images. To do this they must firstly be undistorted. Open 'SCANPOSIMAGES', highlight all images and select ‘Undistort’
- 'Right-click' on a Scan and select 'Colour From Images'. Change to 'Undistorted Images' and highlight all images (for one scan at a time). <OK>
- To create a Panorama image, open 'SCANPOSIMAGES', highlight all images (for 1 scan at a time). 'Right-click' and select 'Create Panorama Image' <OK>. Choose 'Name' and 'Location'

N.B. If the images have a white aura around them it could mean the camera mounting was mis-alligned and the calibration needs adjusting – See Appendix 1.

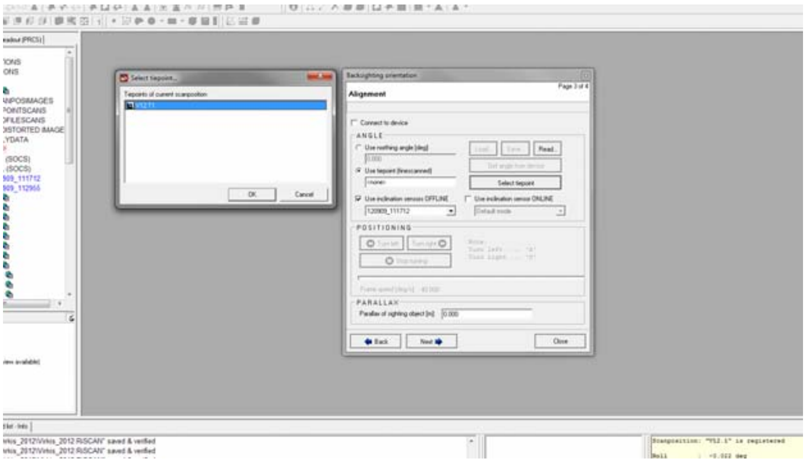
- In order to correctly align the scans to National Grid, and to each other, they must be oriented. Right-Click on 'SOP' (Scanner Orientation and Position) under each scan position and choose 'Backsighting Orientation'.
- Click on Use GLCS tiepoint and choose the point from the list that corresponds to the Scanner position (Ignore Instrument height). <OK> Click Next.



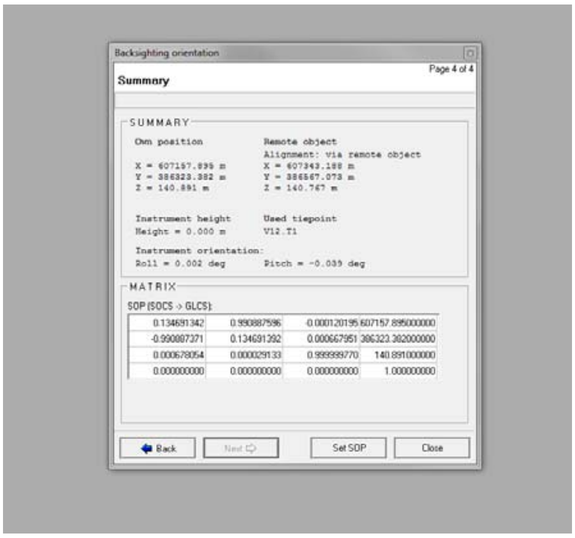
- Click on Use GLCS tiepoint and choose the point from the list that corresponds to the Target position. <OK> Click Next.



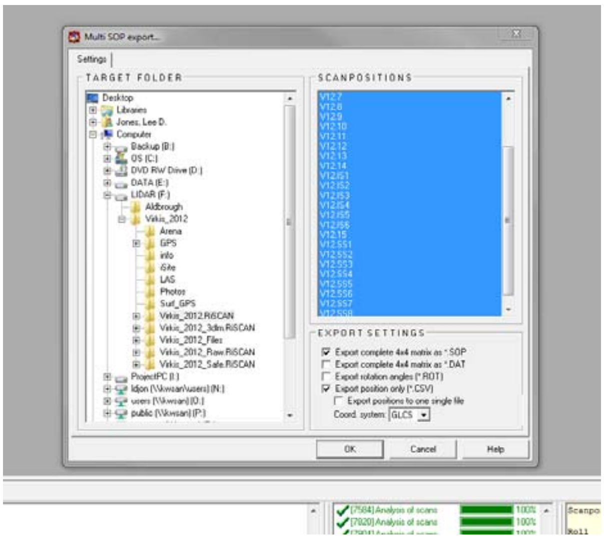
- Make sure that Use inclination sensors OFFLINE box is ticked and the Panorama scan is selected. Highlight the Use tiepoint (finescanned) button and click Select tiepoint. Choose the correct tiepoint for the current Scanner position. <OK> Click Next.



- The programme will extract the inclination values and then display the ‘Summary’ screen. Check the details are correct and click Set SOP. Click Close.



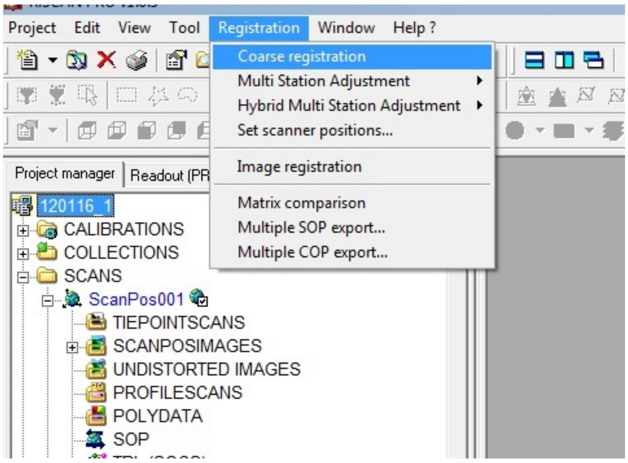
- Repeat this process with ***ALL*** Scanner positions.
- In the survey folder (*.RiSCAN) create a new folder named 'MATRICES' and save ALL the SOP positions <Registration> <Multi SOP export> to this new folder. Make sure *.SOP and *.CSV are ticked and the Coord. system is GLCS. <OK>



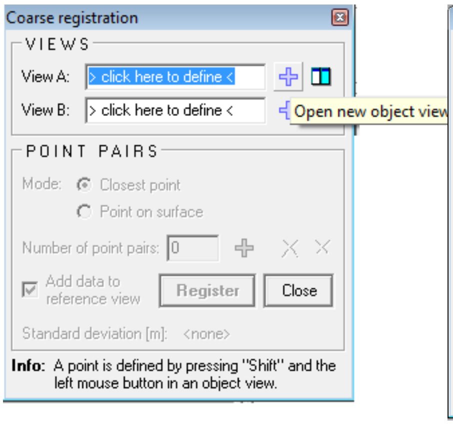
Before the computational scan registration tool, Multi Station Adjustment, can be run it is necessary to register the scans approximately using the Coarse Registration tool. There are two ways this can be done – either by picking pairs of corresponding points in each scan, or by manually translating and rotating each scan by eye onto the fixed scan.

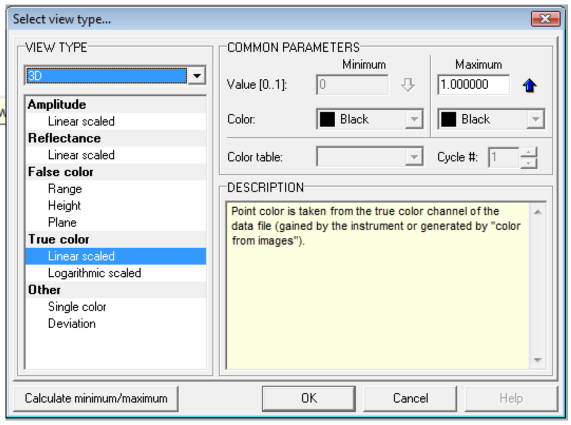
7.2.6.1 PICKING POINT PAIRS:

- From the **Registration** menu select **Coarse Registration**.

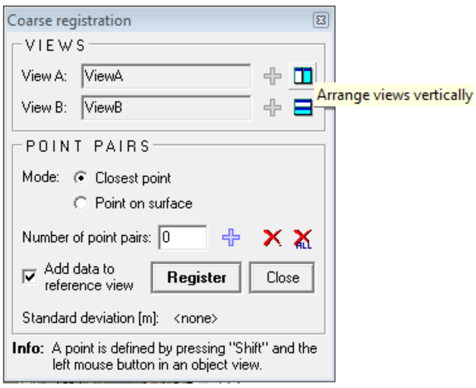


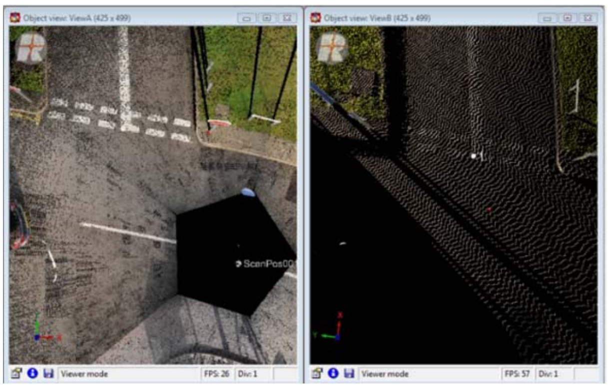
- In the Coarse Registration dialogue box click on the “Open new object view” button for View A. An empty Object view window opens. Drag & drop the “fixed” scan from the Project manager window into the new Object view window. A Select view type… dialogue box opens. Select **True color**, **linear scaled** option and click **OK**.



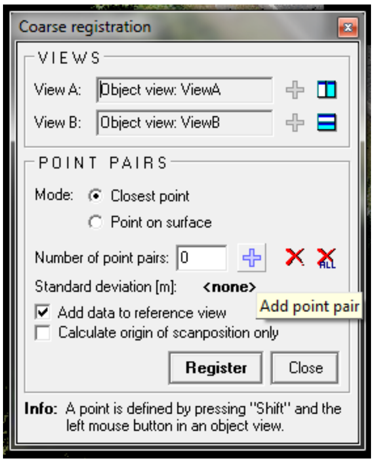


- Repeat for View B and drag & drop the first scan that you want to coarsely register with the fixed scan. Click on the Arrange views button to display both views side by side.

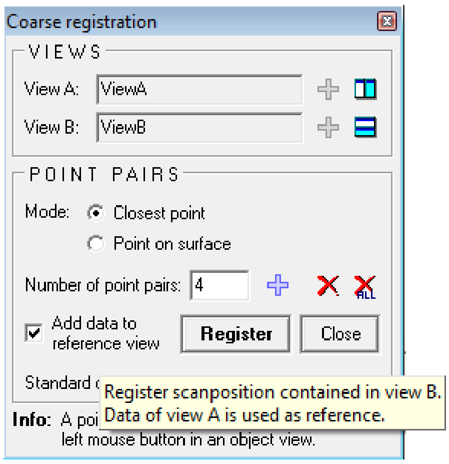




- View the data in both windows from above by clicking on the birds-eye view button. Rotate the scan data in View B using **SHIFT + Right mouse button** so that is orientated the same as the data in View A. Hold **R + Right mouse** button to draw a zoom window in both views to a common feature (e.g. white line, building edge) and select the “tie-point pair” using **SHIFT + Left mouse button** in both views. A yellow dot with the tie point number is displayed in each view (it doesn't matter which view is selected first). Click on the Add point pair button  to accept the tie point pair.



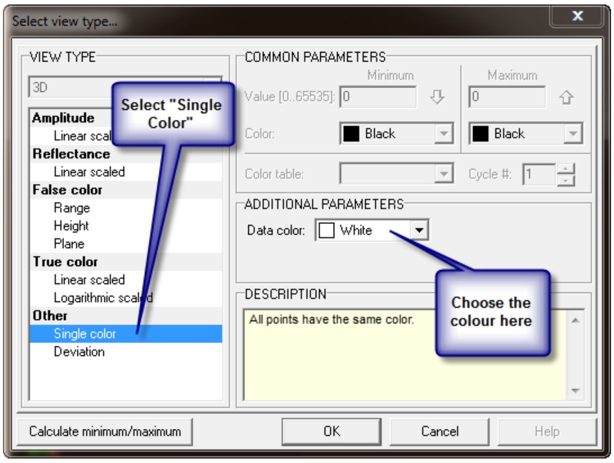
- Repeat the tie-point pair selection procedure until at least 4 pairs have been accepted then click on the **Register** button. The scan data in View B will be reoriented to best match the tie-point pairs. The scan data in View B will be added to the reference view (View A). Check that the standard deviation is acceptable (accurate to <1m).



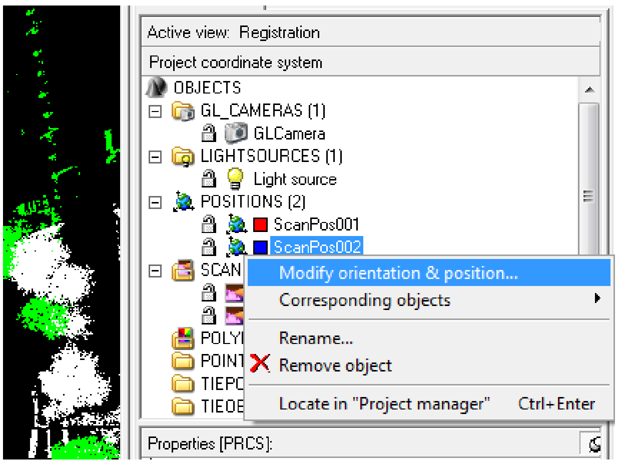
- Close the Coarse Registration Box. Repeat the coarse registration for each scan position in turn to roughly align all of the scan positions.

7.2.6.2 Manually translating and rotating

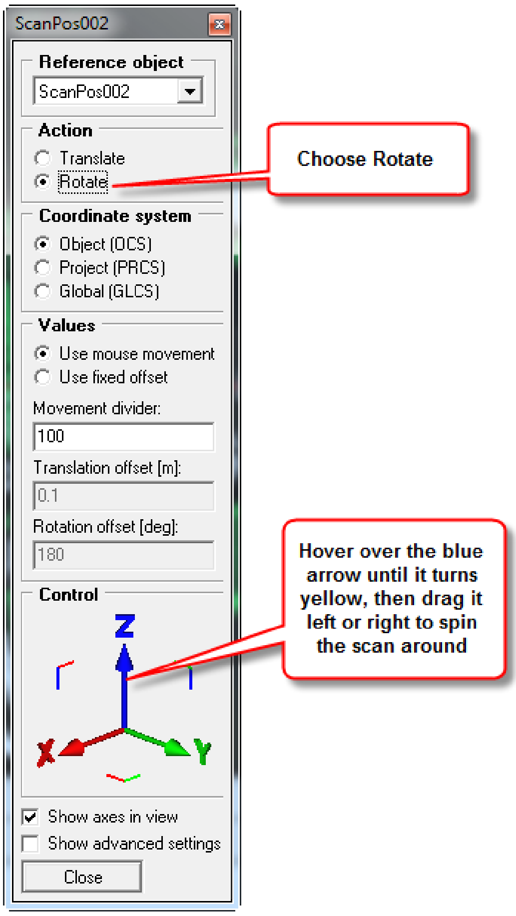
- In the **Project Manager**, right-click the **VIEWS** folder and select "**New object view...**". Enter a suitable name (e.g. Registration) and press OK. Drag the scan that you will hold fixed (is this example ScanPos001) into the view. In the "**Select view type...**" dialogue box, choose "**Other – Single color**" and choose a colour in the drop-down box, then press OK.

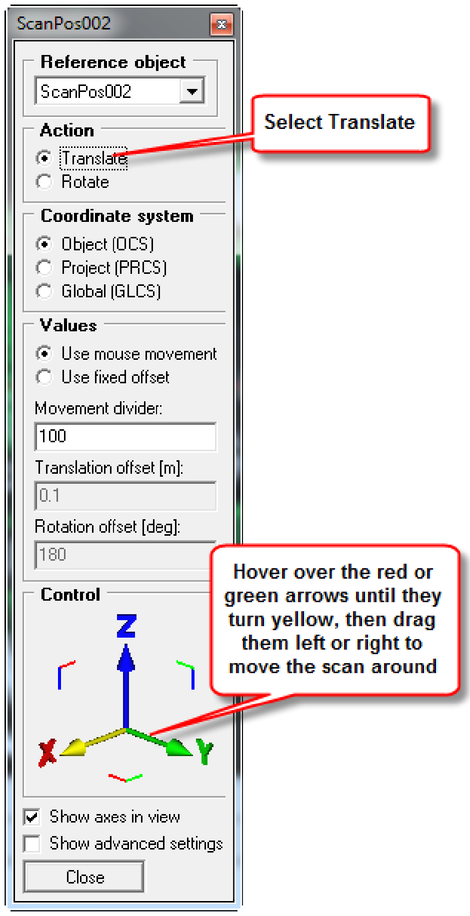


- Repeat for the next scan (in this example ScanPos002), choosing a different colour. You will now have two scans in the Object View, coloured differently. Press the "Bird's Eye View" button  to view both scans from above.
- Switch to the **Object inspector**, and under **POSITIONS** right-click **ScanPos002** (not the scan itself) and choose "**Modify position and orientation**".

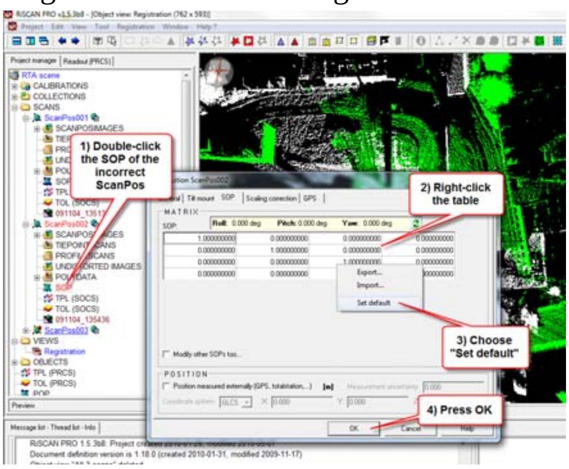


- The Modify Orientation and Position dialogue box appears. Under "**Action**", select "**Rotate**". Hover over the **blue "Z"** arrow and drag left or right to rotate the scan position around until it lines up with the next scan. (Hint: identify the position of the next scan position in the first scan, and rotate the scan until the scan position)





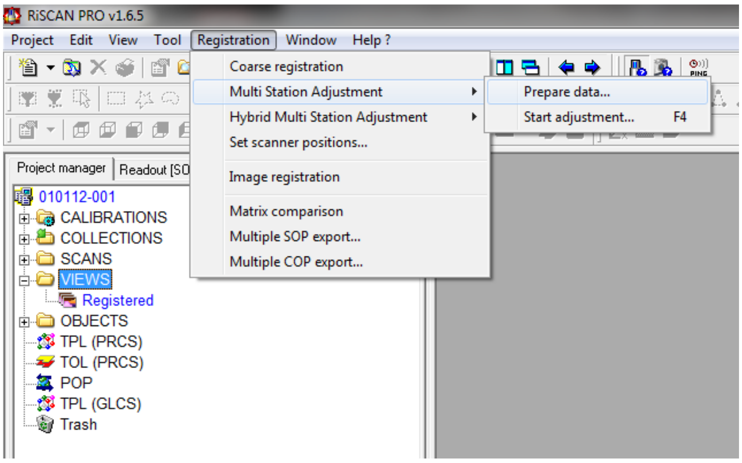
- Then, change the action to “**Translate**”, and drag the **red “X”** and **green “Y”** arrows to move the scan around laterally until it matches up with the fixed scan.
- You may need to switch back to “Rotate” to improve the orientation of the scan once it is closer. Be sure that you **ONLY ROTATE on the blue “Z” axis**, and you **ONLY TRANSLATE on red “X” and green “Y”**. If you make a mistake or get lost, you can set the scan back to the beginning by double-clicking the “SOP” for the incorrect scan position, and right-clicking the table and selecting “Set default”.



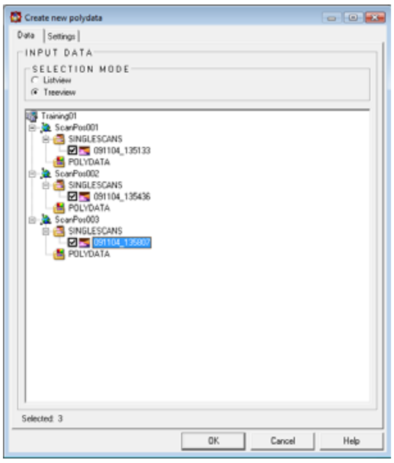
- Repeat for all remaining scans, until you have all the scans aligned approximately.

You are now ready to improve the alignment using Multi Station Adjustment (MSA). The MSA algorithm uses filtered versions of each scan to perform the surface matching registration process. A plane filter is used to identify and triangulate planar surfaces in each scan. The MSA process then identifies common planar surfaces from each scan and shifts the scan data until the best match is achieved.

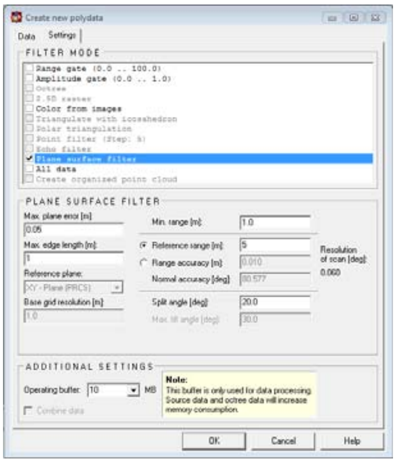
- From the **Registration** menu select the **Multi Station Adjustment > Prepare data** option.



- In the **Create new polydata** dialogue box check all the scans to be plane filtered on the Data tab.



- Switch to the Settings tab and check the **Plane Surface filter** (uncheck any other filter options).

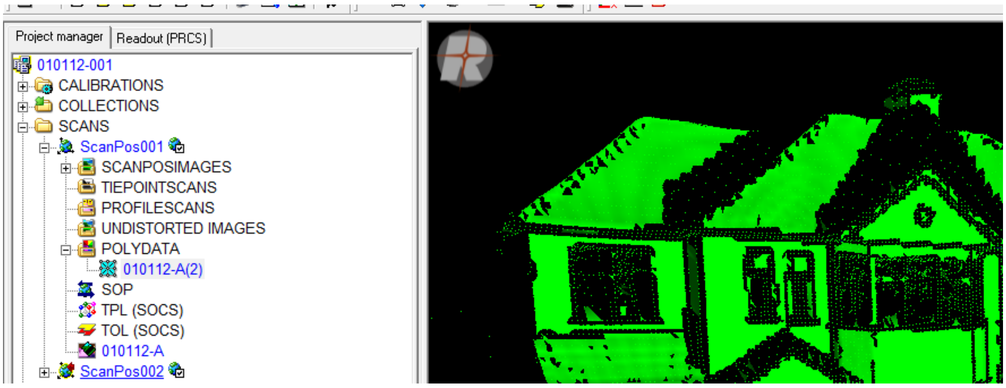


- The following settings are recommended for the Plane Surface Filter:

Parameter	Value
Max plane error [m]	0.05

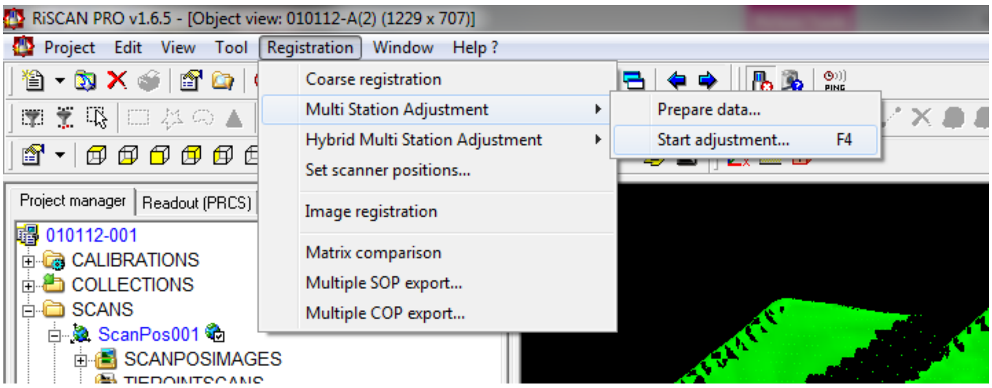
Max edge length [m]	1.0
Min range [m]	1.0
Reference range [m]	5.0
Split angle [deg]	20

- For rural scan scenes with limited planar surfaces it may be necessary to increase the "Max plane error" setting to 0.1 - 0.2m in order to identify sufficient planar surfaces.
- Click **OK** to create the plane filtered data. The filtered data appears in the **POLYDATA** branch of each Scan position in the Project manager window. View each filtered dataset (polydata) to check that it is representative of the actual scan.



7.2.6.3 Multi Station Adjustment

- From the **Registration** menu select the **Multi Station Adjustment** > **Start adjustment** (or press the **F4** short cut button).



- The Multi Station Adjustment (MSA) dialogue pox opens. The dialogue box displays a list of the scan positions to be registered. Check all the scan positions you wish to adjust.
- Select the "fixed" scan position, right click and select the **Lock position and orientation** option.
- The check boxes next to the X,Y,Z and R,P,Y values are unchecked meaning they will not be changed during the calculation. The Scale check boxes should be unchecked for all scans since it should not be necessary to scale the data.
- The registration process is iterative, usually requiring 2 or 3 iterations depending on the accuracy of the coarse alignment and the number of scans. The following PARAMETERS are recommended:

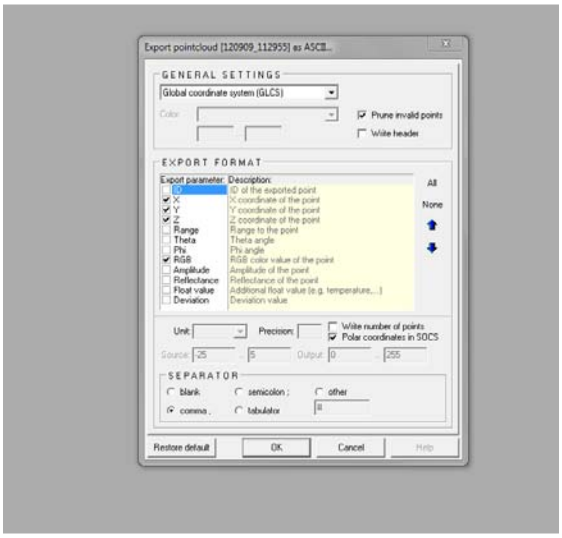
PARAMETER	First iteration	Subsequent iterations
Mode	all nearest points	all nearest points
Search radius [m]	**1.0**	**0.5**
Max tilt angle [deg]	5.0	5.0
Min. change of error 1 [m]	0.10	0.10
Min. change of error 2 [m]	0.05	**0.005**
Outlier threshold [1]	**2.0**	**2 x Error[StdDev] ***
Calculation mode	least square fitting	least square fitting
Update display	seldom	seldom

* The outlier threshold should be set to 2 x Error[StdDev] of each previous iteration

- The ADJUSTMENT check boxes should not be checked. These are for debug purposes only.
- Click **Calculate** to run the first iteration.
- The first iteration may take several minutes depending on the accuracy of the coarse registration and the number of scan positions. When the calculation is complete the Multi Station Adjustment dialogue box will switch to the **Results** tab and 3D plane orientation sphere and residues histogram are displayed. The plane orientation sphere shows the spread of orientation of the various planar surfaces used in the calculation. A good spread of orientations is desirable. The histogram shows the spread of errors for matching surfaces. A normal distribution centred around 0.0m is desirable.
- The STATISTICS section displays the number of polydata observations used in the calculation. This should be several thousand. The **Error [StdDev]** value represents the average surface match. A value of less than 0.02m is desirable. Set the **Search radius** to 0.5m and the **Outlier threshold** to 2 x Error [StdDev] value and repeat the calculation.
- Once an acceptable Error value is achieved the registration statistics can be saved in the form of a CSV file by clicking the **Save calculation statistics to file (*.csv)…** button. Close the Multi Station Adjustment dialogue box and visually check the combined point cloud data.

Save the data.

- In the survey folder (*.RiSCAN) create a new folder named 'DATA'. Right-click each scan. Choose Export, give it a relevant (*.txt) File name, and Save as ASCII (*.*). Click Save. Make sure GLCS appears in the drop-down, Prune invalid points is ticked, xyzRGB (colour) or xyzAmplitude (intensity) are ticked, and the comma button is highlighted. <OK>
- Alternatively Save as LAS1.2 (*.las). This will automatically save the RGB and Intensity data.



- Once All scans have been exported. Save and Close the Project.

8 Visualising the Data

The BGS has a number of high-specification PC’s capable of handling the acquired digital data, including a dedicated data processing PC (WSB, Upper Ground Floor, East). Software to process and output the acquired survey data is listed below. With the exception of Virtalis GeoVisionary and Esri ArcGIS, all these proprietary processing and visualisation software packages fall under single user license restrictions, and as such are either loaded onto dedicated PC’s or controlled by ‘dongle’ technology.

- Riegl RiScanPro (Acquisition & processing VZ scanner data)
- Riegl RiProfile (Acquisition & processing LPM scanner data)
- Leica Geo-Office (Post-processing GNSS data)
- Golden Software Surfer (Gridding scanner data)
- Innovmetric Polyworks (Change models & cross-sections)
- Bentley Pointools (Visualisation of point-cloud data)
- Paradigm GOCAD (Integration with other surfaces e.g. GPR)
- Applied Imagery Quick Terrain Modeler (3D model creation)
- Esri ArcGIS (2D mapping and visualisation)
- Virtalis GeoVisionary (3D mapping and visualisation)
- Split-FX (Rock-fracture analysis)
- Golden Software Voxler (3D visualisation)

In order to get the most out of your data a selection of the above software packages will need to be used. The following is a suggested workflow for the construction of 3D models:

8.2 GNSS DATA

8.2.1 Leica Geo-Office

- Import GNSS data into Leica Geo-Office
- Convert co-ordinates to Local Grid
- Export as ASCII (*.csv) file

8.3 LIDAR DATA

8.3.1 RiProfile

- Carry out 'Backsighting' orientation and 'Alignment' for ***all*** scan locations
- Save SOP positions to MATRICES folder
- ‘Colour from images’ to create coloured point cloud
- Create ‘Panorama’ images
- Modify SOP using Polyworks image files
- Export data as ASCII (xyzi or xyzRGB) files using global co-ordinates

8.3.2 Polyworks

- Import Riegl project from RiProfile
- Choose 'best' scan and 'lock' it. 'Ignore' all but one other
- Carry out 'Best-fit' alignment
- 'Lock' this scan and carry out process again (with third scan)
- Highlight ***all*** scans and 'auto-match' to 'Global reference points'
- Export 'Alignment Matrices' to MATRICES folder

8.3.3 RiScanPro

- Carry out 'Backsighting' orientation and 'Alignment' for ***all*** scan locations
- ‘Colour from images’ to create coloured point cloud
- Create ‘Panorama’ images
- Carry out Scan Registration (Plane Filter and MSA)
- Export data as ASCII (xyzi or xyzRGB) files using global co-ordinates

8.4 MODELLING AND VISUALISATION

8.4.1 Polyworks

- Import ASCII file
- Create a mesh (triangulate scan)
- Convert to 'Reference' object
- Do change models (if required)

8.4.2 QT Modeler

- Import ASCII file
- Cut to size (if necessary)
- Match model altitudes - this should already be done
- Merge models
- Create surface

- Do change models (if required)
- Export as Z-Map

8.4.3 Surfer

- Import ASCII file
- 'Grid' the data using either the Kriging, Nearest Neighbor or Triangulation with Linear Interpolation method
- Create a Contour map. Create a Base map. Create a Post map (save this as a *.shp file)
- Create a 'Wireframe' model from the grid data to drape the previous maps on
- Create a Surface map
- Export maps

8.4.4 GeoVisionary

- Use PointCloud Tool to convert ASCII or LAS files into DAT file
- On the 3D+ Tab Right-Click PointClouds and choose Add PointCloud
- Navigate to the DAT file and click Open
- Refer to GeoVisionary notes

8.4.5 Split-FX

- A User Guide (written by D. Boon) is appended to this report (Appendix 2).

Appendix 1 Re-adjusting camera calibration

This guide will show you how to re-adjust the camera mounting calibration in RiSCAN PRO, following the removal and re-mounting of the camera. This is necessary when the scanner and camera must be separated for storage in their individual carry cases. It may also be necessary if the camera goes out of calibration – if, for example, the camera is knocked, or removed for maintenance.

1. Identify tie-points common to scan and photos

Open the RiSCAN PRO project, and locate a scan in which there are identifiable features (building corners, signposts, road markings, etc.)

Double-click the scan to open it, and use the parameters in Figure 1 to display it. Click the "**Calculate minimum/maximum**" button, and wait for the scan to be processed; then click **OK**.

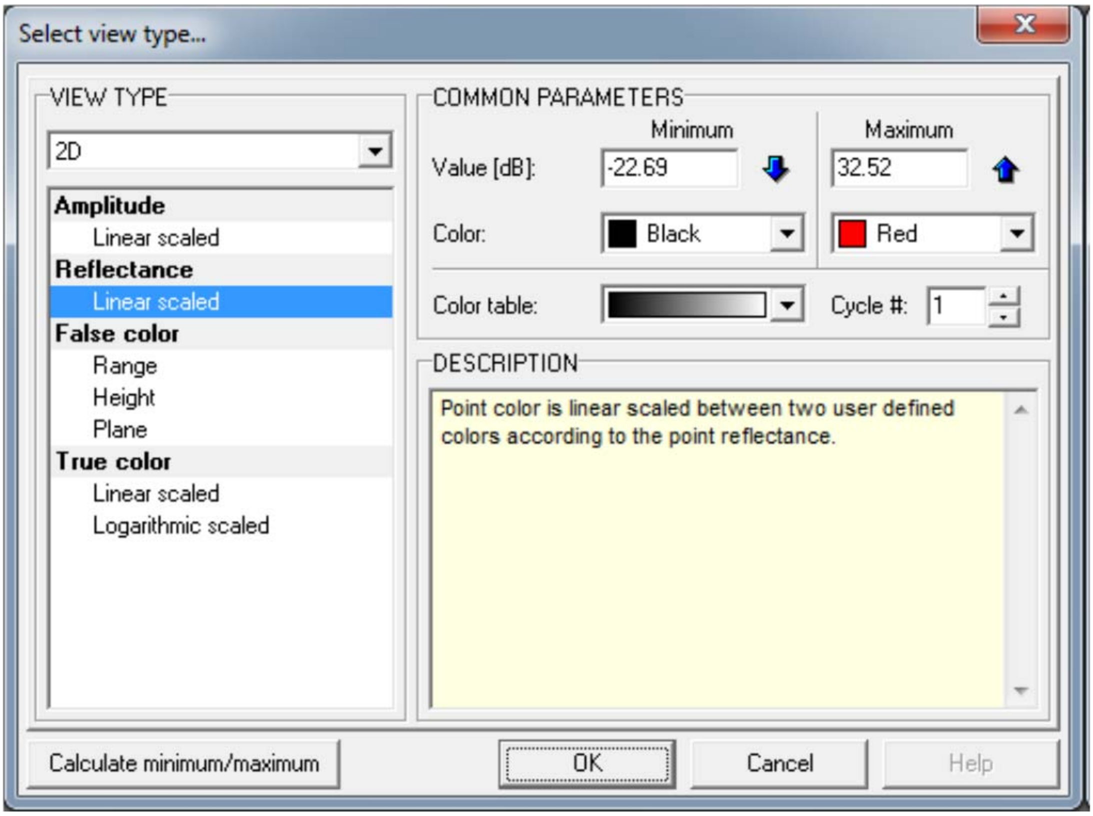


Figure 1: Scan display parameters

Now open the first image, by expanding the "**SCANPOSIMAGES**" folder (Figure 2) and double-clicking an image.

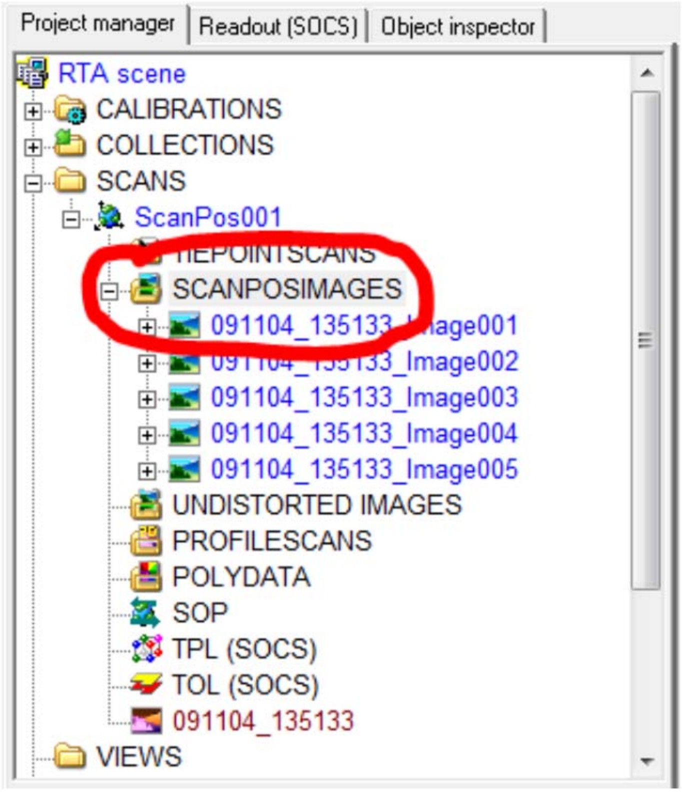
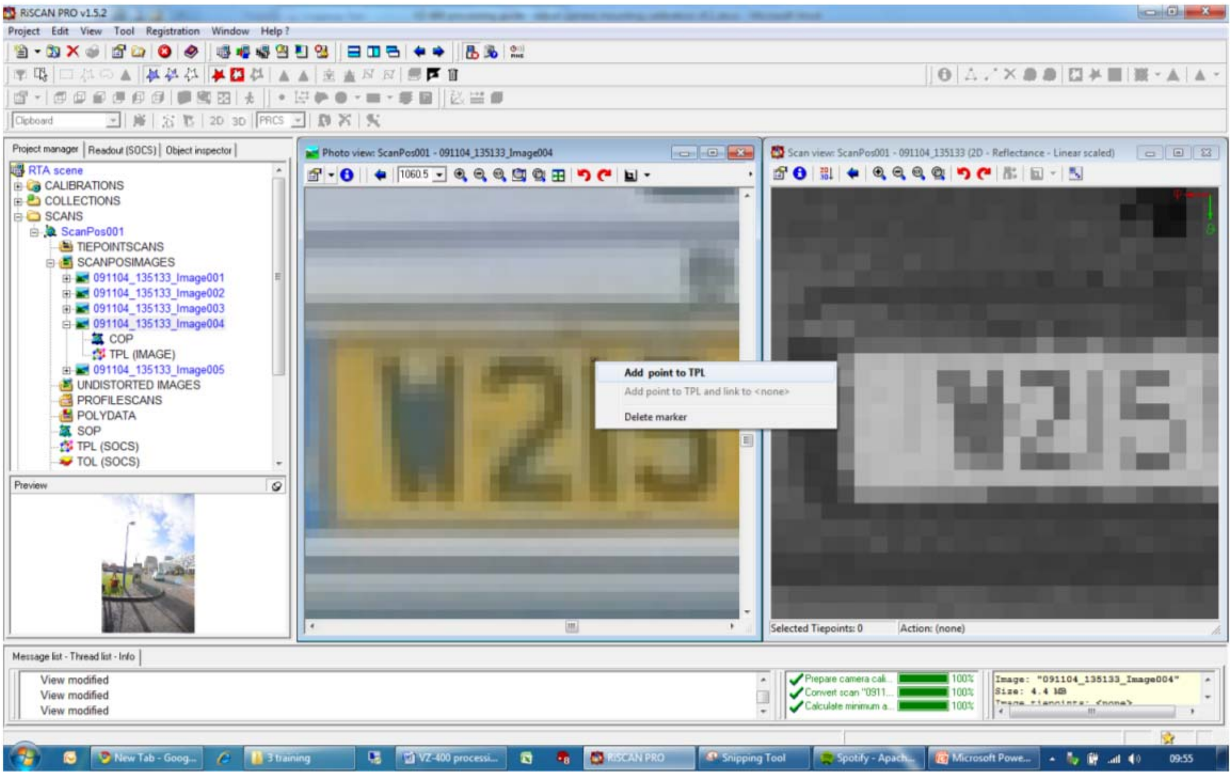


Figure 2: SCANPOSIMAGES folder location

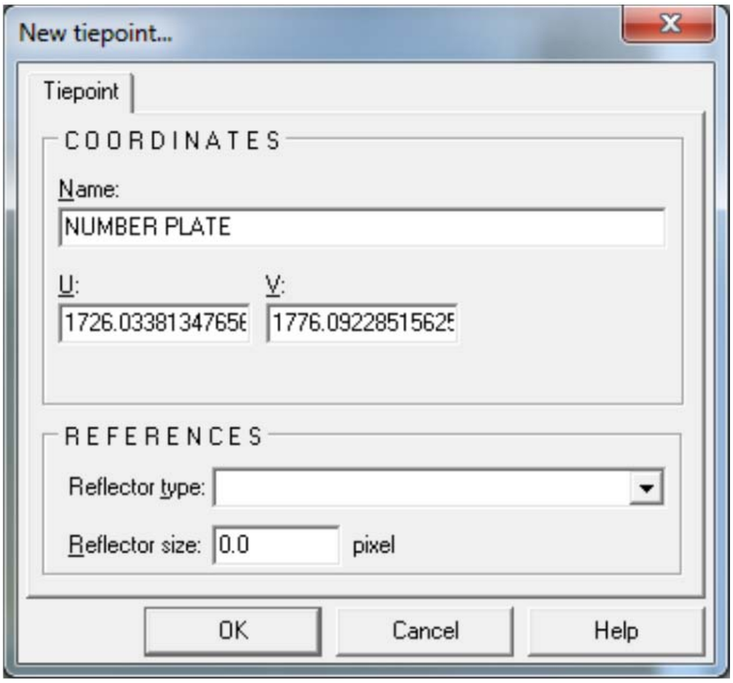
Click the "Arrange windows vertically"  button to arrange the scan and image side-by-side.

Now identify features common to both scan and photo. You are looking for a good spread of point in both the vertical and horizontal directions. Avoid picking points in clusters – make sure there is a good spread throughout the scan.

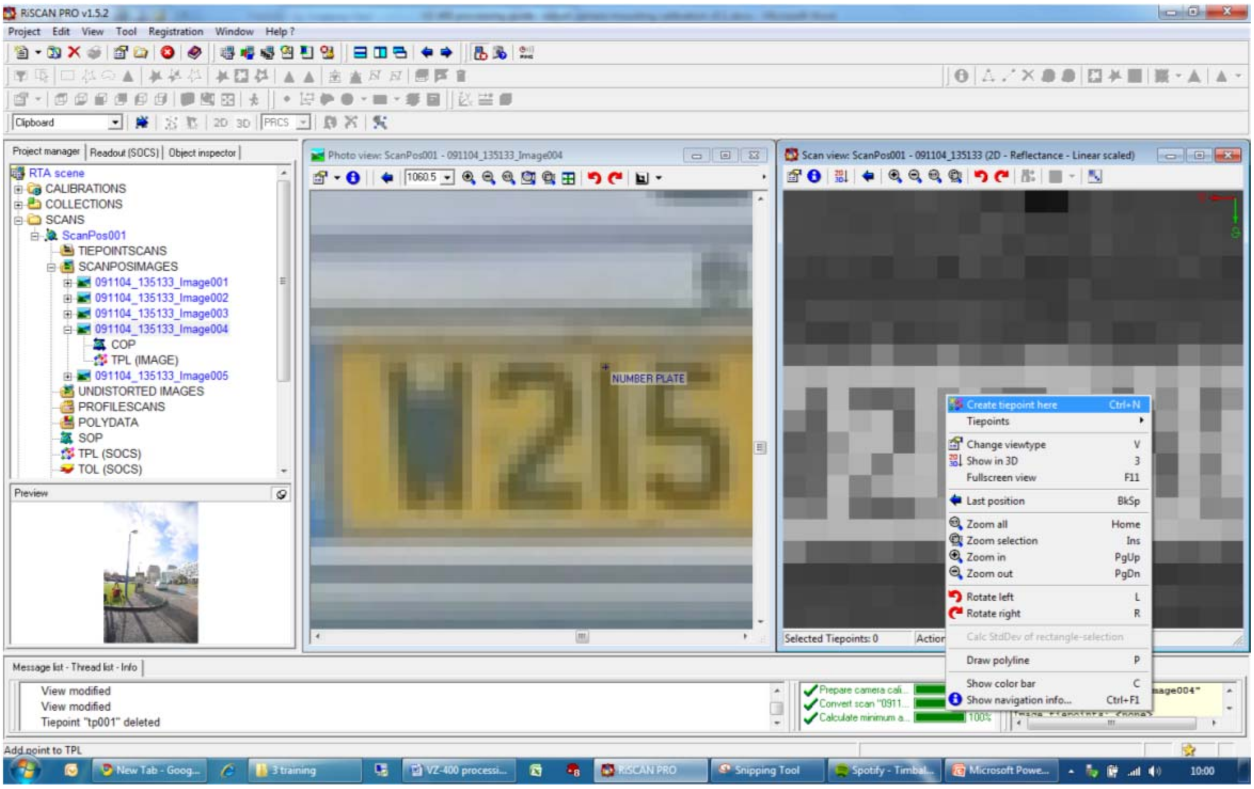
When you have found one, left-click the pixel in the **photo** to place a marker (a small blue cross), then right-click the marker, and choose "Add point to TPL".



In the dialogue box that appears, enter a name for the tie-point and click “OK”.

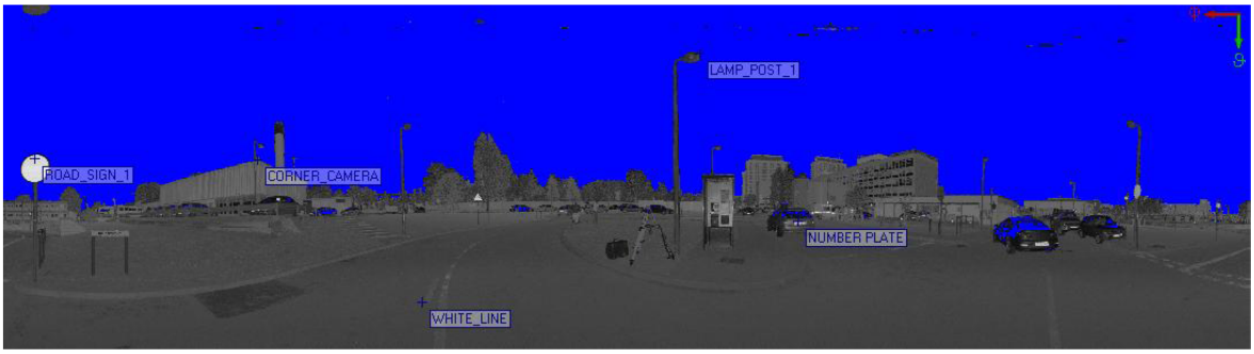


Now find the corresponding pixel in the scan, and right-click the pixel and choose “Create tie-point here”.



In the dialogue box that appears, enter the same name for the tie-point and click “OK”.

Repeat this procedure until you have at least four pairs of corresponding points.

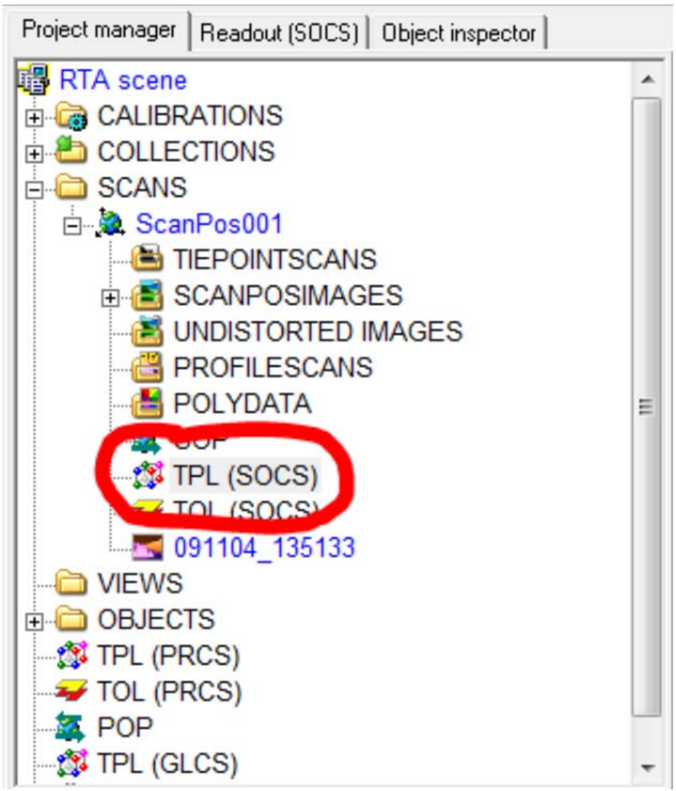


Now, close the scan and photo views by clicking the **small** "X" in the top-right corner of the RiSCAN PRO window (**not** the **red** "X", which would close RiSCAN PRO.

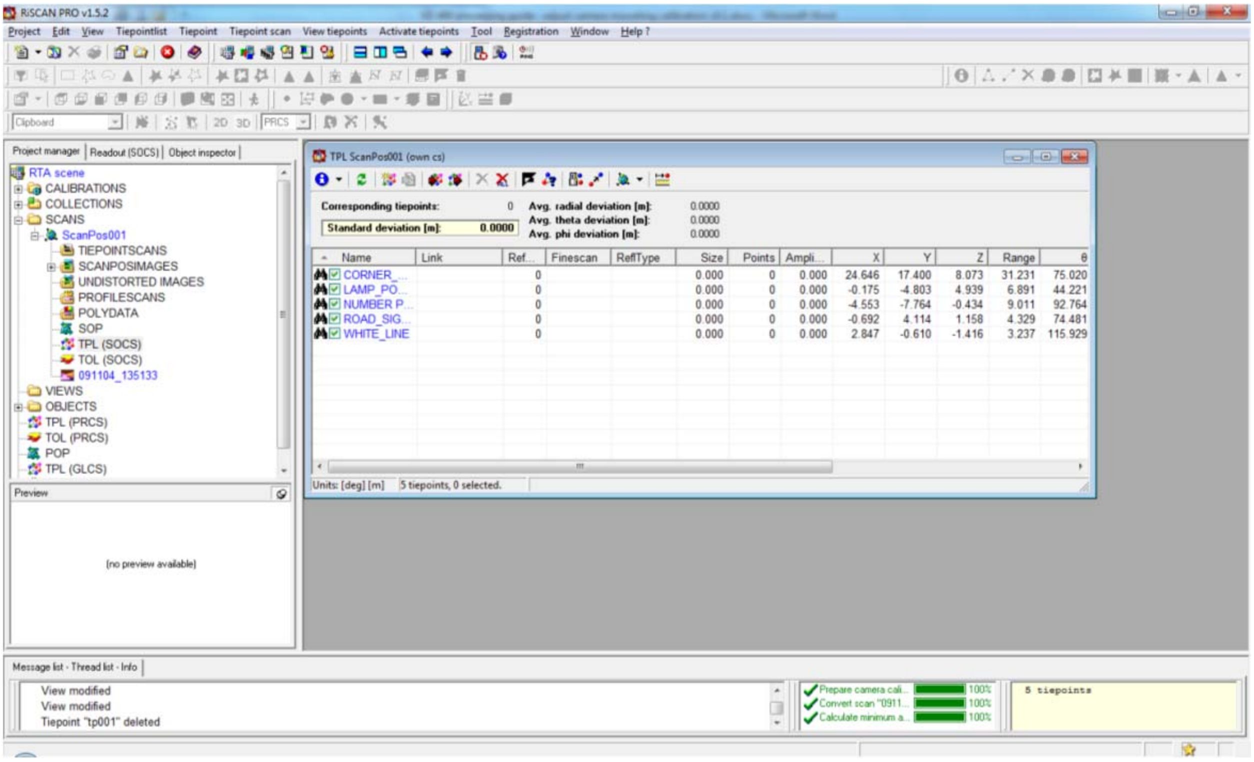
2. Link tie-points together

When you created tie-points, they were added to the "tie point lists" (TPL) of both the scan and the photos. Now we need to link the pairs together, and to do this we need to open both TPLs.

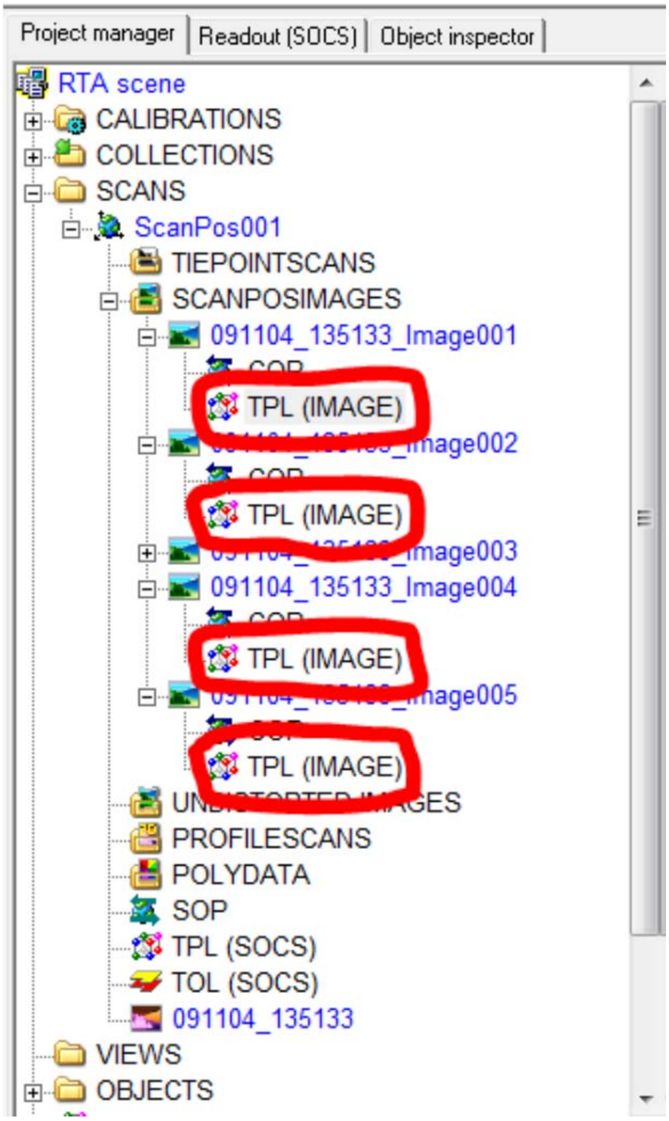
The scan TPL is located just below the SOP in the Project Manager (each Scan Position has it's own TPL). Double-click the item **TPL (SOCS)**.



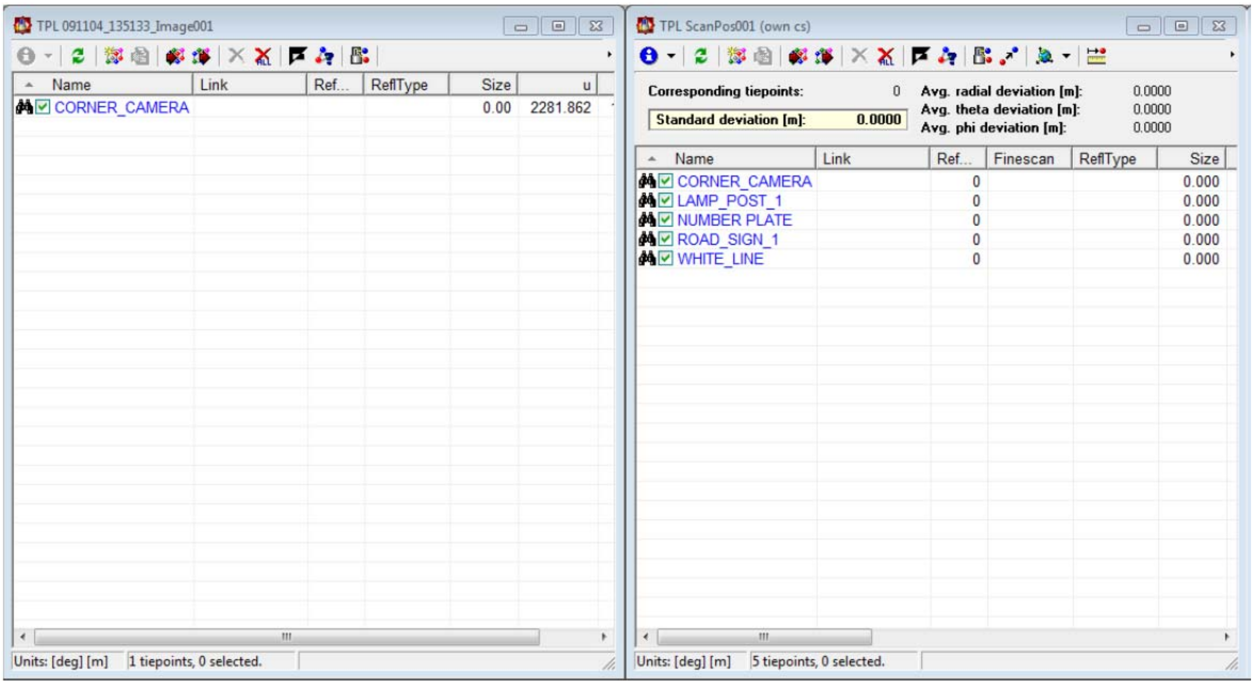
This will open the TPL in the main window.



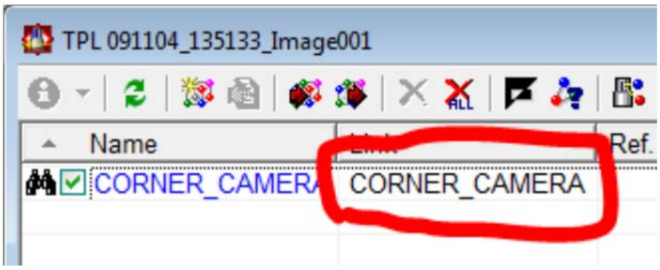
Now open the TPL for the first image in which you have created tie-points. This is located in the SCANPOSIMAGES folder, under the image, and is called TPL (IMAGE):



Click the “Arrange windows vertically”  button to arrange the TPLs side-by-side.

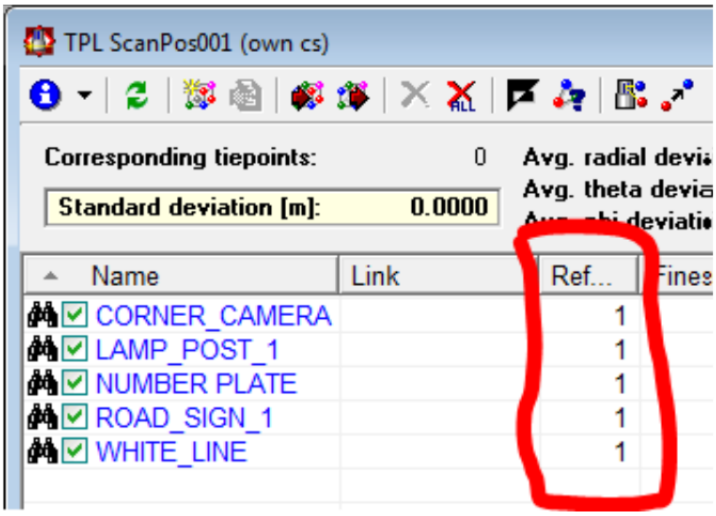


Now, drag the tie-point in the **image** TPL onto the corresponding tie-point in the **scan** TPL- this will create a “link” between the tie-points. Note the “link” column in the image TPL has been filled in.



Repeat for the remaining tie-points. You may have to open the other image TPLs to find the rest of the image tie-points.

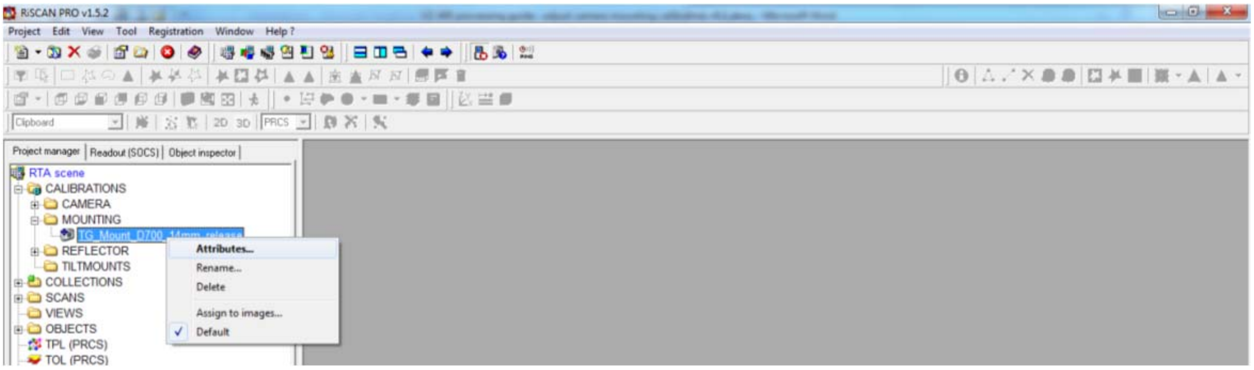
When you have finished, each tie-point in the **scan** TPL should have a “1” in the **Ref...** column This shows that it is referenced by another tie-point.



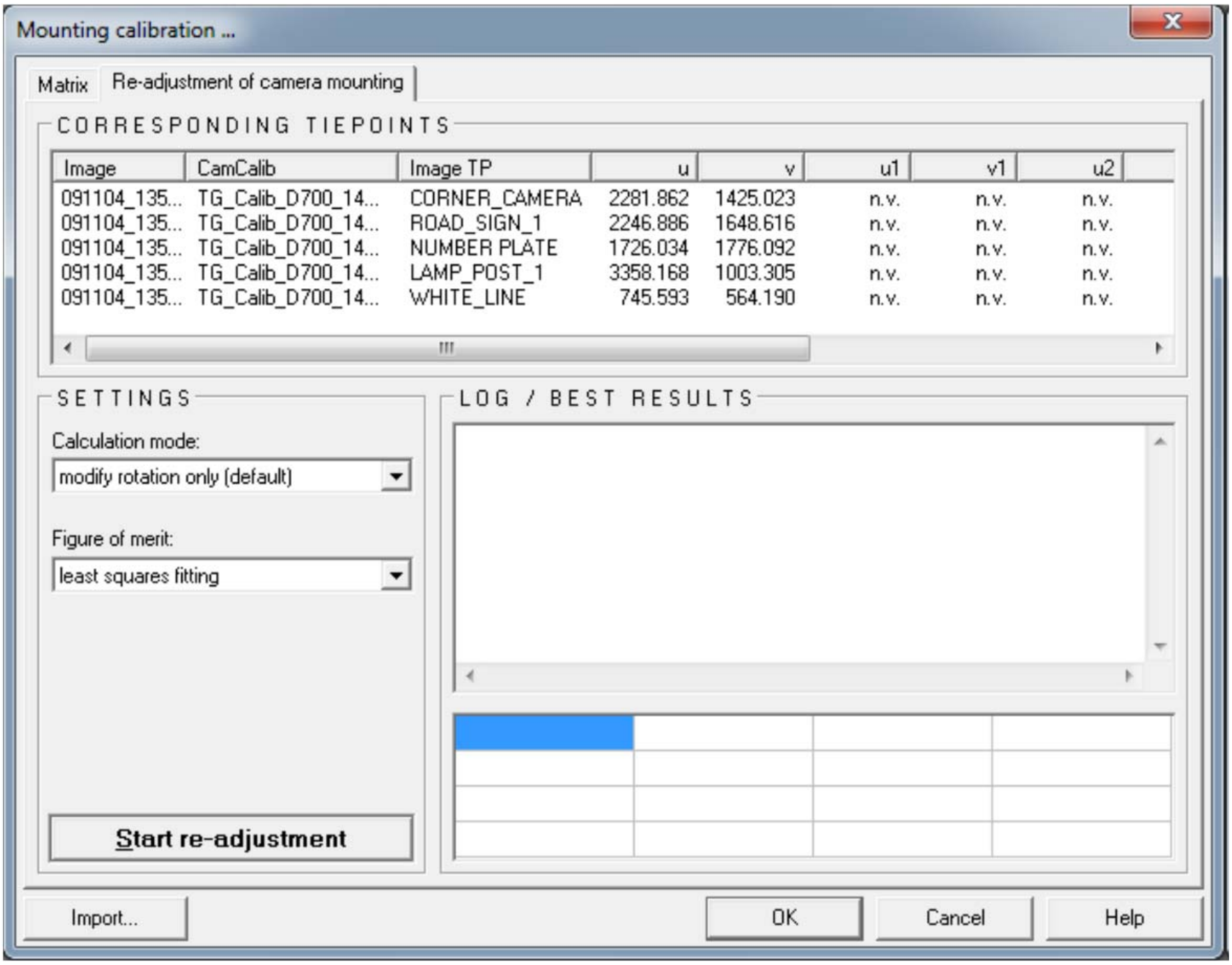
Close the TPLs.

3. Re-adjust the mounting calibration

RiSCAN PRO now has all the information it needs to adjust the calibration. To perform the adjustment, locate the mounting calibration in the folder **CALIBRATIONS** > **MOUNTING**. Right-click it, and choose “**Attributes...**”



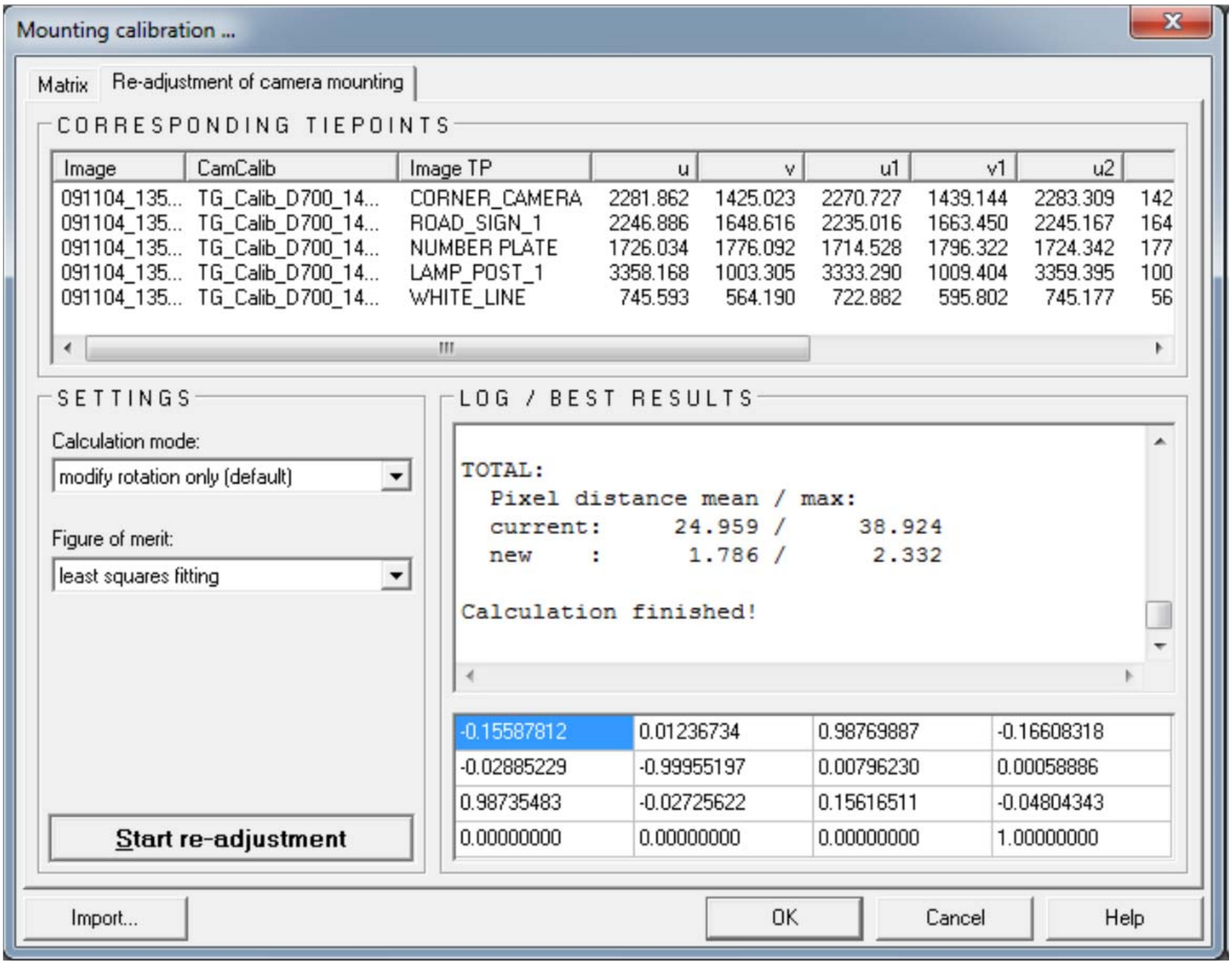
Switch to the tab “**Re-adjustment of camera mounting**”. You will see listed all of the image tie-points that were created.



Check that the following options are set under **SETTINGS**:

Calculation mode: modify rotation only (default) Figure of merit: least square fitting

Click the button “**Start re-adjustment**”. The software will find the best match between the tie-point pairs, and the results will be displayed in the **LOG/BEST RESULTS** panel.



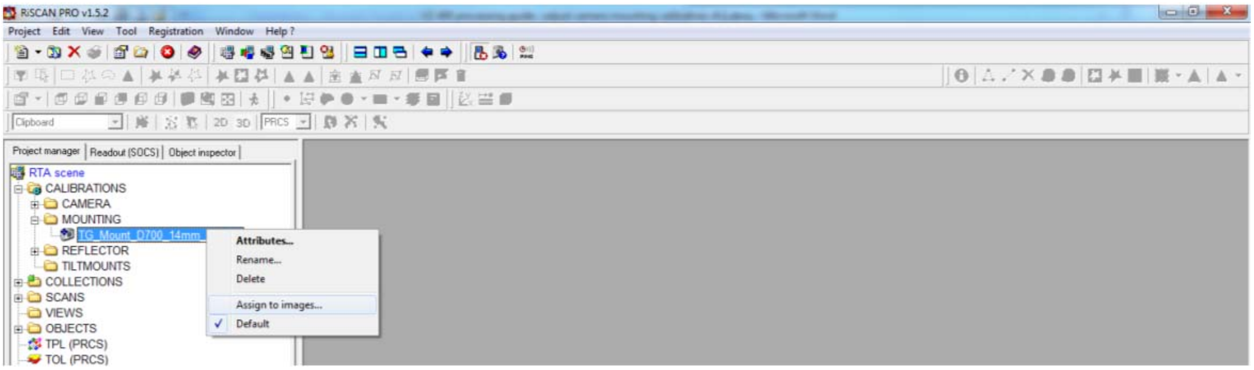
In this example, the distance between the tie-points has been reduced from 24.9 pixels to 1.7 pixels. This means the calibration has been greatly improved, and the images now match the scans to within 2 pixels.

If you are happy with the results, click OK to save the new calibration and move on to the next step. Otherwise, go back to the beginning and select the tie-points more carefully.

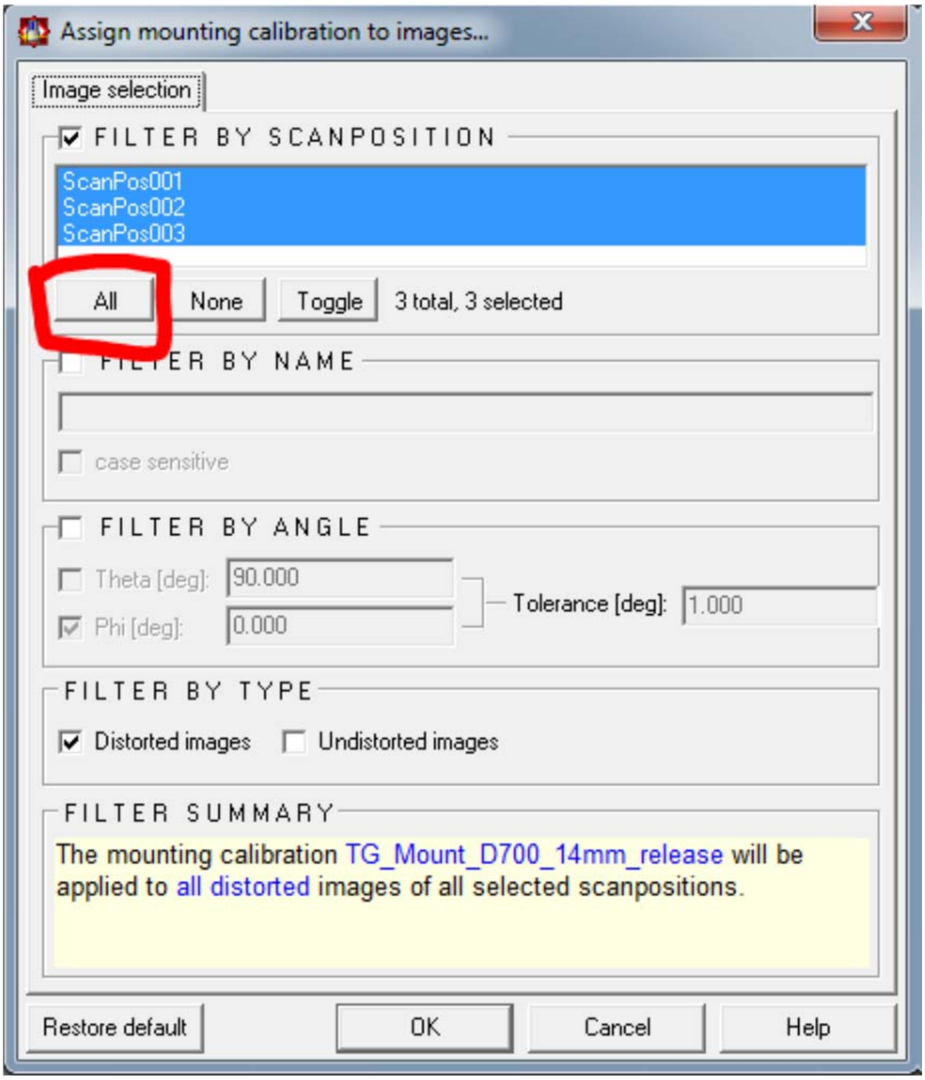
4. Assign new calibration to photos

Now that the calibration has been updated, it must be assigned to the images.

Right-click the mounting calibration again in the Project Manager, and select "**Assign to images...**"



In the dialogue box that appears, click the button "**All**".

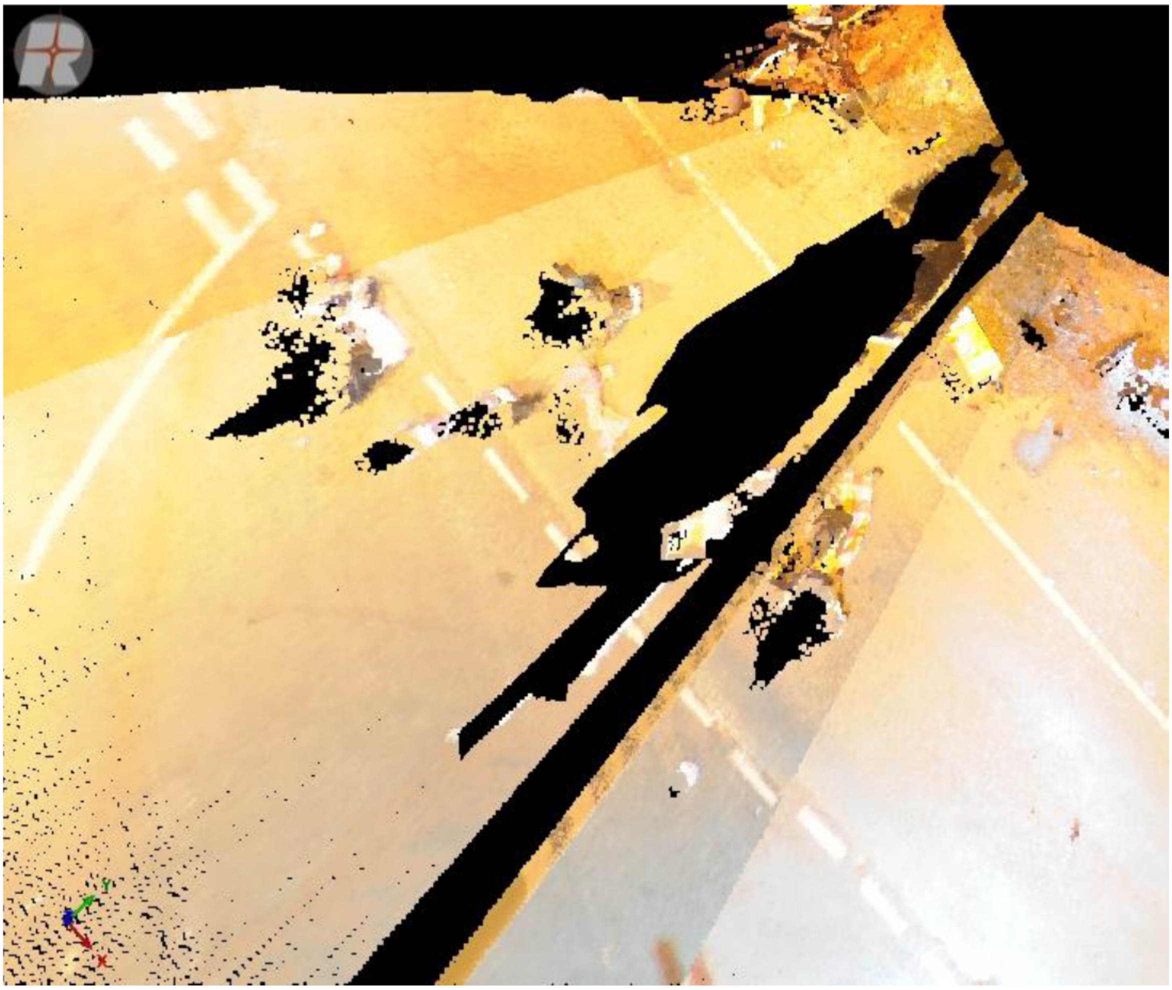


Click “**OK**”. Thee new calibration will be applied to all the images in the project.

5. Re-colour the scans

If the scans had been coloured before this re-adjustment procedure was completed, they will still have the previous colouring. Therefore you must now colour the scans again.

Right-click each scan in turn, and select “Color from images”. The colours will be re-assigned to the scan points, using the new camera calibration.



Before calibration adjustment

After calibration adjustment

Appendix 2 Split-FX User Guide

Extraction of structural data from point clouds derived from TLS

D. Boon (October 2011)

This documents serves as a quick start up guide aimed to walk you through the basic steps required to measure planes -e.g. Dip and Dip Direction from a TLS derived point cloud using Split-Fx (developed by Split Engineering Version 2.1.0). This guide assumes a working knowledge of RiProfile/RiScanPro, the Riegl TLS operation procedure and processing software (see Jones, 2009. *IR/09/050*).

STAGE 1 – IMPORT POINT CLOUD

Before you import you first need to export the point cloud from RiProfile:

- Point clouds can be exported from RiProfile project as an ASCII. Comma delimited with the format x,y,z,r,g,b maintains the colour from images information and greatly aids visual interpretation of the structures to be measured when defining patches.
- If not already done so, *in RiProfile*, filter the scans (v1.6.2) to create a single point cloud (polydata).
- Then right-click on the PolyData object in Project Manager Window and select 'export' (Figure 1). A box should appear (Figure 2). Select the ASCII option and click 'OK'. Another box will open (Figure 3). In the General Settings heading select the GLCS option. If your project has not been geo-referenced select the project system. Also select x,y,z and r,g,b for the file format to preserve colour information in the point cloud. Save the ASCII to the SPLIT FX folder on the E drive or backed-up Local Server.

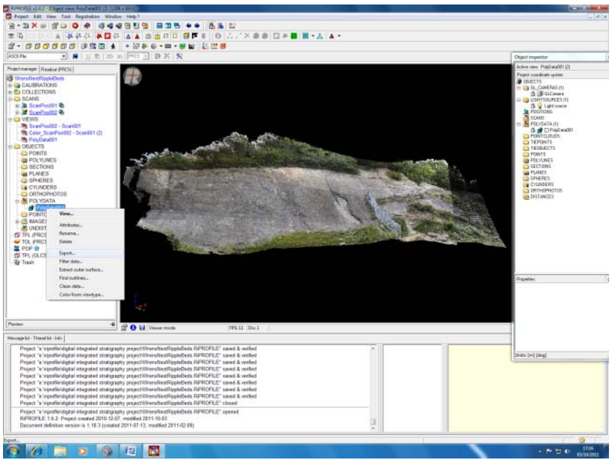


Figure 1 – Export point cloud in RiProfile

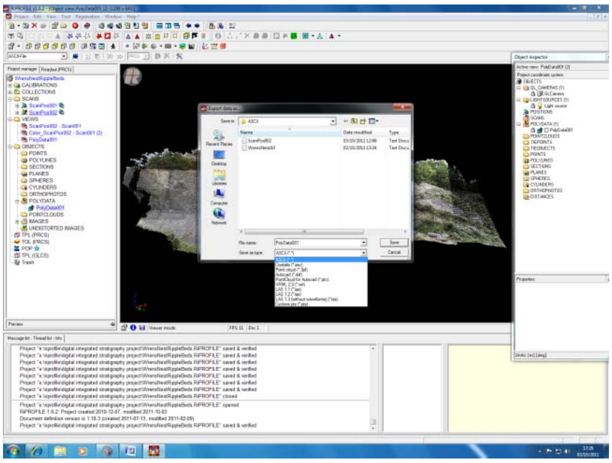


Figure 2 – Save as ASCII

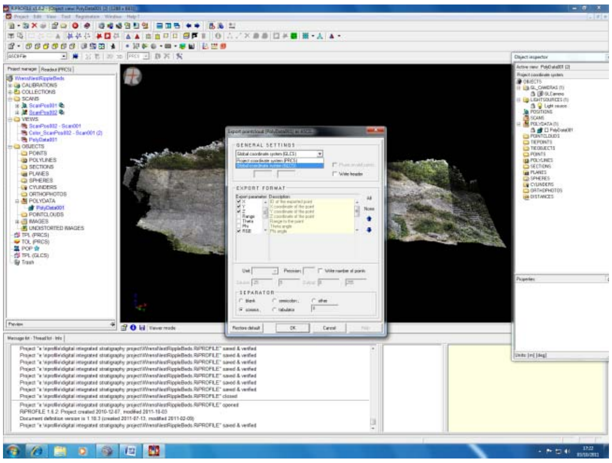


Figure 3 – Choose GLCS and x,y,z, with RGB format to preserve colour information

If you have no dGPS data for the scanner positions or known survey markers in the scans then you cannot orient and register the point cloud. You don't necessarily need to dGPS the scan so long as you measured the azimuth of the scanner in the field (with a compass, and the scanner set to 'park position'). However it is 'good practice' to survey the scanner locations or markers to enable accurate geo-referencing of point clouds.

- Now save and close your RiProfile project. Check that the ASCII.txt file actually saved out. Open it (e.g. in Notepad) and resave a copy with file extension '.xyz'. This extension is enables Split-FX to read the point cloud file.
- 'Fire up' Split Fx. (At time of writing, Oct 2011, we were using Split-FX64 2.1.0 running on Windows7)
- Select 'New' icon to open a new 'Region'. Next click 'file', 'open' and browse to where you saved the ASCII. You should see the .xyz file. Select it and click 'OK'.

You need to inform Split-Fx what file structure your ASCII has so it can read the file correctly. The data from the ASCII (.xyz) is shown in the 'sample text' window. In the 'content column' double-click on a field (currently set to 'ignore' field). Change the field from 'ignoor' to the appropriate field (e.g. X, Y or Z) by selecting from the drop-down list. Repeat this action to correct all the fields one-by-one.

- If you are opening a large point cloud (e.g. >150MB) then you may need to wait for a minute, and then your point cloud should appear, in full RGB glory, encompassed by a ‘bounding box’, in the black window (Figure 4).

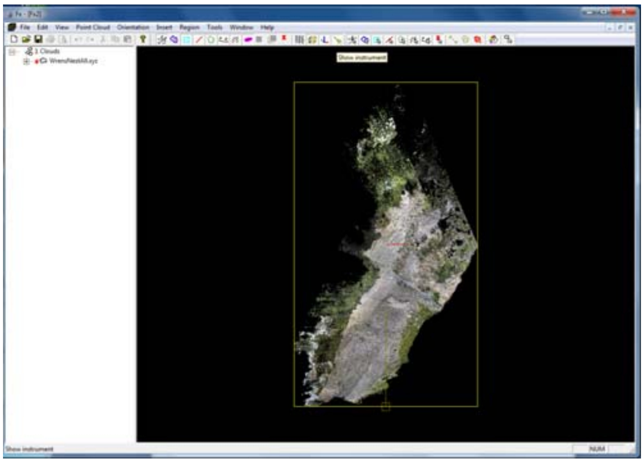


Figure 4 – Colour point cloud displayed in 3D window

TIP: Mouse operation: Holding the right mouse button down allows free rotation and tilt of the model, holding the right button down allows panning, and scrolling the mouse wheel will zoom in and out.

Stage 2 - Create MESH (TIN)

The Brown Box: You will notice a ‘brown box’ with a long arm and a short arm shown in Figure 5. This depicts the ‘scanner orientation’. It defaults to the long arm aligned due north, along the y-axis. The short arm points upwards.

- The surface meshing operation uses the scanner orientation to bias triangle formation. Therefore, you may need to adjust the ‘scanner orientation’ to optimise the mesh generation. The ideal ‘scanner orientation’ is where the long arm is orientated perpendicular to the discontinuity face(s) you wish to measure, thus creating mesh triangles that lie flat/flush with the real surface and that do not bridge erroneous points. You can delete individual triangles. This is why it is best to import a cleaned point cloud containing just the points that define structures of interest (i.e. no vegetation).
- You can delete unwanted points before meshing by activating the ‘mouse mode tool’ then digitising a box. The box draws relative to the viewing direction so be careful to only delete points you want to. Selected points are coloured red. Then press delete. Clear a selection by ‘Edit’ in the main tool bar then ‘clear selection’. ‘Save’ to save the clean point cloud.

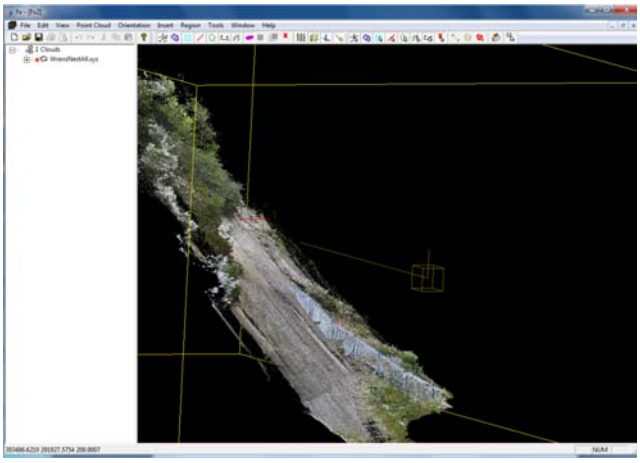


Figure 5 – Scanner orientation symbol (brown box)

- To adjust the scanner orientation, first manually rotate the model (with mouse) so that you are looking directly on to discontinuity surfaces that you want to measure (perpendicular to the plane of the surface or the 'pole'). Then select 'Orientation' then 'Scanner Orientation'. Select the 'Modify the scanner position to match the current view orientation' option.

Note that the azimuth and dip of your current view direction is displayed in the box. 'OK' this and note how the 'Brown Box' in the 3D window has changed its pointing direction. The long arm should now be pointing directly at the surfaces you are interested in measuring plane on. You do not need to add a Note this action does not change the referencing of the points (if they are geo-referenced in a Global or Local project coordinate system).

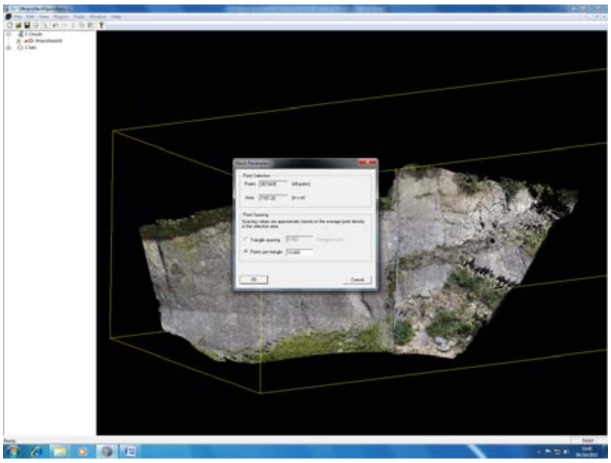


Figure 6 – Define mesh parameters

- When the point cloud has been edited and is ready to be meshed go to 'Point Cloud' in the main tool bar then select 'Create Mesh'. A box will appear as shown in Figure 6. You can control the size of triangles in your mesh. Recommended starting point spacing is 0.15m. Point spacing will depend on the resolution of the scan relative to the scale and roughness of surface you want to measure. Select 'OK' and the mesh will generate. Visually inspect the mesh to see if the triangle size is fine enough to represent the detail of the rock surface. You can toggle the point cloud or mesh on and off and rotate the model to aid visual comparison.

STAGE 3 - DEFINE PATCHES AND DISPLAY IN A STEREONET

- A ‘patch’ is effectively a polygon that defines a selection area for triangles with common orientations. If your mesh represents the rock surface realistically then the triangles will be orientated close to the orientation of that planar structure (e.g. bedding, fault, joint, cleavage, cliff/cutting face. Patching enables a large number of triangles (dependent on your triangle size) to be analysed and therefore allows statistical analysis of all triangle orientations and so statistical based determination of the orientation of a plane.
- Patching can be carried out in either a semi-automated way or completely manually. If you want to measure the orientation of a specific surface in the model then adding a patch manually offers the most freedom and is quickest, though introduced subjective judgment. If you wish to analyse the entire rock face to objectively assess how many discontinuity sets can be recognised then the semi-automated approach may be more appropriate.

To define patches click in to the 3D region (to activate the full toolbar options), click on ‘Point Cloud’ on the main tool bar, then ‘Find patches’. Wait a moment for patches to calculate. Then toggle off the points to reveal the patches, defined as blue polygons as shown in Figure 7.

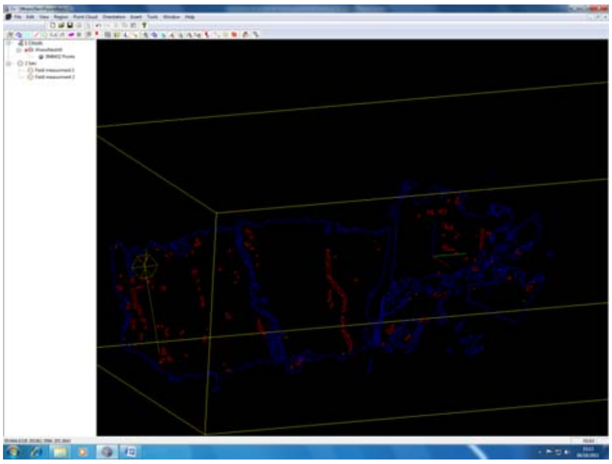


Figure 7 – Display of automatically found patches (Blue areas)

- To see the patches plotted on a stereonet (i.e. the measured discontinuity plane) click ‘Region’ then chose ‘StereoNet View’. A stereonet will appear in a new Region as in Figure 8.

Note that you can change the symbols and display planes as circles or poles. To change stereonet settings right-click within the stereonet view region and a box will appear labelled ‘stereonet properties’.

- To manually measure the orientation of a plane you must define a new ‘patch’ to cover the surface you wish to measure.
- A patch is constructed from nodes (points) and lines connecting the nodes. The nodes can be manually edited (moved or deleted) or new nodes inserted to density lines.
- Entire patches can be deleted by selecting the patch in the 3D region with the mouse mode activated. When selected patch will become highlighted (Figure 8). Hover over a node and right click to delete or insert points (nodes).

To measure a plane you must define a new patch. Change the display to just mesh or combined mesh and points so you can see what you are digitising. From the main tool bar select ‘Insert’ then choose ‘Patch’. The curser will change from an arrow to a cross hair and you are in draw mode. Define the area of patch by digitising onto the surface with right clicks defining nodes. Left click to finish the sketch and the polygon joins automatically. You should see the new plane display in the stereonet view (Figure 9). Measure the poles by hovering your mouse over the stereonet and noting the values in the very most bottom left of the main Split-Fx window. Remember that if you hover over a ‘pole’ you are reading off a pole orientation, so if you want to measure the plane (e.g. bedding: dip, dip direction) you need to convert the pole to a plane orientation.

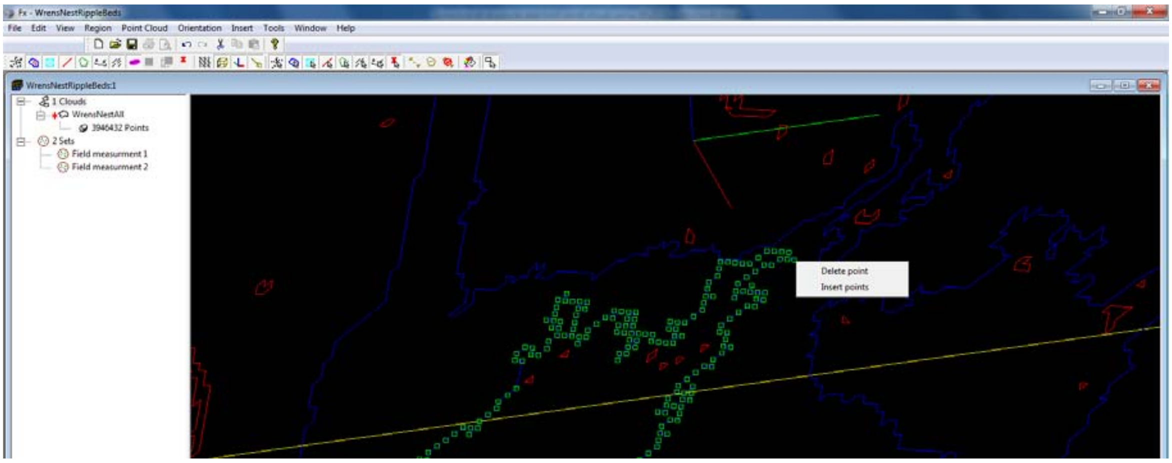


Figure 8 – Manually editing patches

TIP: Minimise the Stereonet View region to see your point cloud in 3D view. Alternatively view all active regions by ‘Window’ then ‘Tile’.

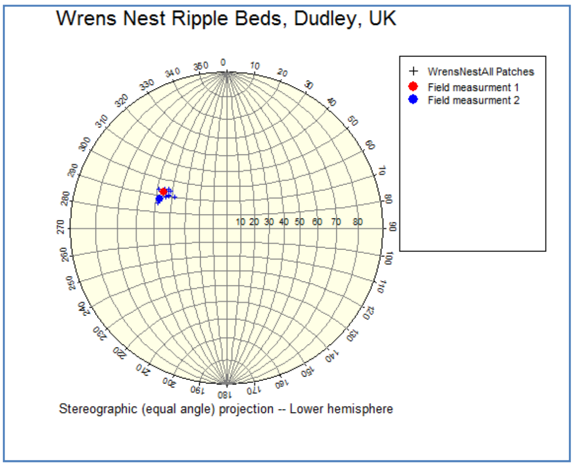


Figure 9 – Example of a Stereonet View region displaying ‘poles’ of field-measured and virtually-measured bedding planes