Faculty of Health, Engineering and Sciences

COMPARISON BETWEEN TERRESTRIAL CLOSE RANGE PHOTOGRAMMETRY AND TERRESTRIAL LASER SCANNING

A dissertation submitted by

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Abstract

Remote sensing has been around since the concept was first theorised by Leonardo da Vinci in 1480. Today due to advancements in technology and computing power it is now more accessible than ever to conduct a survey on a grand scale measuring millions of points in minutes using a variety of techniques. This research project aims to evaluate and compare two remote sensing techniques known as terrestrial laser scanning and photogrammetry.

Surveying is an integral part of any development and as technologies advance more information is expected out of a survey. Photogrammetry and laser scanning are two technologies that are proving invaluable for fast and accurate data collection.
In the author's research an abundance of information was found on individual techniques, however very limited information was found that compared these two technologies together. This research paper is being conducted to help bridge the informational gap between the two technologies and serve as a decision making tool for surveyors to choose which technique will best suite an individual project's needs.

In order to achieve this both techniques where tested under two different scenarios-

1. Site A-Block 11 is an as built survey of a bulk excavation site surrounded by a secant pile wall.
2. Site B-The office is a building façade comprised of concrete beams/columns and glass windows.

The data was then processed and compared using free open source software known as cloud compare.

This study found that when done correctly both techniques have proven to be as successful as each other in the test scenarios. Ultimately, the accuracy of any measurement performed using either technique will depend greatly on a combination of correct instrument operation/technique and a firm understanding of the limitations of each technology. This project will serve as a how too guide for surveyors conducting similar remote sensing surveys and aid in the selection of technique for the project at hand.

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ENG4111/ENG4112 Research Project

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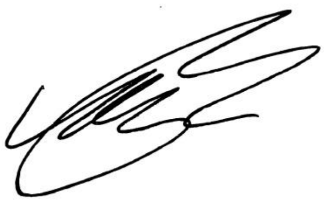
Lachlan Edward Broome



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Chapter 1 – Introduction

1.1 Introduction

Surveying is one of the oldest professions in the world and as technology improves so does the demand for more data captured accurately, safely, cost effectively and under unrealistic time constraints. Traditional surveying techniques though fulfilling the accuracy requirement of the modern era it is not always delivered safely, timely or cost effectively and is generally sparse in its collection. Two alternatives to traditional surveying techniques otherwise known as remote sensing include terrestrial laser scanning (TLS) and terrestrial photogrammetry (TP).

Both Terrestrial laser scanning and terrestrial photogrammetry are techniques that when carried out correctly will yield millions of high precision and accurate points in minutes. The collected data can be used for a variety of applications from initial conception phase's right through to completion in the construction industry, medical applications, manufacturing, monitoring etc.

Both techniques provide excellent visual representations in the forms of point clouds and textured triangulated meshes that are generated from the point clouds. The advantage of these styles of outputs is that anyone can look at the data and recognise the subject based on its visual content as opposed to traditional survey data that can require some training or guidance. The high accuracies and precision of the data collected combined with the visual impact that both these techniques allows for comprehensive data acquisition and data manipulation that satisfies the needs for a broad range of potential users.

1.2 Research Aims & Objectives

This dissertation aims to:

-Test TLS and TP against one another to determine their accuracies and whether they are appropriate for use in various survey applications.

This will be achieved by executing the following objectives:

1. Research for any existing literature relevant to the project topic title.

2. Search for some suitable sites to conduct the field work.

3. Conduct the field surveys with respect to best practice field techniques for each form of survey.

4. Analyse Field data and compare results with regards to accuracy.

5. Conduct Time/cost/benefit analysis of each survey method. To

6. Aid surveyors considering either TLS or TP techniques for a project by demonstrating their abilities in real world applications

7. Identify strengths and weaknesses of each technique.

1.3 Justification

Completing a conventional survey can be tedious, time consuming and as technologies increase so do the expectations of the end users of survey data. This increased expectation can place surveyors in unsafe situations such as live traffic, steep embankments etc. this is where remote sensing come in. Terrestrial laser scanning and photogrammetry are two potential remote sensing techniques that can fulfil the increased expectations of the end users while maintaining a comprehensive collection of data in a safe and efficient manner.

This dissertation seeks to identify strengths and weaknesses of each technique by analysing each technique against the other whilst being mindful of other constraints such as cost, time, benefit and safety. In doing so this paper will help to educate the industry so that anyone seeking to use one of these techniques will be able to make an informed decision as to which technique they employ in order to fulfil their individual requirements.

Chapter 2 – Literature Review

2.1 Terrestrial Photogrammetry

2.1.1 What is Photogrammetry

Photogrammetry is the science of taking 2 or more photographs of an object and measuring/analysing the individual two-dimensional photographs to determine three-dimensional geometry of the object (Jiang, 2008). These photographs must be taken from different positions in order to measure the three-dimensional geometry of the object (Jáuregui, 2003) . As there is usually more than one point of interest being measured the photographs must be taken in such a way that the same points of interest are visible in each photograph in order to measure the differences of the points of interest in each photograph. Historically images where analysed as hard copy Film prints using analog devises. Today with the advancement of computers and digital photography those processes are now obsolete hence this literature review will focus on modern techniques.

Photogrammetry is comprised of two fields – terrestrial and aerial photogrammetry. Terrestrial implies that the images are taken from the ground while aerial photogrammetry is usually taken from an aerial platform such as a UAV or satellite. Terrestrial photogrammetry is classified as being close range photogrammetry if the object being photographed is within 100m (Jiang, 2008).

2.1.2 How Photogrammetry works

When an image is captured the camera is essentially capturing one of the by-products of electromagnetic energy that can come from a multiple of sources. In most cases however this energy originates from the sun. When the electromagnetic energy hits an object three types of interactions occur – reflection, absorption and/or transmission as depicted in figure 2.1. In terms of capturing a photograph the reflective energy is what the camera captures (IDRISI, no date).

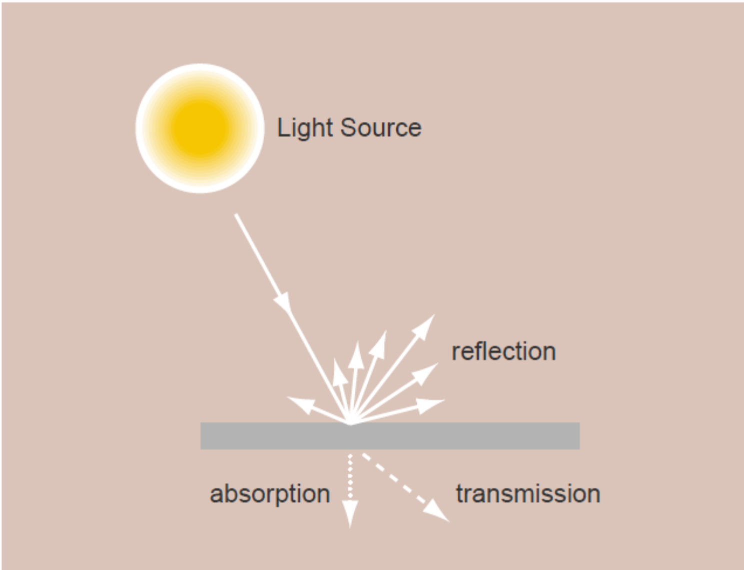


Figure 2.1 an image showing what happens when electromagnetic energy hits a material.

Source (IDRISI, no date)

The science of photogrammetry relies on Central Perspective model geometry. This projection is determined when a picture is taken in its actual space and transferred onto the sensor within the camera (Mikhail, 2001). This statement implies that you are taking the object of interest at a full tree-dimensional scale and reducing it to a smaller scale two-dimensional platform i.e. the imaging sensor. When this occurs the object becomes captured in an individual scale, co-ordinate system, projection and orientation. A pinholes camera model is calculated to model the perspective projections where the reflected electromagnetic energy travels from the object of interest through the aperture (i.e. the pinhole) of the camera onto the image plane (Alshadli, 2015).

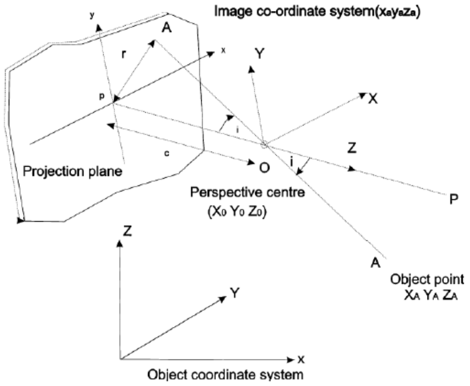


Figure 2.2 The central perspective projection. Source (Luhmann, 2010)

This concept is further defined by saying that the centre of the object space is the same as the centre of the image space. The two spaces are separated by the entrance and exit of the aperture (Schenk, 2005) as shown in figure 2.3.

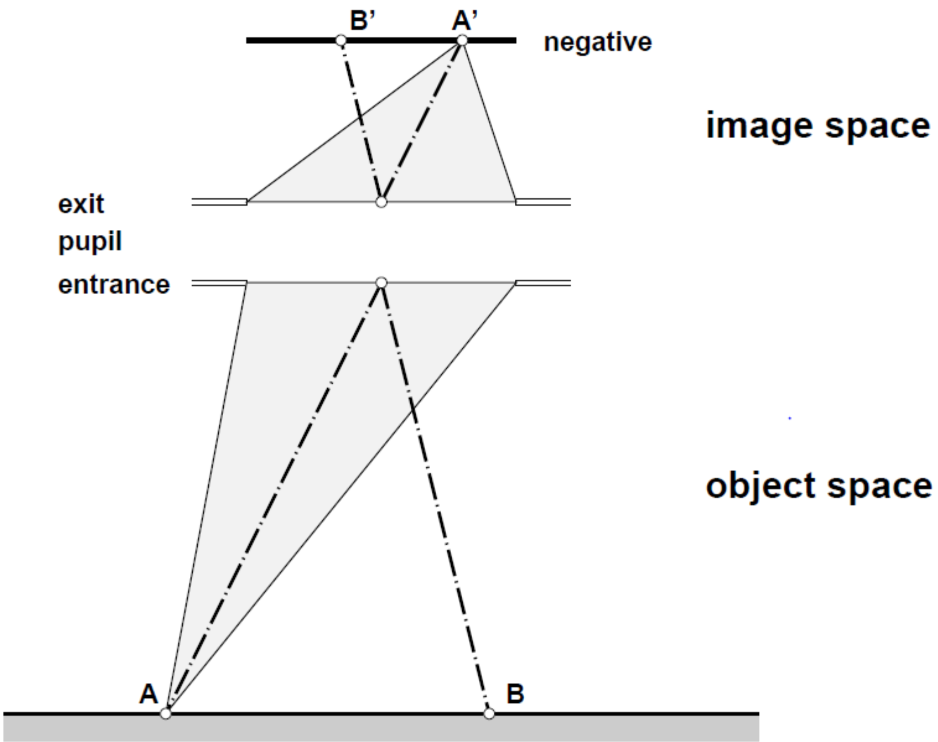


Figure 2.3 The concept of image and object space. Source (Schenk, 2005)

When this technique is done over two or more images relationships between the images can be calculated by co-ordinating the images off this central point and relating these same points in each photo from here a three-dimensional transformation can be calculated and a model formed. Note that the model at this stage will be unscaled and on its own rotation about the X, Y and Z axis until a relationship to the real world is established, this will be covered in more detail in the subsequent sections.

2.1.3 Mathematical concepts

In order to come up with a solution in photogrammetry a multitude of complex calculations are undertaken. These usually take the form of matrices and linear equations solving everything from camera parameters, transformations, lens distortions etc. with today's modern software and hardware these equations are done automatically as part of a bundled series of calculations within the software. As these operations happen autonomously a detailed explanation will not be required as part of this dissertation.

2.1.4 Camera calibration

Camera calibration is an important part of the photogrammetric process and has facilitated the use of inexpensive non-metric off the shelf cameras to be used in photogrammetry. It involves calculating -

• Offsets to the principle point or the point where the true centre of the lens projects a straight line to the image plane (Fryer, 2001)

• Lens distortions – there are two main types of lens distortions-

1. Radial distortions can be barrel or pin cushion in nature (Fryer, 2001). Figure 2.4 represents this by showing the distortion on a rectangular grid.

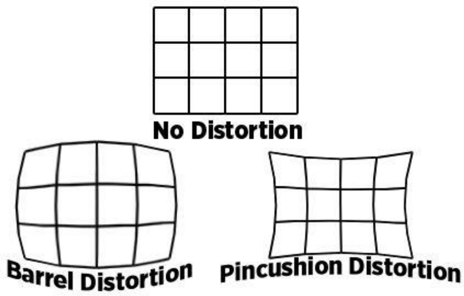


Figure 2.4 Image depicting the different kinds of radial distortions. Source (Quora, 2016)

2. Decentring distortions are caused by the misalignment of the lens on the camera as seen in figure 2.5. The result of this is a rotational or vertical displacement on the image. (Fryer, 2001)

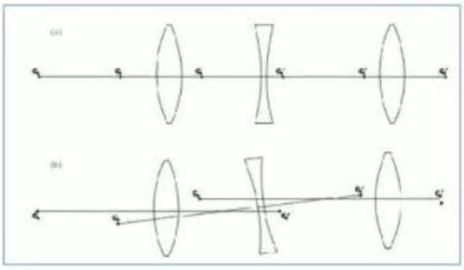


Figure 2.5 Image depicting decentring distortions. Source (Muhammad, 2016)

• Accurate focal length or the distance between the imaging sensor and the point where light intersects inside the lens. (Jiang & Jáuregui, 2010).

These parameters are crucial to calculating the perspective transformation. The bundle adjustment calibration technique is the most common used today. Brown (1989) discussed the requirements for a successful calibration as needing the following-

• A single camera must be used to take at least three images of the object.

• Both the interior geometry of the camera and the point to be measured on the object must remain stable during the measurement process.

• The photogrammetric network must have strong and exercise a high level of convergence.

• At least one image must have a roll angle that is significantly different from the others.

• A relatively large number of well distributed points should be used.

With these minimum requirements in mind there is a further two alternative options to calibration. A calibration conducted prior to the survey using coded targets also known as a stand-alone calibration or a self-calibration method where sufficient common points are found in the images taken conducting the survey (Jiang & Jáuregui, 2010).

As modern software will autonomously locate common points (known as tie points) between photographs it is possible to calibrate a camera without control points (Deseilliguy, 2012). This method can be advantageous as the calibration occurs at the same time as the survey the same camera settings and environmental conditions such as distance to the object being surveyed shall be the same. Therefore a greater accuracy may be achieved (Jiang & Jáuregui, 2010). There are three main steps in calculating automatic tie points-

• Partially locate reliable and dense tie points between images.

• Automatic orientation of images using the previously located tie points.

• The dense automatic matching of orientated images.

This method is becoming increasingly popular especially in the field of "Unmanned Aerial Vehicle" known as UAV's because in order to utilise coded targets for calibration would require the targets to be inconveniently large and present on the ground in the hundreds or thousands (depending on the camera setting and the scale of the job) (Luhmann, Fraser, & Maas, 2016).

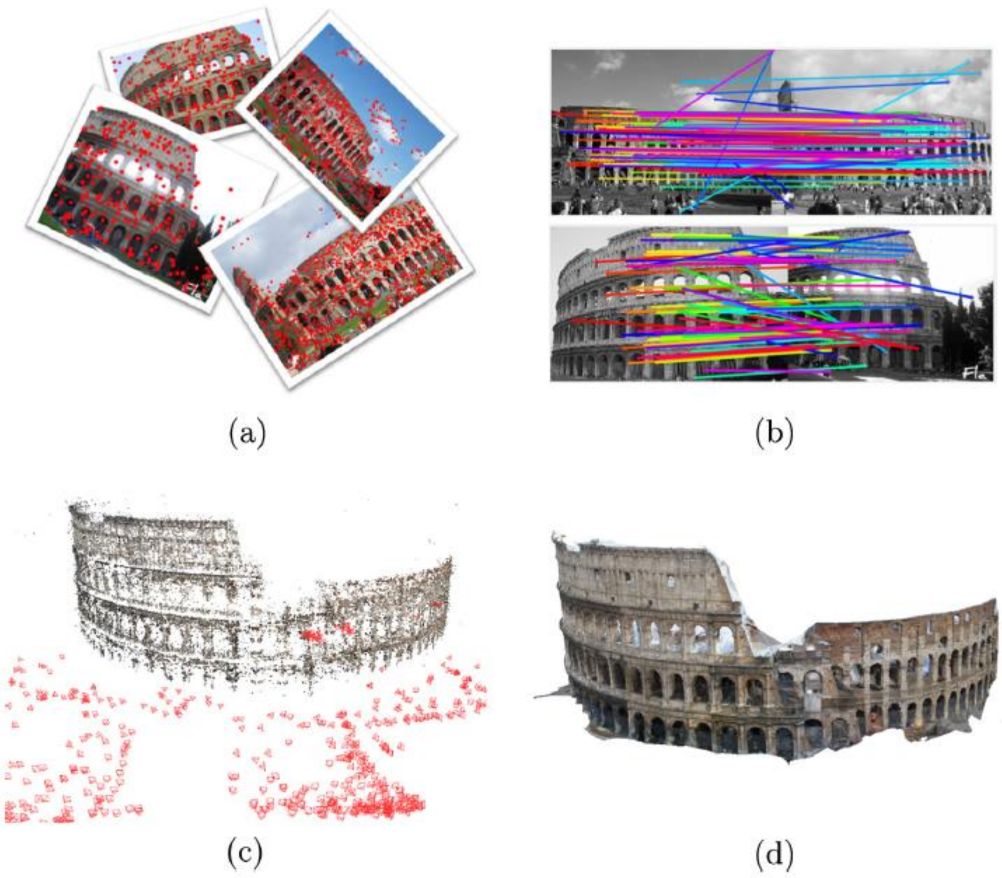


Figure 2.6 Computer generated tie points. Source (Hartmann, Havlena, & Schindler, 2015)

2.1.5 Geo-referencing

As mentioned in previous sections when a model is first created it has no scale or orientation in relation to the X, Y and Z axis. In order to scale and orientate the model there are 7 unknowns that need to be solved for, three co-ordinates shifts, three rotations and a scale. The minimum requirement for solving this is at least 2 control points containing an X, Y and Z value and one more containing a Z value or two control points containing X and Y co-ordinates and three containing Z values (Schenk, 2005).

The definition of a control point is a point with known three-dimensional co-ordinates with a sufficient statistical accuracy to satisfy the requirements of the survey being undertaken. In photogrammetry a ground control point is usually high contrast and easily identifiable as a control point (see figure 2.7 for an example). The positioning of the targets must be done in such a way that it optimises the geometry of the photogrammetric measurements (Woodhouse, Robson, & Eyre, *1999*).

A common method of measuring a ground control point is the use of a theodolite measuring the control points in relationship to each other and an adjoining control network (Woodhouse, Robson, & Eyre, 1999). Note that more observations taken to each control point from several stations will increase redundancies and therefore lower the uncertainties of the control point in question i.e. the stronger the network the less uncertainty in the network. Once the survey is complete it can be reduced preferably in a least squares program so that associated standard deviations can be computed and imported into the photogrammetry software.

Figure 2.7 An example of a checkerboard ground control point.

2.1.6 Imaging sensor

When the shutter of a digital camera opens it exposes light to a chip known as a sensor. There are two main types of sensors, the ‘charged coupled device (CCD)’ and the ‘Complementary metal oxide semiconductor (CMOS)’. Both these sensors are used to capture reflective energy and convert it into an electrical charge to produce an image (Teledyne, 2016) .

Although CDD sensors where the sensor of choice in the beginning due to their smaller production costs today CMOS sensors are the sensor of choice in most imaging applications today (Teledyne, 2016).

These chips can vary in size however the bigger the sensor, the more information that sensor can collect i.e. a wider frame. In addition to varying sizes of sensors different sensor will also have a different resolution or number of pixels per image (Schenk, 2005), (Teledyne, 2016).

2.1.7 Lens selection

When a camera calibration has been undertaken it has been done with certain fixed parameters in mind. Lens length or focal length is one of the fixed parameters therefore if a multi-zoom or multi-focal lens is to be used than it should be fixed to one length. This is because when the focal length is changed it also changes the key parameters used to process the images. Alternatively a fixed or prime lens can be used. This is a lens that has fixed internal geometry and is the preferred type of lens for photogrammetry because with fixed geometry the processing parameters will remain a constant and therefore a better result will be achieved (Schenk, 2005).

2.1.8 Image scale

The image scale is a ratio of the distance from the object being measured, the focal length of the lens being used (Schenk, 2005), (USQ, 2011).

The formula for image scale is $d \div f = 1 \div \text{scale}$. This ratio is important to determining accuracies of a project.

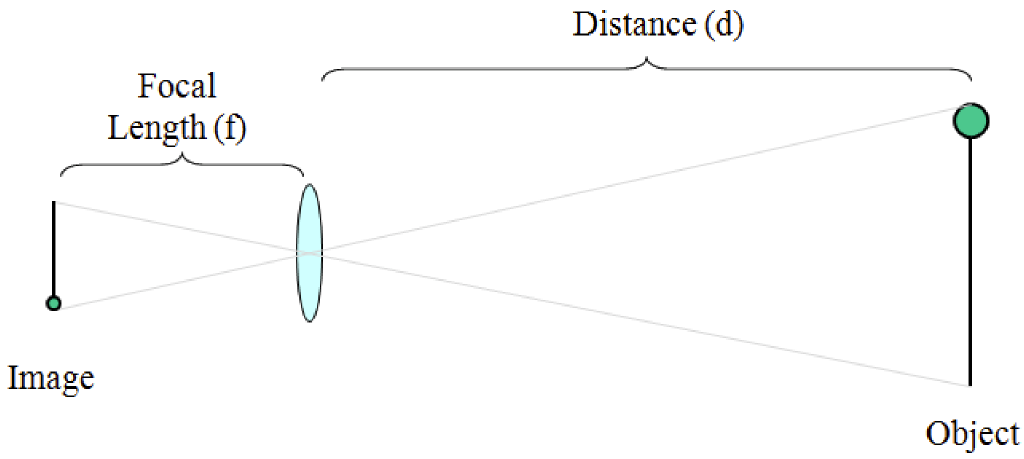


Figure 2.8 Image showing the relationship between focal length and distance to the object being measured. Source (Adam Technology, 2010)

Ground sampling distance (GSD) also referred to as photo resolution is the size of a pixel in the object space scale. To calculate the pixel size in the object space three variables must be know.

• The size of the pixels on the image sensor.

• The focal length

• The distance of the camera to the object.

Once these three variables are known it becomes a simple ratio equation.

$$pixelsize_{ground} = (d \div f) \times pixelsize_{image}$$

(Schenk, 2005), (USQ, 2011)

2.1.9 Determining accuracy

It is possible given the right conditions and the right subject to achieve almost any accuracy using photogrammetry techniques. Determining the accuracy of a job both for pre planning and end results are important to ensure the survey is fit for the intended purpose and that the results meet the requirement of that purpose. The formulas to determining the accuracy are as follows.

$$\sigma_z = \frac{Z^2}{cB}\sigma_p = \frac{Z}{s_p B}\sigma_p = \frac{Z}{b}\sigma_p$$

$$\sigma_x = \sqrt{\left(\frac{x_i}{c\,S_p}\cdot\frac{Z}{B}\sigma_p\right)^2 + \left(\frac{\sigma_{x_i}}{S_p}\right)^2} \text{ or } = \sqrt{\left(\frac{x_i}{c}\sigma_z\right)^2}$$

$$\sigma_y = \sqrt{\left(\frac{y_i}{c\,S_p}\cdot\frac{Z}{B}\sigma_p\right)^2 + \left(\frac{\sigma_{y_i}}{S_p}\right)^2} \text{ or } = \sqrt{\left(\frac{y_i}{c}\sigma_z\right)^2}$$

Where
•*xi* is the image '*x*-axis' co-ordinate
•*yi* is the image '*y*-axis' co-ordinate
•σ*p* is accuracy of measuring parallax ('instrument error')
•σ*z* is mean square error in the *z* co-ordinates (heighting accuracy)
•σ*x*, σ*y* are respectively the mean square errors in the *X* and *Y* co-ordinates
•*B* is the ground/air base distance between camera stations
•*b* = distance between PPs (or photograph camera station positions)
•*c* is principle distance
•*Sp* is the scale ratio e.g. 1:5000
•*Z= the mean distance of the object to the camera station*

(USQ, 2011)

Note that in terms of photogrammetry the X and Y axis are referring to the image plane and the Y axis is referring to the distance of the object to the image plane i.e. the depth of view.

2.1.10 Photogrammetry networks

When a point is measured between a stereo pair of photographs what you are doing is intersecting two vectors. As with conventional surveying Jiang & Jáuregui (2010) stated that camera placement should be done in such a way that the angle between the intersecting point should be as close to a right angle as possible. By doing this you are minimising the area of uncertainty or the error elipse as shown in figure 2.9.

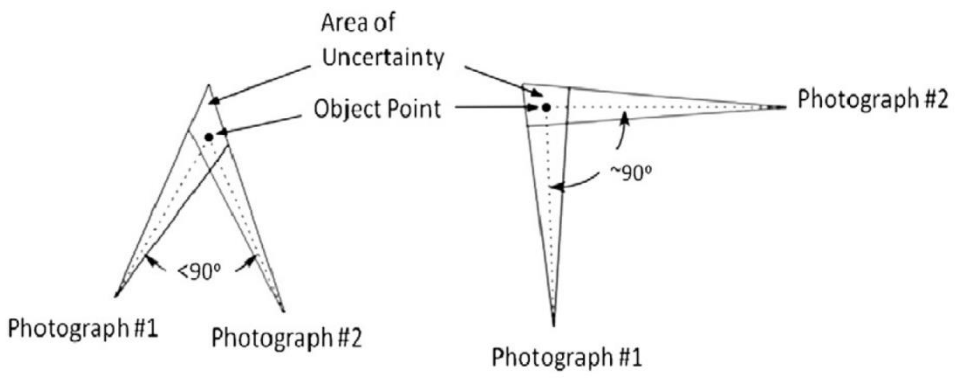


Figure 2.9 Minimising the area of uncertainty. Source (Jiang & Jáuregui, 2010)

This can be done either using one or two cameras noting that if two cameras are used there will be a separate calibration for each camera. By adding more images of the same point the amount of redundancy at that point is increased and the area of uncertainty is further decreased (Jiang & Jáuregui, 2010).

There are three main techniques of terrestrial photogrammetry to creating images where three-dimensional information can be taken i.e. a pair or series of photographs taken from different stand points that can see the same point of interest in each photo.

• The normal technique - this technique is where photographs are taken along a line and are generally parallel with the subject (see figure 2.10a).

• The convergent technique– this technique is where the image plane is angled towards the subject while maintaining the same distance from the subject (see figure 2.10b). This technique is useful for achieving 360 degree views of an object.

• The shifted technique – this technique is where photographs are taken at different distances to the subject and are parallel to the subject (see figure 2.10c).

(Luhmann, Robson, Kyle, & Hartley, 2006)

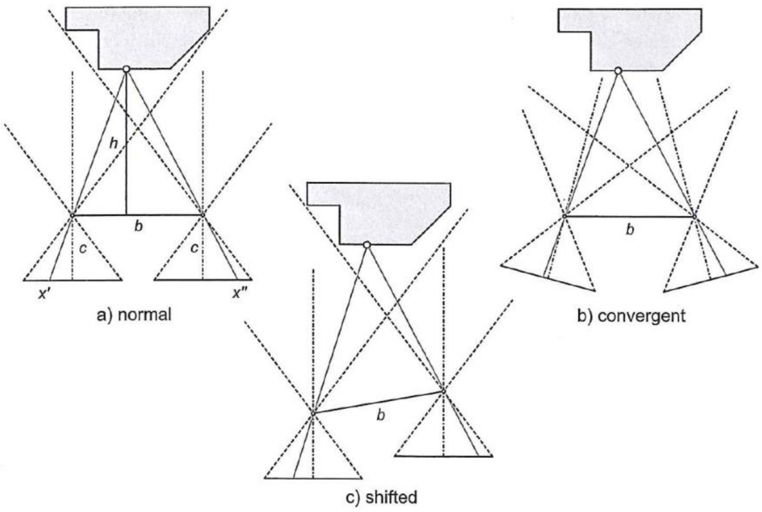


Figure 2.10 Image networking techniques. Source (Luhmann, Robson, Kyle, & Hartley, 2006)

A multi convergent network is the preferred in terms of achieving greater accuracies as it allows for a greater variety of intersecting angles, therefore is generating more redundancies about a point and reducing the area of uncertainty (Luhmann, Robson, Kyle, & Hartley, 2006), (Jiang e. a., 2008). A multi convergent network also attains the best results with regards to a simultaneous calibration of cameras in photogrammetry software by a self-calibrating bundles adjustment (Luhmann, Robson, Kyle, & Hartley, 2006).

2.1.1 Photogrammetry reduction software

Photomodeler is professional photogrammetry reduction software used in the following fields-

- Accident Reconstruction & Forensics
- Archaeology
- Architecture & Preservation
- Biology
- Engineering
- Film, Gaming and Animation
- Geology
- Surveying
- UAS / Drones

This software can be used with coded targets (generated within the software) and is capable of performing a camera calibration. These coded targets can also be used where more precise measurements are required at a specific spot such as monitoring surveys where consistent measurements to specific spots are required to compare the results to a base survey. This software is also used to generate a variety of outputs including-

• Three-dimensional models (geo-referenced to the real world, scaled or not scaled) such as point clouds and triangulated meshes.

• Digital surface models

• Contours.

• Orthorectified images i.e. mosaics and jpegs.

(EOS Systems Inc., 2015).

Pix4D is professional photogrammetry reduction software catering to the following fields-

• Construction

• Mining

• Inspection

• Environment monitoring

• Agriculture

• Emergency response

• Aerial photogrammetry

• Real Estate

This software is primarily focused on use with unmanned aerial vehicles but can also be utilised with terrestrial photogrammetry. PIX4D does not have a camera calibration routine however it performs self-calibrations based on tie points generated from the actual images taken of the subject. This software is used to generate a variety of outputs including-

• Three-dimensional models (geo-referenced to the real world, scaled or not scaled) such as point clouds and triangulated meshes.

• Contours.

• Orthorectified images i.e. mosaics and jpegs.

- Digital surface models.
- NDVI maps or vegetation index maps primarily used for agricultural applications.

(Pix4D, unknown).

2.2 Terrestrial laser scanning

2.2.1 What is terrestrial laser scanning

A terrestrial laser scanner is a device that captures dense point clouds of objects/structures of interest in a short amount of time. The rate at which data is captured is so quick that it ranges around one million three-dimensional points per second (Faro, unknown).

A laser scanner works by a central rotating prism reflecting a laser one vertical line at a time (Ebrahim, 2011). The laser beam will bounce off the object being surveyed and return to the laser scanners sensors. From the return signal the scanner will calculate accurate three-dimensional points. Some scanners will also take a panoramic image of the scene being scanned. This data in conjunction with the scan data during post processing can be used to assign a colour value to each of the scanned points. The result is an array of points in true to life colour.

Although laser scanning technology has been around since the 1960's (Ebrahim, 2011) it has only really started to take off since the late 1990's (Ebrahim, 2011). Advancements in computer storage and computing power have also been a major driving force with this technology being used in full scale survey scenarios.

2.2.2 Types of laser scanners

There are two primary variations of this technology-

• Pulse time of flight is the most rapid form of data capture in the laser scanning range. It involves sending a pulse laser to the target object and measuring the time the laser takes to return to the scanners receiver (Thiel & Wehr, 2012). This is a two way measurement so the time of flight is halved for the calculation. This type of scanning is subject to an increased amount of noise (false measurements) due to the pulse signals ability to bounce of additional objects thus increasing the time of flight (Thiel & Wehr, 2012). The amount of noise will very between scanner models and the sampling methods of the individual scanner. The accuracy of this type of scanning is independent of the distance to the object being measured i.e. the accuracy of this type of scanning does not change due to the distance of the object making this scanner popular for short to long range scanning (Callieri, Cignoni, Dellepiane, & Scopigno, 2009) . Refer to figure 2.11 for a diagrammatic representation of time of flight scanning.

• Phase modulation is a scanner that will emit a continuous laser at the same intensity. The distance is determined by measuring the difference in the wave length from the transmitted signal to the received signal (Thiel & Wehr, 2012). The shorter the transmitted wavelength the better the range resolution however this also means reduced maximum unambiguous ranges. The way to counter this is by sending multi frequency ranging i.e. sending a range of wave lengths where the highest frequency determines the resolution and the lowest frequency the unambiguous range (Thiel & Wehr, 2012) this is also known as modulation. The draw back to this is an unsustainable increase in power usage making this type of scanner more suited to mid to close range scanning (Thiel & Wehr, 2012). Although there is a decreased range with this type of scanner it will yield a greater accuracy than a pulse time of flight scanner (Callieri, Cignoni, Dellepiane, & Scopigno, 2009). Refer to figure 2.11 for a diagrammatic representation of phase modulation scanning.

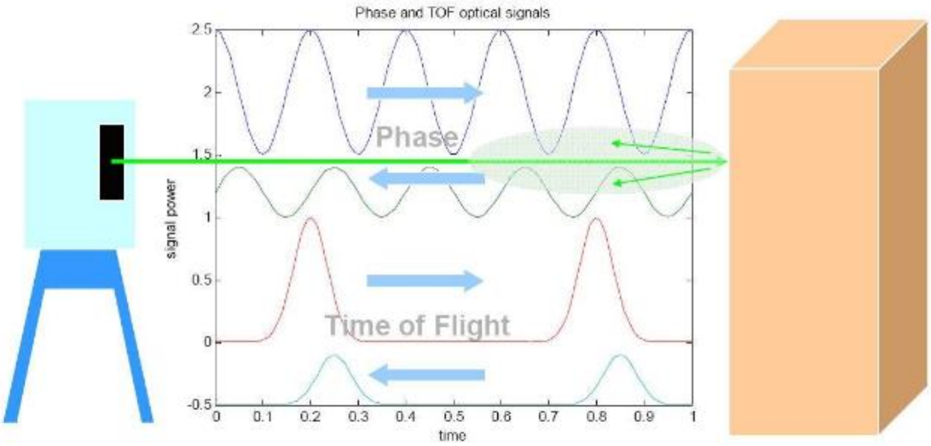


Figure 2.11 image showing the difference between phase base and time of flight scanners. Source (California department of transport, 2011)

2.2.3 Influences on accuracy

• Reflective object properties - Both scanners rely on the on the returned signal reflected back from the object of interest i.e. a white surface has much more reflective properties that a black surface and a shiny surface will not record easily (Boehler & Marbs, Unknown).

• Atmospherics – As with all measuring devices temperature, humidity and pressure will affect the measurement. This type of error will usually be an error in the form of parts per million applied over the distance. This error can be counted by the user inputting the correct atmospheric variables into the instrument at the time of the survey so the instrument can take them into account when measuring (Boehler & Marbs, Unknown).

• Interfering radiation – Laser scanners generally operate on limited frequency bandwidths. This facilitates the use of filters on the instrument to eliminate other bandwidths however if there is an additional source of radiation radiating at the same frequency it may affect the measurement creating noise or prevent the measurement from being recorded thanks to on board noise reduction routines of the scanner (Boehler & Marbs, Unknown).

• Angle of incidence – When the laser hits an object of interest at an acute angle the laser will be spread out over the object affecting the return signal and accuracy (Boehler & Marbs, Unknown).

A comparison study undertaken by Thiel and Wehr (2012) found that Phase based measurement was the more consistent measuring technique and made recommendations that pulse time of flight scanners should be used in long range applications while phase modulation scanners should be used to obtain higher accuracies over short to mid ranges.

2.2.3 Faro Model Focus3D X 330

Due to the varying capabilities and accuracies of individual scanners the remainder of section 2.2 will focus on the scanner being used for this experiment, the Faro model Focus3D X 330.

Figure 2.12 image of a Faro model Focus3D X 330. Source (Faro, unknown)

The focus3D X 330 is a phase based scanner with a factory features as follows-

• Range Focus3D X 330: 0.6 – 330m

• Measurement speed: up to 976,000 points/second

• Ranging error: ± 2mm

• Integrated colour camera: Up to 70 mio. pixel

• Laser class: Laser class 1

• Weight: 5,2kg

• Multi-Sensor: GPS, Compass, Height Sensor, Dual Axis Compensator

• Size: 240 x 200 x 100mm

• Scanner control: via touchscreen display and WLAN

• Noise reduction 50%

(Faro, unknown)

2.2.4 Resolution and quality

• Resolution – The Focus3D X 330 allows you to choose the point density of data collected known as resolution of the data. It is represented as a fraction of the maximum point density over 10m for example 1/1 has a point every 1.534mm over 10 m and at 20m this value will double (Faro, 2011). The trade of is with increased point density the time it take to scan will increase.

• Quality - The Focus3D X 330 has on board noise reduction algorithms and routines that are used to reduce the amount of noise recorded during a scan therefore reducing reduction times (Faro, 2011). As with resolution there is a trade off with the time taken to scan i.e. the higher the quality setting the less noise will be recorded and the longer the scan will take. Conversely the lower quality setting more noise will be recorded and the scan will take less time.

Users have to make a judgement call as to the project requirements, time/cost constraints and balance out the resolution and quality settings so the survey will meet the requirements of the survey being under taken.

2.2.5 Scan registration and geo-referencing

When a Focus3D X 330 is setup it is generally done so on an unknown point with an unknown orientation it is however usually setup so that the scan is perpendicular to earth's gravity with an on board tilt compensator (Faro, 2011). This means that in order to define the scan plane only an additional 2 co-ordinated control points will be required to co-ordinate and orientate the scan. These co-ordinated control points like with photogrammetry are placed using conventional surveying.

Since laser scanning locates a specific resolution and not the entire scene it will not locate the exact centre of a control point, the target is scanned. Then a best fit of the centre of the target is calculated (Harvey, 2004). On the example shown in Figure 2.7 a minimum of 4 points per quadrant are required and the angle of incidence needs to be less than 45° to determine the centre (Faro, 2011).

It is not uncommon to require more than one scan to capture a full scene and seeing how they are done so with unknown orientations and positions during the reduction stage the scans will need to be linked together, this is known as registration. Registration can happen in one of three ways-

• Cloud based registration is where individual scans are linked by the scan data itself. The software is given some approximate common areas and will search for commonalities between the two scans (Trimble, unknown).

• Known instrument co-ordinates and target of orientation (Trimble, unknown).

• Selecting the reference points in each scan and aligning each scan to these common points (Trimble, unknown). This is the most common and recommended practice by ultimate positioning group. The common reference points are fixed diameter spheres placed during the survey and the centres defined within the reduction software. This has proven to be the most effective method as it relies on multiple of points to define the centre. The drawback of this technique is that in order for the software to calculate the centre of the sphere accurately a certain number of points on the sphere will need to be captured. For example using the Focus3D X 330 at ¼ resolution, a 138mm sphere will need to be within 18m so enough points will be measured to define it (Faro, 2011). This means that although the scanner has a factory stated effective range of 330m it is limited to 30m station jumps when you factor in a reasonable geometry for the spheres. Thus making its extended range only useful if you can do a scan and geo-reference it from the one setup.

2.2.6 Laser scanning reduction software

Trimble realworks is reduction software specifically designed for point cloud processing and analysis. This software facilitates scan registration, analysis, modelling and deliverable creation (Trimble, 2016). The software is flexible to various point cloud formats which lends itself to being utilised for analysis of point clouds generated using photogrammetry.

This software lends itself to the following fields-

- Oil and gas
- Building and construction
- Civil and architecture
- Historical preservation
- Industrial facilities
- Law enforcement

(Trimble, 2016)

Chapter 3 – Test Sites And Equipment

3.1 Site selection

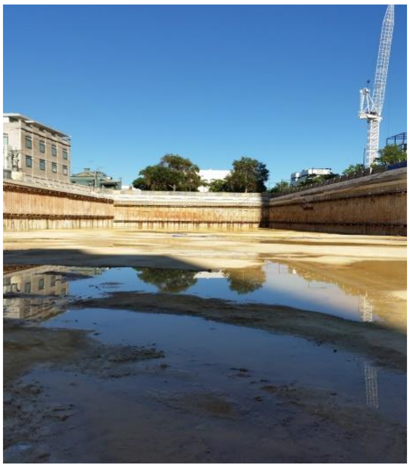
In order to perform the comparison two sites have been selected with the aim of testing the performance of the two remote sensing capabilities.

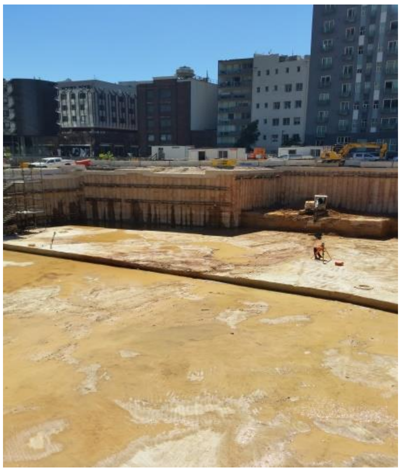
3.1.1 Site A - Block 11

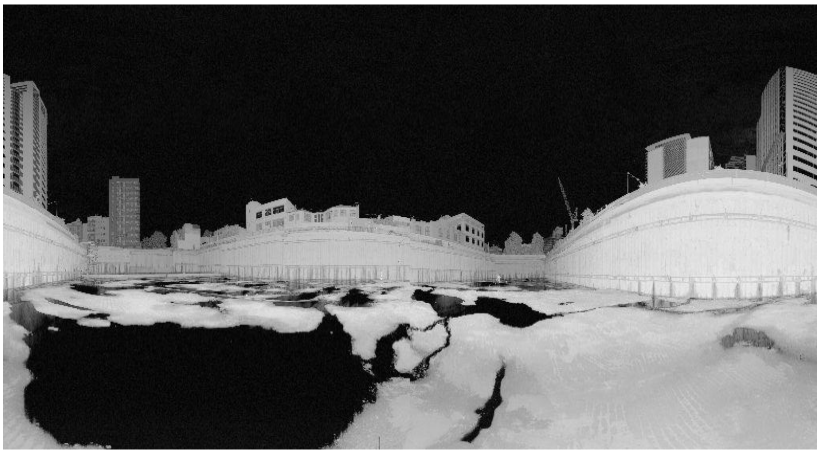
The first site is a large construction site at the end of the bulk excavation phase of construction, known as Block 11 located within the City of Sydney cbd. Block 11 is approximately 130m long in an east west direction by a varying width of 30m to 60m in the north south direction. The site is currently dormant due to the civil bulk excavation works being completed and the building still being designed. Therefore quiet uninterrupted access to block 11 can be enjoyed for the duration of the experiment which is the ideal scenario.

The method of excavation used on this site is secant pile walls and capping beams around the outside of the excavation design area and to dig out the centre using bull dozers, excavators and rock saws. Along the face of the secant walls two stratums of whaler beams and anchor bolts where fix as the hole was excavated to bring the wall into equilibrium with the forces pushing the secant wall towards the excavation. The entry to the hole is via a scaffold on the north western end of the site.

The finished excavated floor of Block 11 consists of Sydney sandstone. This mixed with the rough edges of the secant wall makes Block 11 the perfect candidate for both laser scanning and photogrammetry.







Figures 3.1-3.3 images and scan preview of Site A – Block 11

3.1.2 Site B - The Office

The second site is the back of a two storey office building located in Pymble, NSW. The façade itself consists of a concrete frame with windows throughout, two doorways and an underpass for vehicles to gain access to the back of the building. This site was chosen because the bulk of the façade is made up of windows. Neither laser scanning nor photogrammetry measure accurately on transparent or reflective surfaces such as glass. This makes site B the perfect test on both techniques as it will highlight both of their inherit weaknesses.

Figures 3.4-3.6 images and scan preview of Site B – The Office

3.2 Equipment

3.2.1 Photogrammetry

The digital camera used for the project was a Sony A7R camera body coupled with a Carl Zeiss 35mm f2.8 lens. Both the camera and the lens are owned by the author.

Figure 3.7 an image a Sony A7R camera body Source (CNET, 2016)

Figure 3.8 an image of a Carl Zeiss 35mm f2.8 lens, Source (DpReview, 2016)

The Sony A7R is a relatively new type of camera which uses a mirrorless system. Unlike a traditional DSRL camera the Sony A7R uses the camera sensor to relay the image to the view finder. This reduced the size and weight of the camera significantly which is why mirrorless systems are proving popular with Arial photogrammetry using UAV's.

The Sony A7R utilises an E-mount system to attach lenses. This limited the selection of lenses considerably and the Carl Zeiss 35mm f2.8 was the highest quality lens available that matched the specifications required to undertake both surveys.

Also worthy of note is that both the camera and lens do not have image stabilisation which is highly recommended by the photogrammetry reduction software packages investigated for this project.

Table 3.1 shows the factory specifications of the Sony A7R.

Sensor Size	35.9 x 24.0mm	Focus Points	25 points (CDAF)
Sensor Resolution	36.4 MP	Electronic Front Curtain Shutter	No
Sensor Pixel Size	4.88µm	Video Maximum Resolution	1920×1080 (1080p) @ Up to 60p
Sensor Anti-Aliasing Filter	No	4K Output	No
In-Body Image Stabilization	No	LCD Size and Resolution	3.0″, 921,600 dots
Image Size	7,360 x 4,912	Built-in GPS	No
Viewfinder Type, Dots, Coverage	EVF, 2.4 M dots, 100%	Built-in Wi-Fi	Yes
Built-in Flash	No	Construction	Full Magnesium Alloy
Storage Media, Type	1x SD, UHS-1	Battery Life	340 shots (CIPA)
Continuous Shooting Speed	4.0 FPS	Weight (Body Only)	407g
Native ISO Sensitivity	ISO 100-6,400	Dimensions	126.9 x 94.4 x 48.2mm
Boosted ISO Sensitivity	ISO 50, 12,800-25,600	Price As Announced (MSRP)	$2,299
Autofocus System	Contrast-detection AF		

Table 3.1 Source (Photographylife, 2016)

3.2.2 Laser Scanning

The terrestrial laser scanner utilised for this project is a Faro Focus 3D X330. The X330 is a phased based laser scanner with a range of 0.6m-330m and from 300° vertically to 360° horizontally, with a factory specified ranging error of +-2mm. the scanner is also equipped with a 70 mega pixel camera which can be combined with the scan data the give a true to life colour palette to the point cloud output. The scanner has been generously loaned to the author free of change for this project by UPG Sydney.

Figure 3.9 an image of a Faro Focus 3D X330 laser scanner, Source (Pentland, 2016).

Each site will require several scans to compile the 3D models. In order to stitch each scan together in the reduction software a series of spheres will be placed in the field of view bearing in mind best practice geometry. The spheres are 138mm in diameter and have a magnetic base that can be placed on a metal structure or on a mini magnetic tripod on the ground.

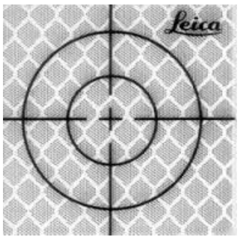
Figure 3.10 an image of 138mm reference spheres, Source (Surveying Epic, 2016)

3.2.3 Geo-referencing

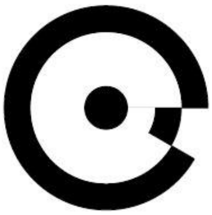
Both Laser scanning and photogrammetry require additional survey information in order to transform the data from a relative space into a real world co-ordinate system. In the case of laser scanning it is required to perform 3 co-ordinate shifts and 3 rotations, photogrammetry requires an addition of a scale value. To achieve this ground control points will be placed using a TS15 1" instrument with an R1000 EDM. As the targets to be used will not be made out of retro tape and will not be reflective prisms the experiment will rely on the instruments reflective and angular capabilities. The reflective capabilities range to 1000 metres with an accuracy of 2mm + 2 ppm. Meaning that in ideal conditions measuring a target at 1000m the quoted reflectorless accuracy of this instrument is 4mm.

Types of targets to be used-

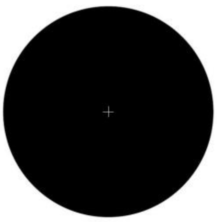
•The control targets to be measured for geo-referencing the photogrammetry and laser scanning will be checkerboard targets printed on waterproof paper. This target can then be glued onto any number of surfaces using an adhesive. As shown in figure 3.11 on the left.



•The ground control used as fixed control points will be an existing network of tape targets. The targets are stickers with a removable backing, which when removed the target me be stuck onto any number of surfaces. As shown in figure 3.12 on the left.



•A coded target for geo-referencing photogrammetry produced through Photomodeler. This target is automatically located and matched in each image thanks to its unique design for each target. This target can be printed and glued onto the subject target using adhesive. As shown in figure 3.13 on the left.



•A black dot target for geo-referencing photogrammetry produced through Photomodeler. This target is automatically located in each image but requires manual matching. This target can be printed and glued onto the subject target using adhesive. As shown in figure 3.14 on the left.

3.2.4 Reductions

The reductions will take place on the authors PC with the specifications as follows-

- Intel i7-3770 CPU @ 3.40GHz
- 32GB of ram upgraded from 16GB for this project
- 64-bit operating system
- NVIDIA Geforce GTX 550 Ti graphics card
- 240 GB solid state drive and a 1TB disk drive

Chapter 4 – Methodology – Field work

4.1 Testing

4.1.1 Laser Scanning

Due to the limited window in which the scanner could be borrowed no pre field testing could be undertaken. Therefore the surveys involving the laser scanner had to be planned based on available literature and advice from UPG (who loaned the scanner).

4.1.2 Photogrammetry

Testing for photogrammetry involved solving two initial problems. One being whether to use PhotoModeler or Pix4D and the other was to determine whether to use a parallel or convergent method of data capture. As site A – Block 11 was visited regularly by the author it was the perfect test case to determine which combination of the above stated variables would be adopted for the project.

Parallel and Convergent image capture-

For this test the eastern wall and a portion of the southern/northern walls of Block 11 where selected. The eastern wall contains varying depths which will test the software's ability to populate automated tie points. While the portions of the northern and southern walls are to see how the software will handle turning corners.

As the wall is approximately 12 metres high at its highest point this distance will be used to calculate to required scale and thus the planned distance away from the wall line.

Scale= height of the wall ÷ height of the camera sensor

$=12 \div 0.024 = 500$

Distance off the wall line = scale x focal length

$= 500 \times 0.035 = 17.5$

Pixel size = pixel size on camera sensor x scale

= 0.0048mm x 500 = 2.4mm

X axis object length = scale x X axis image space

= 500 x 0.0359 = 17.95

The distance off the wall being 17.5 metres was measured out and images where every 2 metres for the parallel method which will provide an image overlap of 88.9%. The convergent method involved taking a photo at approximately a 45° angle to the wall, walking forward 14 metres and angling the camera at a 45° angle in the opposite direction along the wall. The next step is to walk 12 metres back and repeat the process. This method takes a lot longer however due to the angle of the camera a far greater overlap is achieved and the area of uncertainty is decreased thanks to the resulting angle of incidence being close to 90°.

To get around the corners the images where taken at the fixed offset as far as would allow and then taken on a sweeping arc until in line with the next wall to be captured. This technique was used for both methods.

As it would take far too long to measure out each stand point a pacing method was used. All photographs were also taken on a tripod and a camera remote control used to minimise any blur in the photos caused by vibrations or the user not holding the camera steady. Figure 4.1 depicts the parallel method while figure 4.2 depicts the convergent method.

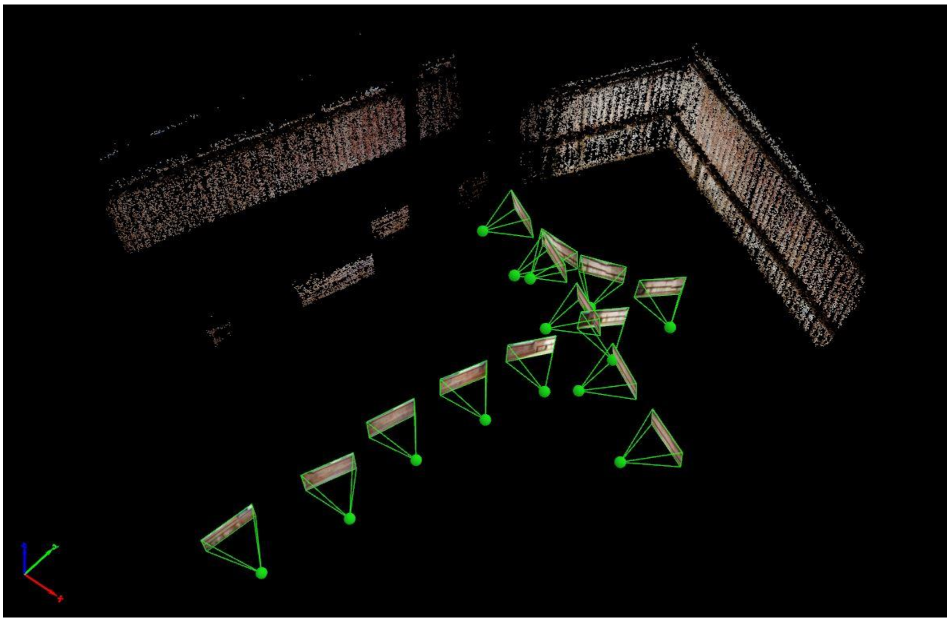


Figure 4.1 an image of the parallel method from Pix4D

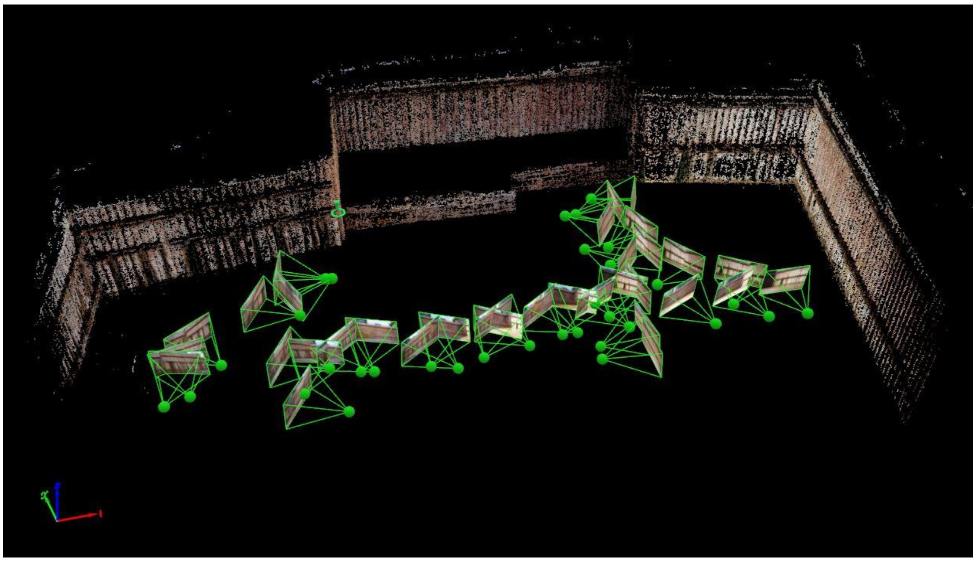


Figure 4.2 an image of the convergent method from Pix4D

The photos where then run through the reduction software, see the results section on page 35 for the selected technique.

Photomodeler or Pix4D-

Prior to any field work Photomodeler recommends conducting a camera calibration although it is capable of calibrating from the subject photos. Pix4D conversely calibrates each job based on the photos taken.

To calibrate a camera for Photomodeler a series of coded targets where created in the software and printed off with each page containing 5 coded targets. The target sheets where arrange in a matrix like configuration with varying heights in a well-lit room sealed off from external influences such as wind. As shown in figure 4.3 below.

Figure 4.3 an image of the camera calibration matrix

The camera was set up on a tripod looking down at the targets and a series of photos were taken. The photos were taken approximately parallel to each side of the target matrix using 3 different camera orientations. Four photos were taken holding the camera normally. The camera was turned 90 degrees to take another 4 photos, then turning the camera a further 180 degrees to take the last 4 photos.

Figure 4.4 images of the camera orientations for camera calibration

The photos where then imported to Photomodeler for processing. The software automatically recognised the coded targets, processed the photos and outputted a calibration report. This process took approximately 30 minutes per attempt (from start to finish) and was repeated 12 times with the best results selected and stored within the software for use in future projects. Table 4.1 shows the calculated camera calibration variables computed with an overall RMS of 0.215 pixels (or 0.52mm based on the pixel size calculations) and a maximum of 0.850 pixels (or 2.04mm based on the pixel size calculations).-

Principle point X	Principle point Y	R1	R2	R3	T1	T2
18.156143 mm	11.932496 mm	-4.899e-005	1.085e-007	0.000e+000	-3.431e-005	-2.001e-005

Table 4.1 camera calibration results for attempt 9

With the calibration results the test project was run through Photomodeler. The software as a default assumes all the photos were taken in order and therefore looks for points of interest in the adjoining photo based on each photos time stamp. With the available computing hardware the software took an inordinate amount of time for the parallel photos to stitch and orientate and when completed only half the project had matches meaning the remaining photos had to be matched manually and the project re-optimised.

The above procedure was repeated for the convergent photos. This time the photos where matched, optimised and orientated autonomously without the need for the author to manually match photos.

The next step was to create the densified point clouds and mesh the densified surfaces. On this step the software crashed repeatedly on each technique with the longest computing time being approximately 5 hours before the processes where terminated. The reasoning behind terminating the process was because this was only a sample set of photos. For the whole site it was estimated based of the size of the site and the amount of photos taken in the test samples, being 33 for convergent and 50 for the parallel technique. The required number of photos to create a point cloud over the site would exceed 250 photos which would require an indeterminable processing time with no guarantee that the program would not crash.

Pix4d was trialled next, unlike Photomodeler no camera calibration values are require to run the project as these values are calculated based on the images taken and the automatic tie points calculated/matched in each photo.

Pix4d is primarily used for areal photogrammetry and upon importing the photos looks for a geo-tag. The Sony A7r however does not have an inbuilt GPS receiver and is therefore unable to geo-tag photos. As a default Pix4d will import the photos with a coordinate geo-tag of Easting=0, Northing=0, Elevation=0 and the software recognised this and will begin to stitch the photos together based on the time the photo was taken e.g. in time stamp order.

The parallel technique photos where imported into the software and the stitching process started. The software failed to stitch half the photos together with the author manually tying the remaining photos, a densified point cloud was then generated. The time taken to output the initial processing, densified point and mesh was approximately 1.5 hours. Figure 4.1 shows the extent of the autonomous stitching for the parallel method while figure 4.2 shows the extent of the test site.

The convergent method imported and stitched the photos together seamlessly and the dense point cloud and mesh created in approximately 27 minutes. See appendix B for the Pix4d quality report.

<u>Results-</u>

-The convergent method was selected because it naturally decreases the area of uncertainty by increasing the angle of incidence and the photos stitched together in both Pix4d and Photomodeler with minimal user effort resulting in less reduction time.

-Pix4d was selected over Photomodeler because it works far more efficiently i.e. requires less computing power than Photomodeler and created an output in far less time.

4.2 Site A – Block 11 Field Work

4.2.1 Traversing Geo-Referencing Control

As this is a real job the existing site control will be adopted consisting of tape targets situated around the excavation hole primarily on the capping beams or whalers. The author is confident in doing so as 2 weeks prior to the field work being carried out the existing survey control for the site was readjusted to take out any uncertainty. This was done as part of the usual due diligence as the control is situated on the secant pile walls which are prone to movement. If any movement occurs between the readjustment and the control survey it will be highlighted in the least squares adjustment. This is because when the secant pile walls do move they tend to move in one direction which is towards the hole due the forces of the materials on the outside of the walls pushing in e.g. water pressure, soil, tucks etc. using tape targets will also help to eliminate plumb errors and spread existing errors across the control.

Prior to any field work being undertaken a hazard assessment and tool box discussion was undertaken for the required tasks and an appropriate safe work method statement altered accordingly and signed.

Checkboard targets where placed in various location around the site. Some were glued on the capping beam using an adhesive spray. Placing these marks required the use of a harness as the existing protective barrier at the edge of the excavation had to be removed in order to reach the capping beam to glue the target on. Other checker targets where placed on whalers around 2 metres from the toe of the excavation and on timber boards prepared the day before laid at ground level against the secant pile walls.

The Total station (TS15 1” R1000) was set up in the middle of the excavation in the North south direction and on the western end inside the excavation. From there the on board sets of angles program was used to take a set of face left and face right observations to the existing control and to the checkerboard targets placed. Only the visible and marks with reasonable geometry from the setup where measured. The instrument was then moved to the East along the hole to repeat this process. The idea was to try and measure each checkboard at least twice from a different setup in order to create a redundancy both as a check and to achieve a smaller standard deviation. Figure 4.5 shows the network diagram of the control traverse, note that the marks in the middle are the station setups and the marks highlighted red are the existing control points.

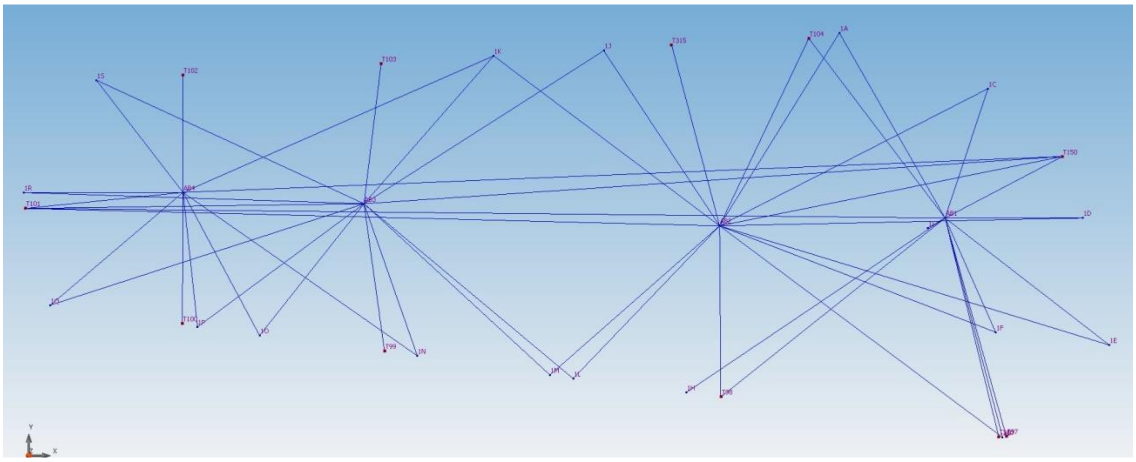


Figure 4.5 image showing the control network diagram from Elfy V2.4

This process took approximately 2 hours to set up and 1.5 hours to measure. The data was then exported for processing.

4.2.2 Photogrammetry

The same planning calculations from 4.1.2 apply for this data capture as it is the same site. A starting point was selected on a straight wall line and where a control checker target was located to serve as a network close for the photos. The same spacing and convergent technique as stated in 4.1.2 was used until a full circuit of the excavation hole was completed. In order to capture sufficient images on the floor of the excavation images where taken along the top of the excavation looking downward. These images where taken using the parallel technique due to the following safety reasons-

- The side of the excavation is bounded by hoarding and required a ladder in order to see inside the hole.

- To minimise the amount of time spent near the edge of the excavation.

310 images where captured during the survey and took 2 hours to complete due to using the convergent technique. If the parallel method was utilised it is conceivable that the survey could have been completed in half that time.

Figure 4.6 shows the image network as a snap shot from Pix4d with the green lines indicating an image projection.

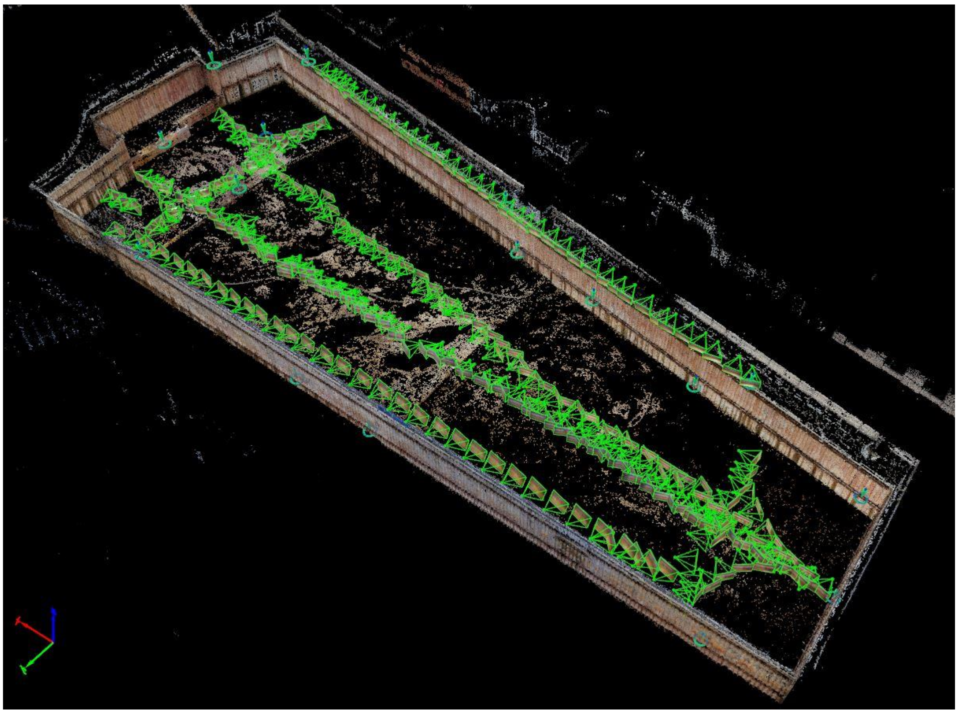


Figure 4.6 an image showing the Photogrammetric control network

4.2.3 Laser Scanning

The planning for the scan of Site A – Blk11 was based around the Faro 3D focus being set at ½ resolution and 4x quality. This resolution setting captures a point cloud of 3.068mm over 10m with a scan time of 12 minutes. Based on the Faro and Trimble Realworks user manuals with a ½ resolution setting a checkerboard target need to be within 18m and a 138mm reference ball within 15m of the scanning station. The intention is to use the same checkerboard targets as the photogrammetry to geo-reference the scans and the reference balls to stitch each scan together while maintaining a 15m parallel line with the excavations secant pile wall lines.

The narrowest section of the site was selected as the starting point with 138mm reference balls placed along the centre line between intended scan stations. From there the scans where leapfrogged along the site moving the reference balls so as to keep the balls within 15m from the next planned stations. Figure 4.7 shows the locations of the scanning stations relative to the site. 9 scan stations where require to capture the site taking 15 minutes setup time per scan, with 12 minutes per scan it took a total of 4 hours field work to complete the site.

Figure 4.7 an image showing scan station locations in Trimble Realworks

4.3 Site B – The Office

4.3.1 Traversing Geo-Referencing Control

Prior to any field work being undertaken a hazard assessment was undertaken for the required tasks. As a result of the hazard assessment it was deemed that a safe work method statement will not be required.

Four tape targets where placed as primary control, 2 at either end of the job. Checkboard targets where placed at the ends of the façade and along the face. Due to lack of access only one target was able to be placed at the second level of the façade. The targets were glued on to the façade using an adhesive spray.

The Total station (TS15 1" R1000) was set up at the south end of the. From there the on board sets of angles program was used to take a set of face left and face right observations to the primary control and to the checkerboard targets placed. Only the visible and marks with reasonable geometry from the setup where measured with the primary control being measured at every setup. The instrument was then moved to the North along the façade to repeat this process a further 5 times. The idea was to try and measure each checkboard at least twice from a different setup in order to create a redundancy both as a check and to achieve a smaller standard deviation. Figure 4.8 shows the network diagram of the control traverse, note that the marks in the middle are the station setups and the marks prefixed with T are the primary control points.

This process took approximately 1 hour to set up and a 1/2 hour to measure. The data was then exported for processing.

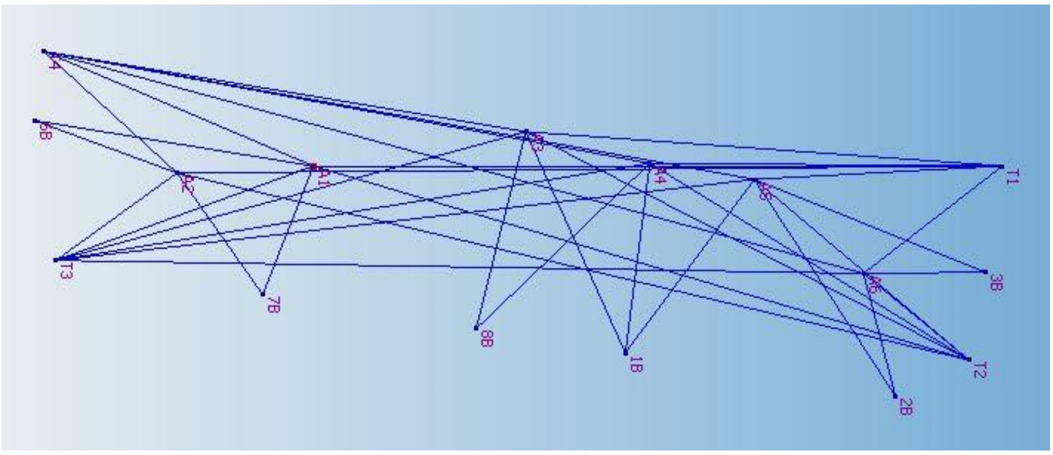


Figure 4.8 image showing the control network diagram orientated East West from Elfy V2.4

4.3.2 Photogrammetry

As the Building is approximately 10 metres high this distance will be used to calculate to required scale and thus the planned distance away from the wall line.

Scale= height of the wall ÷ height of the camera sensor

$=10 \div 0.024 = 416.67$

Distance off the wall line = scale x focal length

$= 416.67 \times 0.035 = 14.6$

Pixel size = pixel size on camera sensor x scale

$= 0.0048\text{mm} \times 416.67 = 2\text{mm}$

X axis object length = scale x X axis image space

$= 416.67 \times 0.0359 = 15$

The distance off the wall being 14.6 metres was measured out in the field and the camera view finder checked. It was decided that another 1.5 metres away from the target was required to capture the whole façade.

The convergent method was used taking a photo at approximately a 20° angle to the wall, walking forward 12 metres and angling the camera at a 20° angle in the opposite direction along the wall. The next step is to walk 10 metres back and repeat the process. To get around the two corners at either end the images where taken at the fixed offset as far as would allow and then taken on a sweeping arc until in line with the next wall.

As it would take far too long to measure out each stand point a pacing method was used. All photographs were also taken on a tripod and a camera remote control used to minimise any blur in the photos caused by vibrations or the user not holding the camera steady. 56 images where captured during the survey and took 1/2 an hour to complete due to using the convergent technique. If the parallel method was utilised it is conceivable that the survey could have been completed in half that time. Figure 4.9 depicts the Photogrammetric network taken from Pix4d with the green lines indicating a camera station projection.

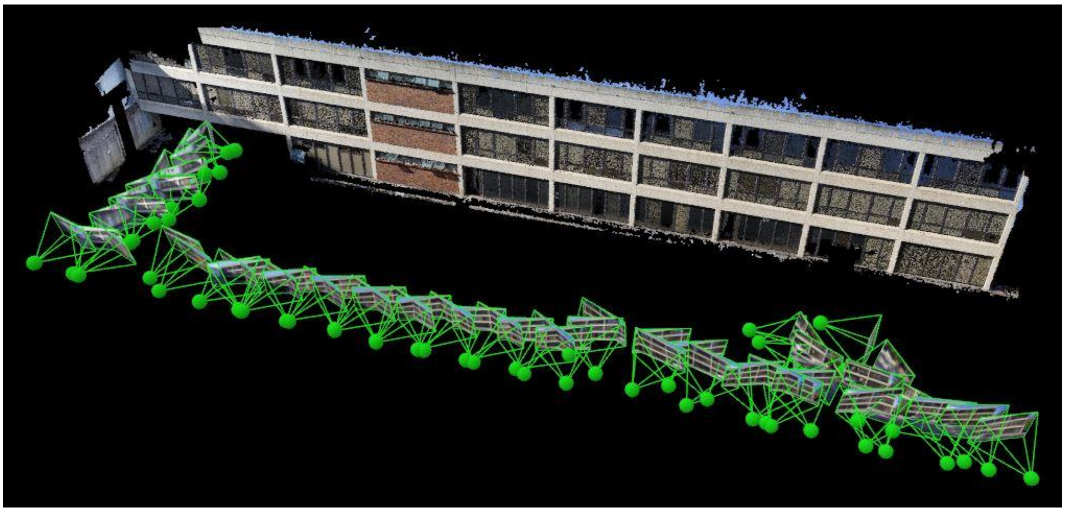


Figure 4.9 an image showing the Photogrammetric control network

4.3.3 Laser Scanning

The planning for the scan of Site B – The Office was based on the same resolution and quality settings as used for Site A – Blk11.

The intention is to use the same checkerboard targets as the photogrammetry to geo-reference the scans and the reference balls to stitch each scan together while maintaining an 8m parallel line with the façade of the building.

The Southern end of the building was selected as the starting point with 138mm reference balls placed along the centre line placed high and low between the next intended scan station. From there the scans where leapfrogged along the site moving the reference balls so as to keep the balls within 15m from the next planned stations. Figure 4.10 shows the locations of the scanning stations relative to the site. 4 scan stations where require to capture the site taking 5 minutes setup time per scan, with 12 minutes per scan it took a total of 1 hour 8 minutes field work to complete the site.

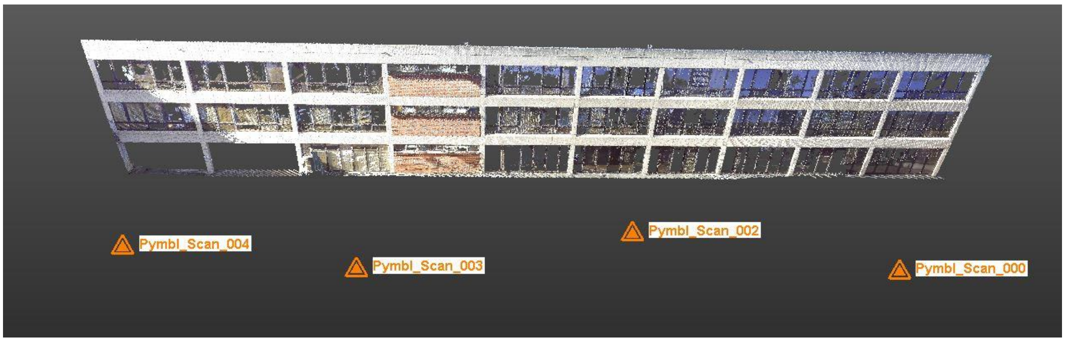


Figure 4.10 an image showing scan station locations in Trimble Realworks

Chapter 5 – Methodology – Processing

5.1 Site A – Blk11 Reductions

5.1.1 Geo-Referencing Control Reductions

The traverse data was run through Elfy V2.4 a least squares reduction software. The first step is to reduce the traverse observations i.e. average out the measurements from each station. The control coordinates where then entered into the control data base and held fixed for Easting, Northing and Reduced level then a 2D and 1D least squares adjustment calculated. The calculations took approximately 0.5 hours to complete. Table 5.1 shows the computed reduced co-ordinates; note that there are no Standard deviations for the control tape targets as these are fixed marks. See appendix C for the full Elfy reduction report.

Table 5.1 Least Squares Control Output For Site A - Blk11

Pt No	Easting	Northing	RL	Description	Std Dev E	Std Dev N	Std Dev RL
T97	333682.5690	6248972.4860	11.5690	Control Tape	NA	NA	NA
T98	333647.6100	6248977.3430	11.0210	Control Tape	NA	NA	NA
T99	333606.4010	6248982.9570	10.7340	Control Tape	NA	NA	NA
T100	333581.6470	6248986.3470	10.6560	Control Tape	NA	NA	NA
T101	333562.3960	6249000.4580	9.9700	Control Tape	NA	NA	NA
T102	333581.6760	6249016.8240	9.9890	Control Tape	NA	NA	NA
T103	333605.9870	6249018.2560	10.0220	Control Tape	NA	NA	NA
T104	333658.3730	6249021.3090	10.0200	Control Tape	NA	NA	NA
T150	333689.4720	6249006.8310	12.3700	Control Tape	NA	NA	NA

T310	333681.6590	6248972.4370	18.1590	Control Tape	NA	NA	NA
T315	333641.5670	6249020.5330	16.1280	Control Tape	NA	NA	NA
AB1	333675.0762	6248999.2852	10.9746	Stand Point	0.5	0.6	0.7
AB2	333647.4523	6248998.3214	10.3867	Stand Point	0.5	0.5	0.7
AB3	333603.8922	6249001.0359	10.0265	Stand Point	0.5	0.6	0.7
AB4	333581.7200	6249002.4196	10.0785	Stand Point	0.6	0.7	0.8
1A	333662.1297	6249021.9912	17.3778	Checker Board Target	1.2	1.2	1.5
1C	333680.3207	6249015.1462	9.4051	Checker Board Target	1.1	1.2	1.5
1D	333691.9527	6248999.2860	10.4443	Checker Board Target	1.2	1.2	1.5
1E	333695.1988	6248983.6946	17.5890	Checker Board Target	1.2	1.2	1.5
1F	333681.2718	6248985.2715	9.3973	Checker Board Target	1.1	1.2	2.1
1G	333682.1205	6248972.3745	18.1493	Checker Board Target	1.2	1.2	1.5
1H	333643.3714	6248977.8905	10.8457	Checker Board Target	1.6	1.7	2.1
1I	333672.9746	6248998.0611	9.2990	Checker Board Target	1.6	1.5	2.1
1J	333633.2585	6249019.8061	9.7791	Checker Board Target	1.1	1.1	1.5
1K	333619.7728	6249019.1711	8.8177	Checker Board Target	1.0	0.9	1.3
1L	333629.5074	6248979.5909	16.9574	Checker Board Target	1.1	1.1	1.5
1M	333626.6687	6248980.0294	9.0679	Checker Board Target	1.1	1.1	1.5
1N	333610.4202	6248982.3910	10.8515	Checker Board Target	1.2	1.2	1.6
1O	333591.0971	6248984.8714	8.4770	Checker Board Target	1.1	1.2	1.6

1P	333583.4972	6248985.9292	16.0445	Checker Board Target	1.1	1.2	1.6
1Q	333565.4782	6248988.5994	10.7679	Checker Board Target	1.2	1.2	1.6
1R	333562.1710	6249002.3979	10.0814	Checker Board Target	1.2	1.2	1.6
1S	333571.0954	6249016.1959	10.0232	Checker Board Target	1.2	1.2	1.6

5.1.2 Photogrammetry Data Reductions

A total of 310 photos were taken of site A and were imported onto a new Pix4d job. As mentioned earlier the images are not geo-referenced so they import with zeroed coordinates. From this stage the processing can be broken up into several steps.-

Step 1-At the importing stage the software gives an option to state what co-ordinate system the job will be reduced on. The control co-ordinates are on a local MGA system i.e. they were reduced on MGA ground, so an arbitrary co-ordinate system was selected.

Step 2- This step is to run an initial processing routine. The purpose of this is to allow the software to stitch all the photos together which makes finding the geo-referencing marks much easier. This process took 24 minutes and successfully stitched 85% of the photos together. The photos that could not be positioned were the photos taken using the parallel method from around the top edge of Blk11. These photos required manual matching.

Pix4d will compute tie points for the unresolved images and make approximate image matches among the remaining photos. So by manual matching the user is confirming that the best guess matches are correct. This process took a further 30 minutes to complete.

Step 3- Once all the images are stitched together it produces what is known as a ray cloud. This ray cloud is an unscaled representation of all the tie points used to stitch the images together. It is at this point that the geo-referencing stations are registered on each individual image that shows an individual station. The easiest way to achieve this is by clicking on a tie point that is near a check board station. This action will bring up all the photos that show the area selected on a side panel. The user simply selects the option to create a new tie point and picks the centre of the checker target in each image and assigning the new points their unique point id. This process was repeated for all of the checker targets.

Step 4- the ground control point/manual tie point manager was accessed and all the checker targets had their co-ordinates and standard deviations updated as per the listing under heading 5.1.1. Of all the checker targets three were initially held fixed with the remaining left as check points to test how accurate the processing would be when minimally constrained. A target was selected on the East, West and half way along the southern wall. These three targets where selected due to there even spread throughout the job. The initial processing routine was then re-run with a resulting ground sampling distance of 2.8mm which is greater than calculated because of the additional images taken from the top of the excavation. Tables 5.2-5.4 show initial results see appendix D for the full report.

Focal Length	Principle Point X	Principle Point y	R1	R2	R3	T1	T2
35.223 [mm]	17.563 [mm]	11.629 [mm]	0.054	-0.245	0.031	-0.000	0.001

Table 5.2 Camera calibration results-3 fixed points

GCP Name	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified Number of Images
1D (3D)	0.000	0.000	0.000	0.209	15 / 15
1R (3D)	0.000	0.000	0.000	0.183	15 / 15
1L (3D)	0.000	0.000	0.000	0.307	29 / 29
Mean (m)	-0.000057	-0.00004	0.000013		
Std Dev (m)	0.000168	0.000138	0.000105		
RMS Error (m)	0.000177	0.000144	0.000105		

Table 5.3 Fixed point residuals-3 fixed points

Check Point Name	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified Number of Images
1A	-0.0053	0.0048	0.0311	0.2128	30 / 30
1S	0.0006	-0.0006	0.0029	0.2023	19/19
1K	-0.0061	0.0025	0.0324	0.2394	32/32
1J	-0.0088	0.0059	0.0325	0.1957	32/32
1E	0.0028	-0.0116	-0.0100	0.3249	13/13
1G	-0.0054	-0.0042	-0.0117	0.2986	16/16

1F	-0.0099	0.0015	0.0011	0.2253	19/19
1M	0.0012	0.0041	0.0011	0.3036	25/25
1N	0.0037	0.0025	0.0010	0.3365	24/24
1O	0.0064	-0.0005	0.0008	0.4707	24/24
1P	0.0096	-0.0020	0.0011	0.2344	17/17
1Q	0.0084	-0.0034	0.0033	0.3302	21/21
1I	-0.0107	0.0080	0.0105	0.1884	15/15
Mean (m)	-0.001047	0.000530	0.007398		
Std Dev (m)	0.006771	0.004949	0.014513		
RMS Error (m)	0.006851	0.004977	0.016290		

Table 5.4 Check point residuals-3 fixed points

The initial results are better than expected with the exception of points 1A, 1K and 1J. These points lie on the northern wall which is outside of the 3 fixed points projected plane. It is most likely that this is the reason that there Z values are lying around 30mm's. To test this theory an additional fixed point was selected '1K' and the initial processing re-run. Tables 5.5-5.7 show the results see appendix E for the full report.

Focal Length	**Principle Point X**	**Principle Point y**	**R1**	**R2**	**R3**	**T1**	**T2**
35.223 [mm]	17.564 [mm]	11.614 [mm]	0.054	-0.245	0.031	0.000	0.001

Table 5.5 Camera calibration results-4 fixed points

GCP Name	**Error X [m]**	**Error Y [m]**	**Error Z [m]**	**Projection Error [pixel]**	**Verified Number of Images**
1D (3D)	0.000	0.000	0.000	0.201	15 / 15
1R (3D)	0.000	0.000	0.000	0.187	15 / 15
1L (3D)	0.000	0.000	0.000	0.315	29 / 29
1K (3D)	0.000	0.000	0.000	0.249	32/32
Mean (m)	-0.00003	-0.000033	-0.000061		
Std Dev (m)	0.000139	0.000108	0.000368		
RMS Error (m)	0.000142	0.000113	0.000373		

Table 5.6 Fixed point residuals-4 fixed points

Check Point Name	**Error X [m]**	**Error Y [m]**	**Error Z [m]**	**Projection Error [pixel]**	**Verified Number of Images**
1A	-0.0032	0.0062	0.0006	0.2172	30 / 30
1S	0.0027	-0.0008	-0.0129	0.2004	19/19
1J	-0.0025	0.0031	-0.0002	0.2031	32/32
1E	-0.0007	-0.0025	0.0033	0.3267	13/13
1G	-0.0047	0.0021	0.0053	0.3034	16/16
1F	-0.0068	0.0018	0.0076	0.2239	19/19
1M	0.0011	-0.0029	0.0008	0.3069	25/25
1N	0.0032	-0.0025	0.0000	0.3387	24/24
1O	0.0050	-0.0064	0.0020	0.4666	24/24
1P	0.0109	-0.0002	0.0043	0.2339	17/17
1Q	0.0071	-0.0036	0.0125	0.3267	21/21
1I	-0.0072	0.0065	0.0033	0.1922	15/15
Mean (m)	0.0004	0.0001	0.0022		
Std Dev (m)	0.0054	0.0038	0.0057		
RMS Error (m)	0.0054	0.0038	0.0061		

Table 5.7 Check point residuals-4 fixed points.

Holding the fourth point fixed has confirmed that the error was due to the point lying outside the previous results fixed point plane as 1A and 1J's Z values are now less than a millimetre. These results indicate that by just holding the four points fixed a user can expect to achieve an accuracy of around 5mm on the three axis in the majority of the model. The exemptions to be the X value for point 1P and the Z Values for points 1S and 1Q.

Given the nature of the subject being measured these results more than meet the accuracy requirements of a work as executed survey with the camera setup used. Now that the expected accuracy between marks has been established the project was re-run holding all control points fixed. As the distance between control marks will be lessened, it is likely that a proportionately greater accuracy could be achieved. This however cannot be checked without placing more targets. Tables 5.8-5.9 show the results see appendix F for the full report.

A point cloud was produced with the results looking promising however it appears that due to the water on the floor of the excavation the resulting floor point cloud will likely require further analysis to assess its reliability as survey data.

Focal Length	Principle Point X	Principle Point y	R1	R2	R3	T1	T2
35.222 [mm]	17.571 [mm]	11.614 [mm]	0.054	-0.246	0.033	0.000	0.001

Table 5.8 Camera calibration results-fully constrained

GCP Name	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified Number of Images
1D	0.000	0.000	0.001	0.206	15/15
1A	0.000	0.000	0.000	0.219	30/30
1R	-0.001	0.001	0.000	0.220	15/15
1S	0.000	0.000	-0.002	0.191	19/19
1K	0.000	0.000	0.001	0.265	32/32
1J	0.000	0.000	0.000	0.222	32/32
1L	0.000	0.000	0.000	0.297	29/29
1E	0.000	0.000	-0.001	0.337	13/13
1G	0.000	0.000	-0.001	0.300	16/16
1F	0.000	0.000	0.003	0.241	19/19
1M	0.000	0.000	0.000	0.293	25/25
1N	0.000	0.000	0.000	0.326	24/24
1O	-0.001	0.000	-0.001	0.483	24/24
1P	0.001	-0.001	0.000	0.234	17/17
1Q	0.001	0.000	0.002	0.358	21/21
1I	0.000	0.001	0.000	0.193	15/15
Mean (m)	-0.000039	-0.000001	-0.000101		
Std Dev (m)	0.000556	0.000437	0.001160		
RMS Error (m)	0.000558	0.000437	0.001164		

Table 5.9 fixed point residuals-fully constrained.

The point cloud data was then segmented to the areas of interest for further processing. The data was then exported as las/laz files for the point cloud data and Ply/Dxf formats for the textured mesh. These files will be used for further analysis in cloud compare.

5.1.3 Laser Scanning Data Reductions

Trimble Realworks 8.1 was used to reduce the scan data with the following steps used-

1. The raw FLS files where imported and converted into a Realworks format. The conversion process took 55 minutes or about 6 minutes per scan.

2. Once imported the scans where auto registered by stating the types of target used, In the case of Blk11 138mm spheres and black and white checker targets where selected. In this step the software detects the stated targets and by analysing there vectors will stitch the scans together.

3. The control co-ordinates where imported.

4. The geo-referencing tool was then used to match 3 control targets with the automatically detected checkerboard targets. Table 5.10 shows the control residuals for the minimally constrained adjustment. As Realworks does not report on these residuals the co-ordinates had to be pulled out manually from the auto detected checkerboard targets. See appendix G for the full Trimble Realworks report.

Blk 11 Minimally Constrained			
Pt ID.	ΔX (mm)	ΔY (mm)	Δ Z (mm)
1A	1.8	7.3	8.6
1B	Destroyed		
1C	-4.1	4.1	19.3
1D	0.4	9.2	5.5
1E	0.5	-0.1	0.0
1F	2.1	3.7	6.0
1G	-6.5	0.4	-7.6
1H	Destroyed		
1I	Not Measured		
1J	-2.8	7.3	15.9
1K	-3.5	6.0	14.3
1L	3.0	-0.9	0.3
1M	-1.1	6.7	-1.3
1N	-2.0	4.4	2.4
1O	Not Measured		
1P	1.3	-2.4	-0.6
1Q	-5.1	7.2	-5.9
1R	-3.5	1.0	-0.3

1S	-3.7	2.8	9.2
Mean (mm)	-1.5	3.8	4.4
Std Dev (mm)	2.8	3.4	7.6
RMS Error (mm)	3.22	5.10	8.78

Table 5.10 Checkerboard target residuals-minimally constrained.

Table 5.11 was produced to show how the residuals in table 5.10 are distributed throughout the scanning stations due to the larger than expected values for 1C, 1J and 1K.

Table 5.11 shows a RMS error of 2.3mm within the 3 fixed control points; however table 5.10 indicates that the RMS error on the check control is closer to 5.7mm. As a scanner is rated to +-0.002 m distance accuracy some of this error may be explained by the angle of incidence of some of the checkerboard targets to the scanner. All the targets however where measured within a >45° angle of incidence recommended by Faro suggesting the white paper on this instrument was being a little optimistic.

Scan Station	Mean Residual Error (m)
Cub_blk11003	0.0014
Cub_blk11004	0.0017
Cub_blk11005	0.0020
Cub_blk11006	0.0019
Cub_blk11007	0.0013
Cub_blk11008	0.0017
Cub_blk11009	0.0038
Cub_blk11010	0.0022
Cub_blk11011	0.0034
Mean (mm)	0.0022
Std Dev (mm)	0.0009
RMS Error (mm)	0.0023

Table 5.11 Scan station residuals-minimally constrained

- The previous step was repeated holding all of the checkerboard target control fixed with table 5.12 showing the resulting checkerboard station residuals. See appendix H for the full Trimble Realworks report.

- As the point clouds shift with the scan stations the point cloud was produced automatically with the results looking promising however it appears that due to the water on the floor of the excavation the resulting floor point cloud will likely require further analysis to assess its reliability as survey data. There also appears to be far more holes in the scan data of this section then that of the photogrammetry.

Blk 11 Fully Constrained			
Pt ID.	ΔX (mm)	ΔY (mm)	Δ Z (mm)
1A	4.2	5.2	-5.9
1B	Destroyed		
1C	-2.4	-2.0	5.2
1D	1.9	2.9	-5.2
1E	1.7	-3.5	-3.4
1F	3.0	-2.2	2.6
1G	-5.7	-2.3	-6.3
1H	Destroyed		
1I	Not Measured		
1J	-1.1	2.8	1.8
1K	-1.6	1.9	1.5
1L	4.0	-2.3	1.4
1M	-0.4	2.5	-0.1
1N	-1.1	1.3	3.4
1O	Not Measured		
1P	2.6	-2.8	1.6
1Q	-1.2	-1.3	-1.1
1R	-2.1	-0.8	-4.4
1S	-1.8	0.7	-0.3
Mean (mm)	0.0	0.0	-0.6
Std Dev (mm)	2.7	2.5	3.5
RMS Error (mm)	2.69	2.55	3.16

Table 5.12 Checkerboard target residuals-Fully constrained

The scan data was segmented to the areas of interest and then further segmented into individual walls and the floor for ease of further processing. The data was then exported in their individual sections as DXF files for further analysis.

5.2 Site B – The Office

5.2.1 Geo-Referencing Control Reductions

The traverse data was run through Elfy V2.4, a least squares reduction software. The first step is to reduce the traverse observations i.e. average out the measurements from each station. As the job was conducted on an assumed orientation and co-ordinate system in order to process the data the first temporary station was held fixed along with an azimuth from that station to the furthest tape target.

The next step was to conduct a 2D and 1D least squares adjustment. The calculations took approximately 0.5 hours to complete. Table 5.13 shows the computed reduced co-ordinates; note that there is no Standard deviation for station A1 as this mark was held fixed mark. See appendix I for the full Elfy reduction report.

Table 5.13 Least Squares Control Output For Site B - The Office

Pt No	Easting	Northing	RL	Description	Std Dev E	Std Dev N	Std Dev H
T1	500.0000	2043.1815	20.5651	Control Tape	1.4	0.9	1.1
T2	512.1517	2041.0904	20.7072	Control Tape	1.6	1.0	1.1
T3	505.9126	1983.8672	20.7442	Control Tape	1.2	0.9	1.1
T4	492.8098	1983.0838	18.9352	Control Tape	1.2	0.9	1.1
A1	500.0000	2000.0000	20.0000	Stand Point	NA	NA	NA
A2	500.4324	1991.4511	20.0090	Stand Point	0.9	0.8	1.1
A3	497.8552	2013.3195	20.0557	Stand Point	0.9	1.0	1.3
A4	499.8308	2021.0885	20.0402	Stand Point	1.0	1.0	1.3
A5	500.8365	2027.6362	20.0627	Stand Point	1.2	0.9	1.2
A6	506.7262	2034.4783	20.0376	Stand Point	1.4	1.0	1.3
1B	511.7060	2019.5506	26.6524	Checker Board Target	1.2	1.2	1.6
2B	514.4280	2036.4845	22.1277	Checker Board Target	1.8	1.4	1.8
3B	506.6520	2042.1050	20.3919	Checker Board Target	1.9	1.4	1.8
6B	497.1490	1982.5070	18.4220	Checker Board Target	1.3	1.1	1.5
7B	508.0605	1996.8282	20.6520	Checker Board Target	1.1	1.1	1.5
8B	510.2058	2010.1851	19.5238	Checker Board Target	1.3	1.4	1.8

5.2.2 Photogrammetry Data Reductions

A total of 56 photos were taken of site B and were imported into a new Pix4d job. As mentioned earlier the images are not geo-referenced so they import with zeroed coordinates. The same step from 5.1.2 where followed.-

Step 1- The control co-ordinates are on a local co-ordinate system and orientation so an arbitrary co-ordinate system was selected.

Step 2- The initial processing routine was run. This process took 5.5 minutes and successfully stitched all of the photos together.

Step 3- The geo-referencing checkerboard stations where registered on each individual image that shows an individual station on the raycloud. This process was repeated for all 6 of the checker targets.

Step 4- the ground control point/manual tie point manager was accessed and all the checker targets had their co-ordinates and standard deviations updated as per the listing under heading 5.2.1. Three checkboard targets where held fixed with the remaining left as check points to test how accurate the processing would be when minimally constrained. The targets where selected so that one target on either end on the job and one in the middle where held fixed. These three targets where selected due to there even spread throughout the job. The initial processing routine was then re-run with a resulting ground sampling distance of 2.2mm which is more than pre-calculated because the distance off the wall was increase to capture a larger area in each image. Tables 5.14-5.16 show initial results see appendix J for the full report.

Focal Length	Principle Point X	Principle Point y	R1	R2	R3	T1	T2
35.208 [mm]	17.552 [mm]	11.659 [mm]	0.055	-0.242	0.031	0.000	0.001

Table 5.14 Camera calibration results-minimally constrained

GCP Name	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified Number of Images
A1 (3D)	0.000	0.001	0.000	0.139	11/11
A3 (3D)	0.000	-0.001	0.000	0.188	4/4

A6 (3D)	0.000	-0.001	0.000	0.398	6/6
Mean (m)	0.000	0.000	0.000		
Sigma (m)	0	0.0008165	0		
RMS Error (m)	0	0.001	0		

Table 5.15 Fixed point residuals-3 fixed points

Check Point Name	**Error X [m]**	**Error Y [m]**	**Error Z [m]**	**Projection Error [pixel]**	**Verified Number of Images**
A2	-0.0020	-0.0070	-0.0150	0.302	9/9
A7	-0.0120	0.0050	0.0090	0.325	15/15
A8	-0.0200	0.0010	0.0070	0.269	14/14
Mean (m)	-0.011333	-0.000333	0.000333		
Sigma (m)	0.007364	0.004989	0.010873		
RMS Error (m)	0.013515	0.005000	0.010878		

Table 5.16 Check point residuals-3 fixed points

The results show a reasonable amount of error highlighted on the check shots in table 5.16. There are two conceivable reasons for this enlargement in the error residual compared to Site A Blk11-

- Images are not stitching/orientating correctly due to the amount of glass on the façade. As highlighted in the literature review photogrammetry does not perform well when measuring to reflective or transparent surfaces.
- Station A6 was located on a low concrete wall with a tree adjacent. It is possible that the tree is causing issues with image stitching in this area and the error is translating through the rest of the project. To test this theory the initial processing was re-run leaving station A6 as a check point and adopting the next available target on the façade itself.

The results came back only marginally better so it can be assumed that the additional error is creeping in due to the surface being measured, the geometry of the photographic network and the geometry of the control used. All control points where then held fixed and the process re-run. Tables 5.17 & 5.18 show the results, see appendix K for the full report from Pix4d.

Focal Length	**Principle Point X**	**Principle Point y**	**R1**	**R2**	**R3**	**T1**	**T2**
35.218 [mm]	17.556 [mm]	11.599 [mm]	0.055	-0.242	0.031	0.000	0.001

Table 5.17 Camera calibration results-Fully constrained

GCP Name	**Error X [m]**	**Error Y [m]**	**Error Z [m]**	**Projection Error [pixel]**	**Verified Number of Images**
A1 (3D)	0.000	0.000	0.001	0.194	11/11
A2 (3D)	-0.001	-0.001	-0.001	0.299	9/9
A3 (3D)	0.001	0.001	-0.001	0.139	4/4
A6 (3D)	0.000	-0.001	-0.001	0.452	6/6
A7 (3D)	0.000	0.000	0.003	0.287	15/15
A8 (3D)	-0.002	0.000	0.000	0.255	14/14
Mean (m)	-0.000333	-0.000167	0.000167		
Sigma (m)	0.000943	0.000687	0.001462		
RMS Error (m)	0.001155	0.000577	0.001826		

Table 5.18 Fixed point residuals-Fully constrained

The point cloud data was then generated and segmented to the areas of interest for further processing. The data was then exported as las/laz files for the point cloud data and Ply/Dxf formats for the textured mesh. These files will be used for further analysis in cloud compare.

5.2.3 Laser Scanning Data Reductions

Trimble Realworks 8.1 was used to reduce the scan data with the following steps used-

1. The raw FLS files where imported and converted into a Realworks format. The conversion process took 24 minutes or about 6 minutes per scan.

2. Once imported the scans where auto registered by stating the types of target used i.e. 138mm spheres and black and white checker targets where selected.

3. The control co-ordinates where imported.

4. The geo-referencing tool was then used to match 3 control targets with the automatically detected checkerboard targets. Table 5.19 shows the control residuals for the minimally constrained adjustment. As Realworks does not report on these residuals the co-ordinates had to be pulled out manually from the auto detected checkerboard targets. See appendix L for the full Trimble Realworks report.

Site B - The Office_ Minimally Constrained			
Pt ID.	ΔX (mm)	ΔY (mm)	Δ Z (mm)
1B	2.0	-3.0	1.9
2B	-0.4	-1.4	1.2
3B	-1.8	-0.4	5.4
6B	-0.1	2.3	-0.3
7B	1.1	1.8	2.5
8B	1.7	0.3	0.2
Mean (mm)	0.4	-0.1	1.8
Std Dev (mm)	1.3	1.8	1.9
RMS Error (mm)	-1.4	-1.8	-2.6

Table 5.19 Checkerboard target residuals-minimally constrained.

Table 5.19 shows that the minimally constrained adjustment has yielded excellent results compared with the photogrammetry.

5. The previous step was repeated holding all of the checkerboard target control fixed with table 5.20 showing the resulting checkerboard station residuals. See appendix M for the full Trimble Realworks report. As can be seen in table 5.20 there is not really a great improvement between

registrations, in this case three targets where more than adequate for the task being undertaken.

Site B - The Office_ Fully Constrained			
Pt ID.	ΔX (mm)	ΔY (mm)	Δ Z (mm)
1B	2.2	-3.3	1.0
2B	-0.6	-1.6	0.4
3B	-2.2	0.6	-1.4
6B	-0.9	2.3	-0.6
7B	0.5	1.7	1.5
8B	1.1	0.2	-0.8
Mean (mm)	0.0	0.0	0.0
Std Dev (mm)	1.4	1.9	1.0
RMS Error (mm)	-1.4	-1.9	-1.0

Table 5.20 Checkerboard target residuals-Fully constrained.

The scan data was then segmented to the areas of interest and then further segmented into individual walls and the floor for ease of further processing. The data was then exported in as a DXF file for further analysis.

Chapter 6 – Analysis

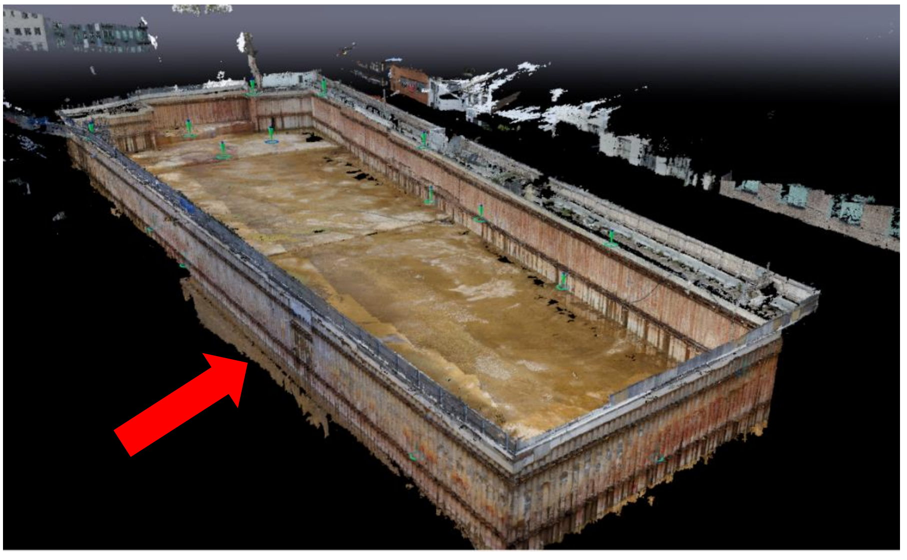
6.1 Comparisons

To examine the accuracy of the data collected for the point cloud datasets an open source software known as Cloud Compare was utilised. This software will measure the distance between two point clouds and or surface models and re-assign one of the point clouds to a colour scale. This colour scale will increase intensity the further away the two datasets are from each other with the range being adjustable which aids in filtering out noise.

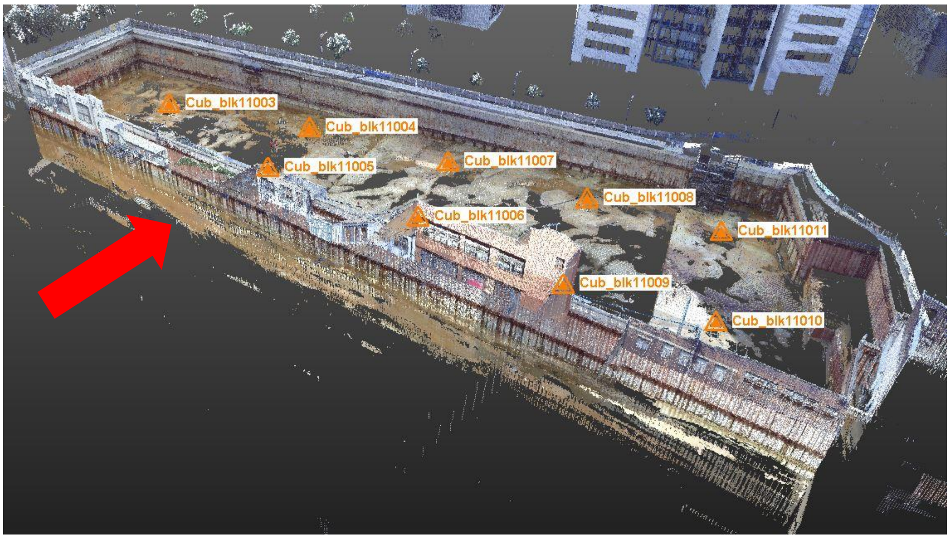
The disadvantage of measuring a distance between point clouds is the output is non-directional meaning that it will only represent a magnitude. The other option, to measure between a surface and point cloud will show both a magnitude and a direction in the form of a different coloured scalar field i.e. one colour for one direction and a different colour for the other. Due to the computing power and time required to generate a surface from such dense point clouds the author conducted all comparisons on a point cloud to point cloud based analysis.

6.1.1 Site A – Blk11

An initial visual analysis on both laser scanning and photogrammetry datasets revealed an obvious flaw in both of them. Due to the floor of the excavation being covered with water to various degrees the base of the pile wall has been project well below the finished floor level of the hole. Figures 6.1 and 6.2 show the prolongations highlighted by red arrows note the darker colour tones.

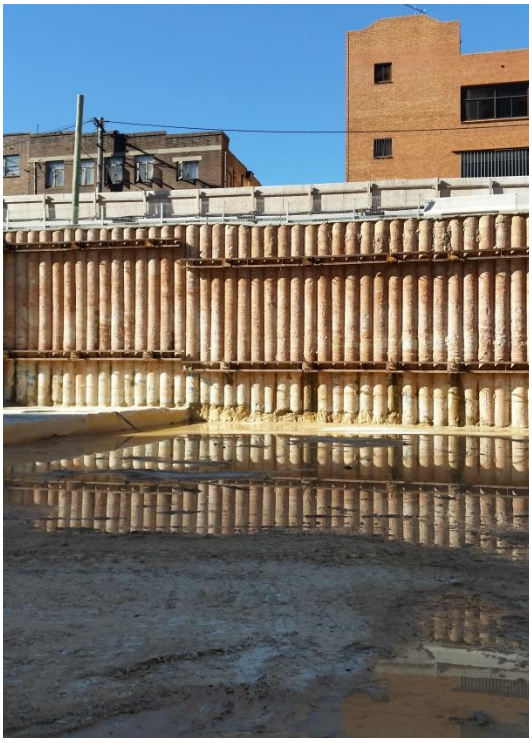


Figures 6.1 image showing pile prolongation Site A – Block 11-Photogrammetry-Cloud Compare



Figures 6.2 image showing pile prolongation Site A – Block 11-Laser Scanning-Trimble Realworks

Interestingly the laser scan data had a prolongation of approximately twice that of the photogrammetry. This phenomenon can be explained by the water adjacent to the secant pile walls. Figure 6.3 it shows the walls being prolonged in a reflection on the water. It appears that the resulting scan and photogrammetry have located the prolongation in the same way i.e. by the reflection of the water.



Figures 6.3 image showing reflection of piles in water Site A – Block 11

These anomalies where removed along with any other superfluous surrounding data.

With the presence of water on the excavation floor any information extrapolated from the point cloud datasets will require a more thorough investigation to ascertain accuracy with any kind certainty

For ease of calculations in cloud compare the datasets were also segmented into 5 smaller sections, one for the floor and four for the walls. The individual sections were then processed in Cloud Compare with figures 6.4-6.8 being the respective outputs.

The comparison results for the secant pile walls between Laser Scanning and Photogrammetry appear to be in the range of 0-7mm of each other. These results are well within tolerance for this style of survey and given that the surface rough and undulating 3mm out sideways could easily affect the result by that much. As the shape of the excavation is a closed figure no further checking of length or width is necessary. It would appear to be conclusive that when measuring the wall surface with the equipment and settings used a surveyor could expect to get the same result from either technique.

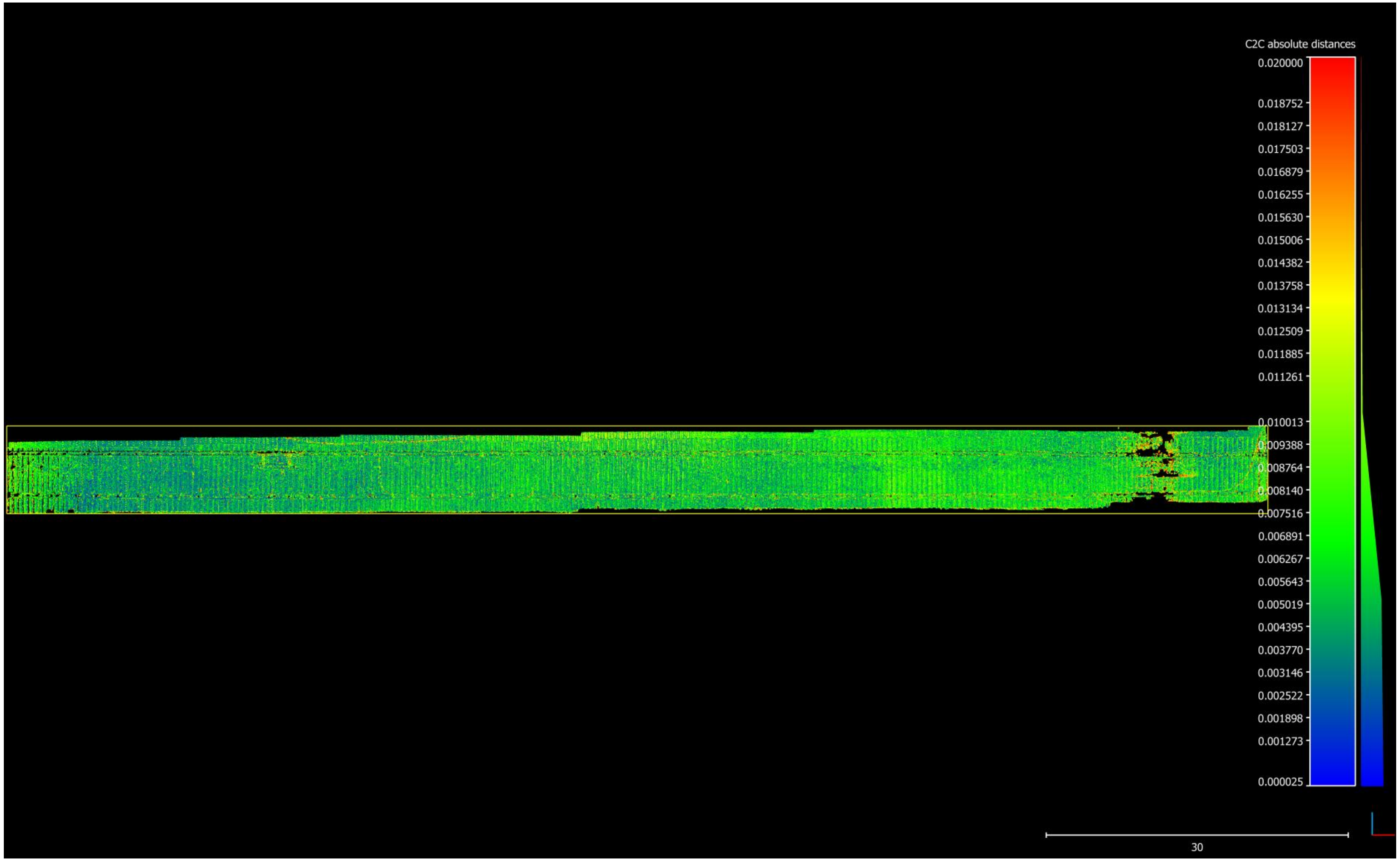
The data collected on the floor of Site A - Blk11 was far more ambiguous as figure 6.8 reveals the spread of the comparison between Photogrammetry and Laser Scanning is in the range of 7mm-20mm. The most unity between the two data sets appears to be along the middle of the excavation in an East West direction with the larger differences show along the North and South of the hole. This result together with the sparseness of the scanning data required more testing to be conclusive of its accuracy.

A level grid of natural surface RLs at 3m intervals was taken across the site, although it is a relatively small data set compared to the scanning and Photogrammetry point clouds it shall serve as the point of truth for the comparison.

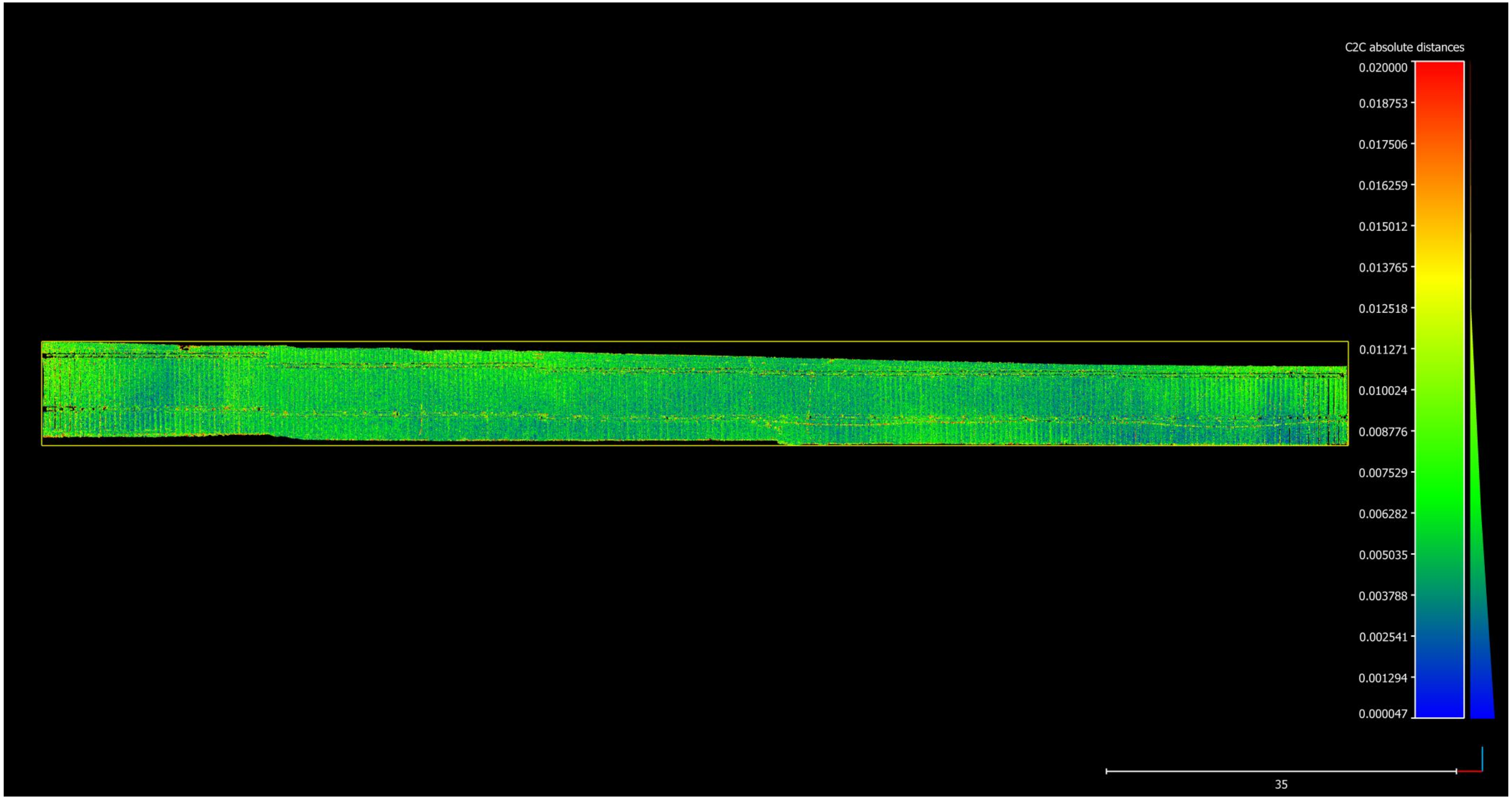
Figures 6.9 show the comparison between the conventionally surveyed excavation floor and the Photogrammetry point cloud. The resulting average ranges are 0mm-20mm with random spikes of separation of up to 50mm across the site.

Figures 6.10 show the comparison between the conventionally surveyed excavation floor and the Laser Scanned point cloud. The resulting average ranges are 0mm-20mm with random spikes of separation of up to 50mm across the site. There appears to be slightly more points closer to 0mm separation then was shown in the photogrammetry comparison.

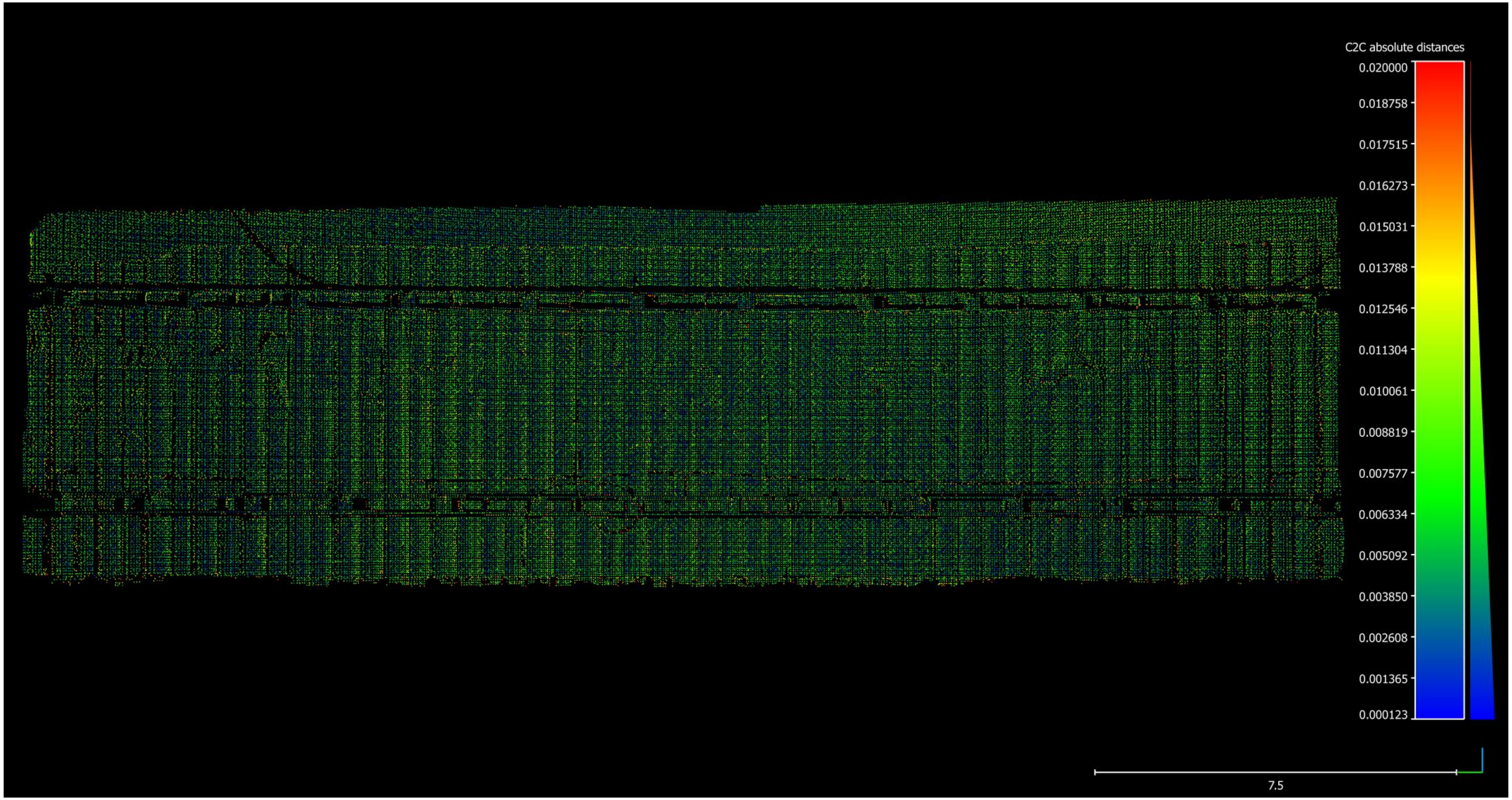
Regardless of the scan dataset being a slight improvement to the Photogrammetry, because of the magnitude of the anomalies and there random distribution it is clear that neither Photogrammetry nor scan derived data would be suitable for survey standard outputs under a wet floor condition.



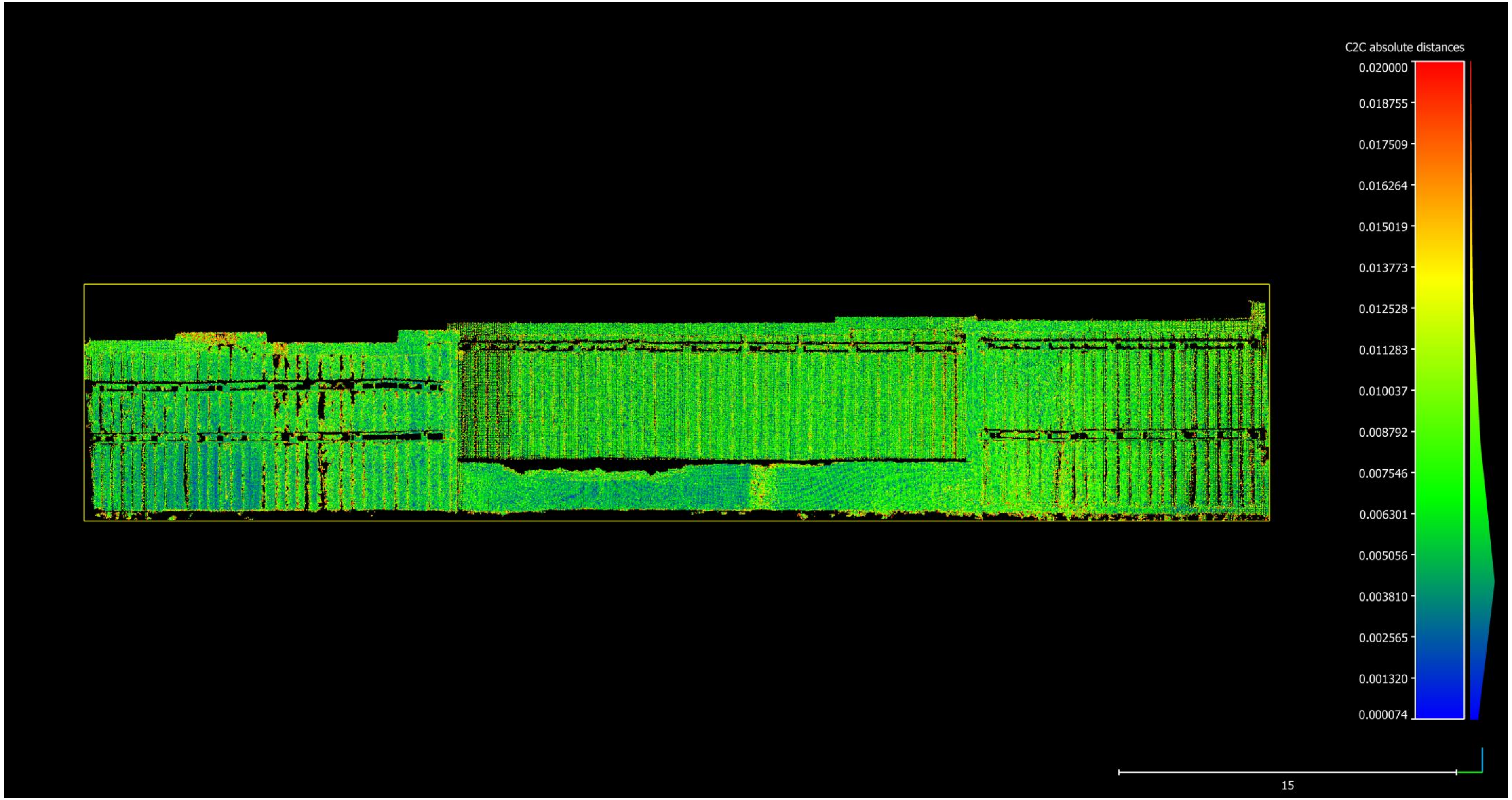
Figures 6.4 image showing northern wall comparison Site A – Block 11-Cloud Compare



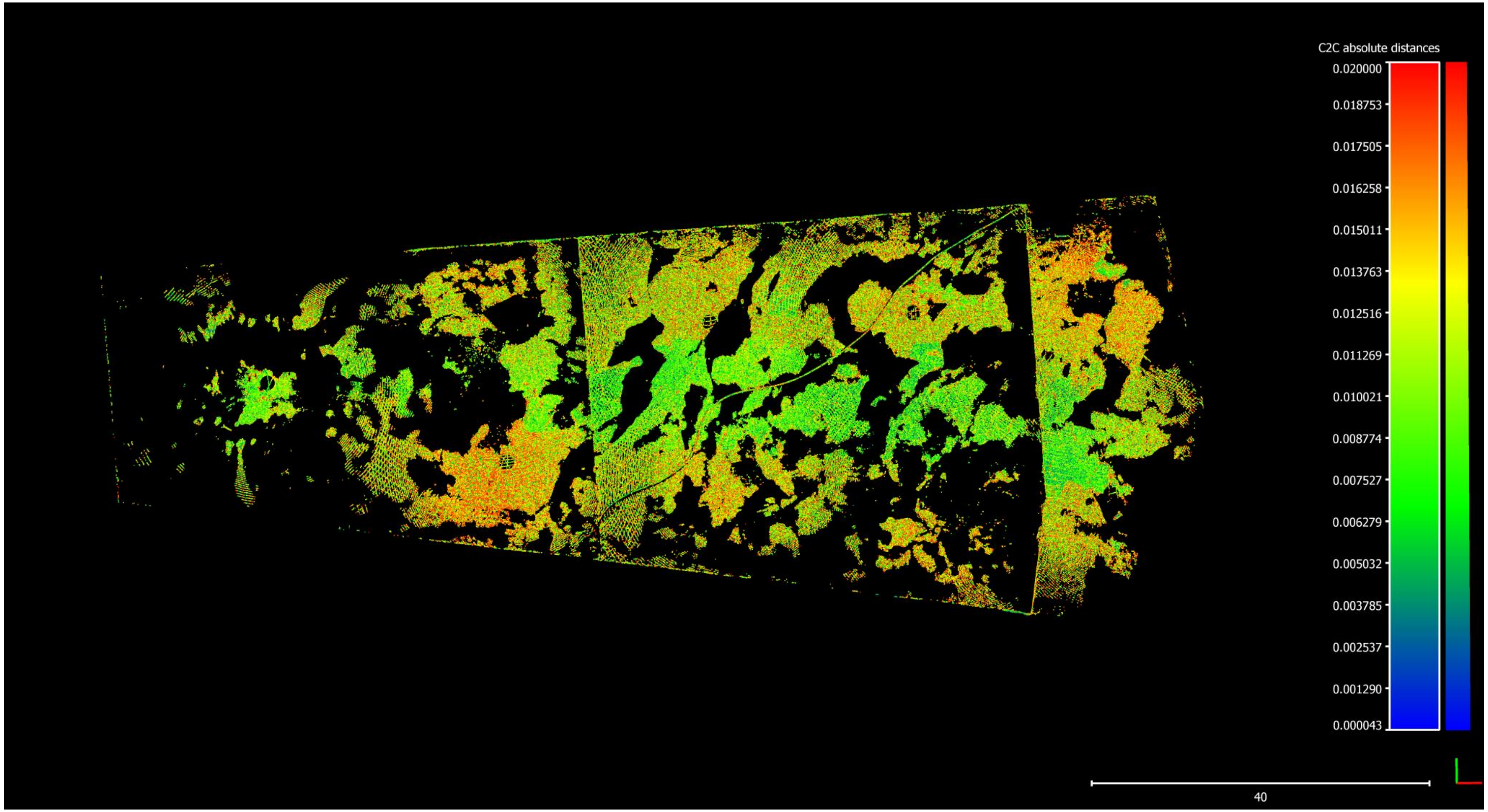
Figures 6.5 image showing southern wall comparison Site A – Block 11-Photogrammetry to Laser Scanning-Cloud Compare



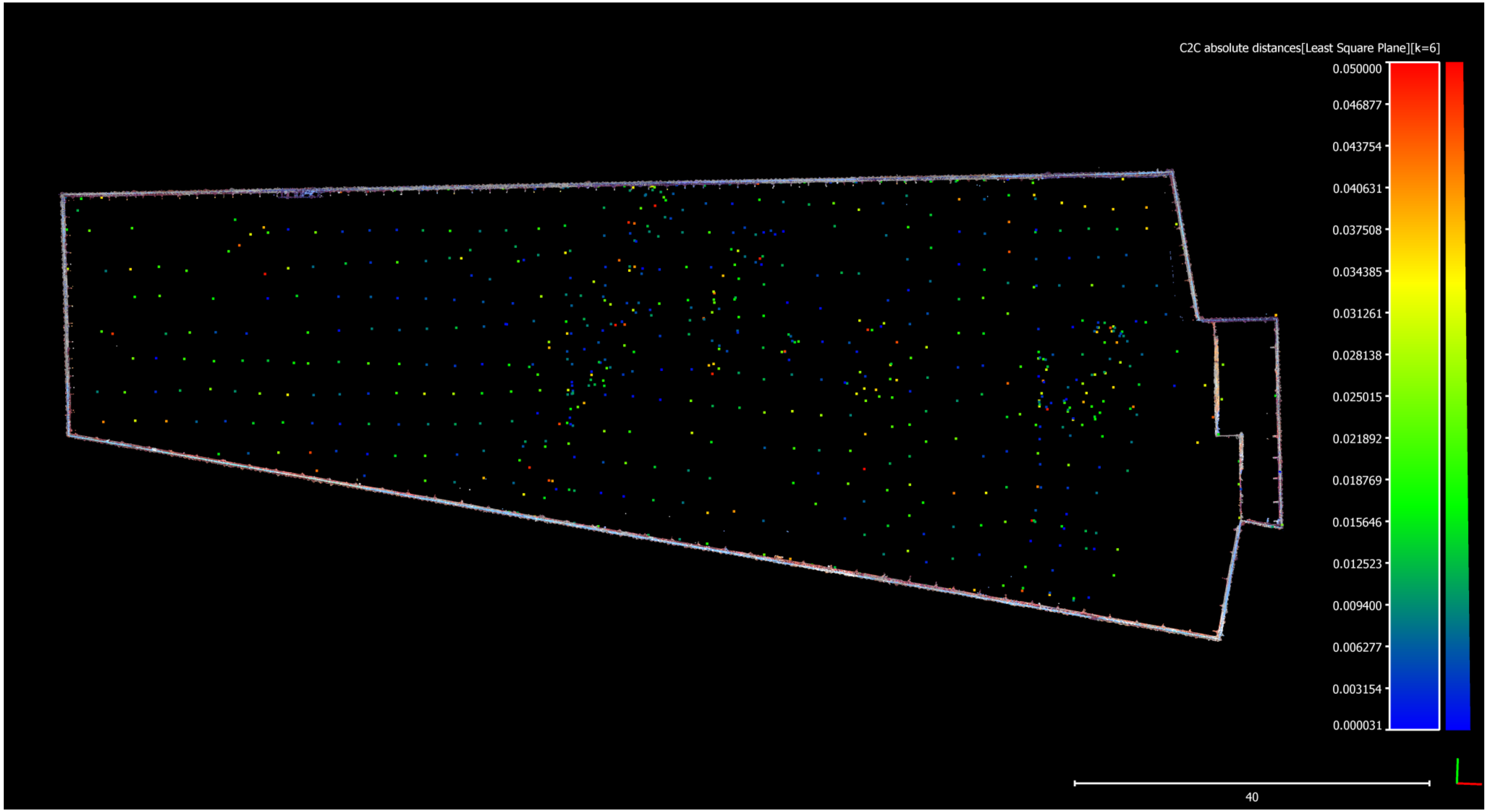
Figures 6.6 image showing Eastern wall comparison Site A – Block 11-Photogrammetry to Laser Scanning-Cloud Compare



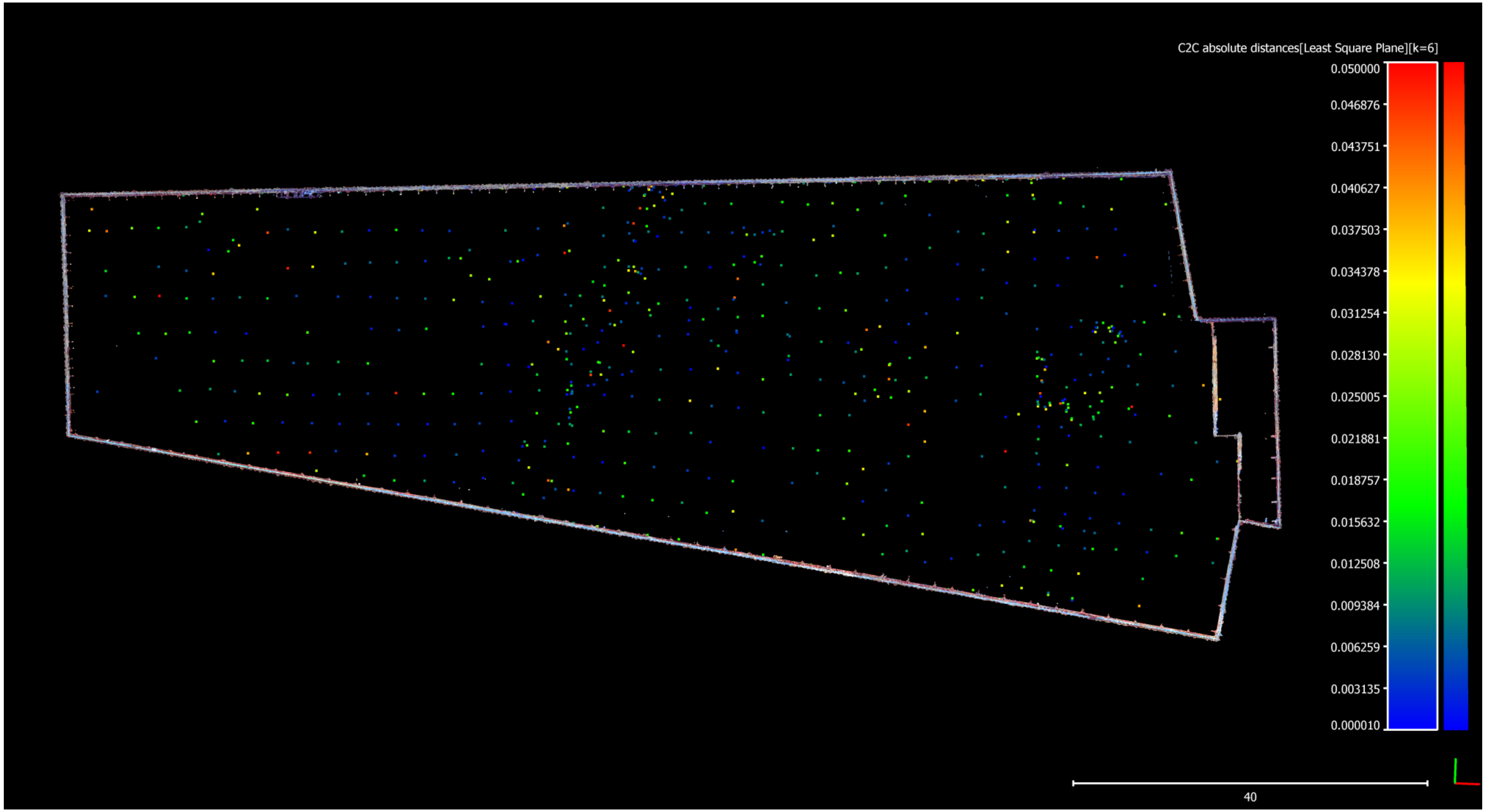
Figures 6.7 image showing Western wall comparison Site A – Block 11-Photogrammetry to Laser Scanning-Cloud Compare



Figures 6.8 image showing finished floor comparison Site A – Block 11-Photogrammetry to Laser Scanning-Cloud Compare



Figures 6.9 image showing finished floor comparison Site A – Block 11-Conventional Surveying to Photogrammetry-Cloud Compare

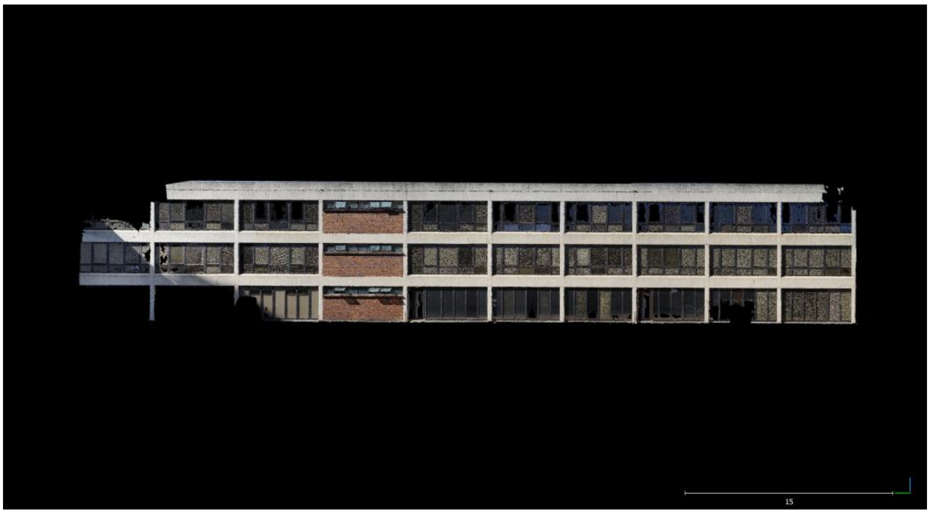


Figures 6.10 image showing finished floor comparison Site A – Block 11-Conventional Surveying to Laser Scanning-Cloud Compare

6.1.2 Site B – The Office

In the initial visual inspection of the Photogrammetry point cloud, it appears that the weaker photographic network of photos Pix4d was unable to resolve the two top corners of the building. The corner on the right could be explained by the low wall, tree and void adjoining the building when coming around the corner to close off onto some control. The left hand corner may be due to the void underneath the building causing the photo reductions a 1/3 loss in potential quality tie points. Neither off these too missing sections comes as a surprise as the photographic network was one directional and the lack of available tie points due to the amount of glass on the building. There are also some missing sections along the base which have been cut out as a car and some garbage bins blocked the view of the building at the time of survey.

The colour and cloud density are excellent as Seen in figure 6.11 for the Photogrammetry derived point cloud.



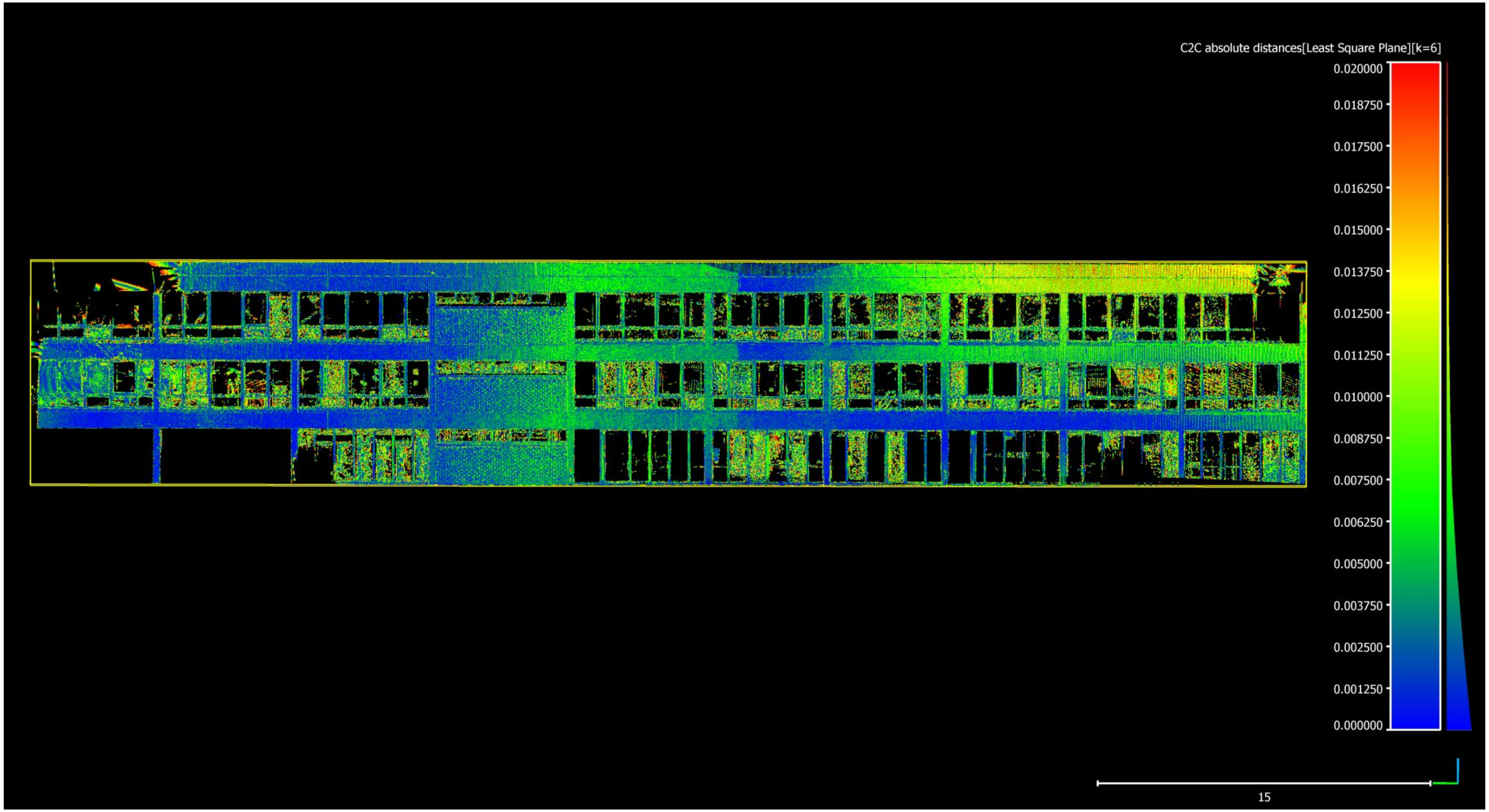
Figures 6.11 image showing Photogrammetry derived point cloud-Cloud Compare

The scan data however resolved with what appears to be a comprehensive point cloud. The point cloud colour quality however is dull and of poor quality. See figure 6.12 for scan derived point cloud.

Both clouds resolved for points within the windows most likely due to the blinds being visible from the outside.

Figures 6.12 image showing Scan derived point cloud-Cloud Compare

A comparison was then run in Cloud Compare as seen in figure 6.13. As the author did not have enough time to run any conventional surveying checks the laser scan data shall be considered the point of truth for this comparison. The majority of this comparison is within 0-6mm which is well within excepted limits for an elevation style survey. The exception to this is the missing data on the top left corner and the top right corner appears to be peeling away by 12mm. This is still an acceptable outcome for this style of survey and could be easily rectified by improving on the camera geometry or measuring in an additional control mark in the corner to pull the data back into line. This was not done due to time constraints however the missing sections of the building would require further work to resolve in a real world application.



Figures 6.13 image showing compared point clouds-Cloud Compare

6.2 Cost/Benefit Analysis

Now that the fieldwork and reductions have been completed it is time to consider the objective ‘Aid surveyors considering either TLS or TP techniques for a project by demonstrating their abilities in real world applications’. In considering how to evaluate each technique it was decided to break down each technique into several categories and assign a numerical score to each category. The idea being that the user can select the categories that are most important to their task, add up the scores with the lowest score being the indicator that this technique will best suit the task. Conventional surveying is the bench mark for measurement within the industry and has been used as the benchmark for this analysis. The following categories where considered for each site -

•**Equipment cost**- As equipment costs will fluctuate depending on what is utilised only the equipment used will be considered in this analysis. The theodolite used on both sites was a Ts15 1” R1000 valued at approximately $40000 and assigned a value of 10. As both Laser scanning and Photogrammetry both require Geo-referencing the value of the additional equipment was applied to the value of the theodolite as a ratio to its score.

•**Reduction software cost**- This field was populated using the same technique as in the equipment cost, by applying a ratio to the value of the theodolite being used to the costs of the software’s being used.

•**Field time & Reduction time**- To populate these categories ten points was assigned to a standard 8 hour day. As Site A-Blk11 is a real job the quantity of field time was known to the author, Site B-The Office however was assigned a time value based on the author’s experience.

•**Skill Level Field & Office**- These categories where populated based on the authors professional opinion with conventional surveying being considered to require the highest skill level being assigned a value of 10.

•**Accuracy**- Again as conventional surveying is considered the industry standard it was assigned a score of 1 with Laser Scanning and Photogrammetry receiving higher scores due to the tendency for noise, noise being additional random points in space to a non-existent object.

•**Data Richness**- This category refers the amount of data captured i.e. the separation between point clouds. In the field tests conducted Photogrammetry had the tightest point groupings it was assigned the lowest score with scanning and conventional surveying being assigned proportional values.

See tables 6.1 and 6.2 for the category ratings of each site.

	Equipment Cost	Reduction Software Cost	Field time	Skill Lvl Required Field	Reduction Time	Skill Lvl Required Office	Accuracy	Data Richness	Total
Conventional Surveying	10	1.25	30	10	30	10	1	10	102.3
Laser Scanning	30	1.25	5	3	10	6	3	3	61.25
Photogrammetry	11	2.5	2.5	6	10	2	4	1	39

Table 6.1 Cost benefit analysis of Site A-Blk11

	Equipment Cost	Reduction Software Cost	Field time	Skill Lvl Required Field	Reduction Time	Skill Lvl Required Office	Accuracy	Data Richness	Total
Conventional Surveying	10	1.25	5	10	5	10	1	10	52.25
Laser Scanning	30	1.25	1.25	3	5	6	3	3	52.5
Photogrammetry	11	2.5	0.62	6	5	2	4	1	32.12

Table 6.2 Cost benefit analysis of Site B-The Office

As can be seen in table 6.1 and 6.2 when all the evaluating categories are considered Photogrammetry is the clear overall winner. However in using these tables the author stresses that only the important categories of the proposed venture should be considered. For example if accuracy is the number one priority than conventional surveying should be used. Conversely if a lower field skill level is prioritised than laser scanning should be used. A combination of important priority could also to use.

Chapter 7 – Further Research And Conclusion

7.1 Further Research

Some possible further research topics include-

• Experimenting with 4K videogrammetry.

• Repeat the same experiments using longer distances. Theoretically the Laser scanner will lose accuracy over longer distances however using the right equipment setup Photogrammetry will maintain accuracy.

• Trialling different equipment setups. The experiments in this dissertation where aimed at matching the two technologies into the same accuracy class.

• Trialling close range aerial Photogrammetry against terrestrial laser scanning. In theory because the angle of incidence on the terrestrial laser scanner is quite acute the aerial photos should yield better results.

7.2 Conclusion

The Literature review was conducted primarily to ascertain best practice techniques for both Laser Scanning and Photogrammetry. However it was discovered that very little peer reviewed literature existed that compared one technique to the other. It is the hope that this dissertation helps place another link in the chain that helps bridge the gap in the existing knowledge bank and to serve as a decision making aid for professionals.

The results of the fieldwork suggest that there are no significant differences between Laser scanning and Photogrammetry under the conditions of the test subjects surveyed with the equipment used. The analysis showed measured differences of between 0 – 7mm with two exemptions-

• A section in site B-The Office where the photographic network and perhaps the placement of the control were insufficient due to the author's inexperience with the field techniques of this style of survey. This error was highlighted early in the reduction stage where a minimally constrained adjustment took place and in a real working scenario would have required further fieldwork to rectify the issue.

• Both techniques failed to achieve consistent results on site A-Blk11 excavation floor. Both techniques where proven to be inconsistent with the actual basement floor by comparing both techniques to a sample of conventionally surveyed data. Even though the data collected was relatively sparse it highlighted that neither technique yielded reliable results. This is due to the varying levels of water on the excavations floor at the time of the survey and was the expected result for both techniques as neither technique is recommended to be used to collect data through water instead conventional surveying should be utilised.

During the reduction phase it was apparent that laser scanning resulted in a dull colour pallet while photogrammetry yielded a true to life coloured point cloud.

A cost benefit analysis was conducted based on the equipment used and the tests conducted for the comparison. This analysis was done in the form of a marking matrix with several key deciding factors given a score. In both test cases photogrammetry was the clear overall winner due to the equipment being relatively inexpensive. It is recommended however those users of the marking matrix select the fields that are most important to their needs add up the scores to aid in making the decision. The marking matrix was developed as a guide only based on the experiences while conducting field tests and is not a standalone decision tool.

Based on the results achieved in this dissertation using the equipment setups both Laser Scanning and Photogrammetry are excellent choices for creating point cloud models.

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Appendix A

Project specification

ENG4111/4112 Research Project

Project Specification

For:	Lachlan Edward Broome
Title:	A comparison between 3d laser scanning and close range terrestrial Photogrammetry for 3d modelling
Major:	Surveying
Supervisor:	Albert Chong
Enrolment:	ENG4111 - EXT S1, 2016
	ENG4112 – EXT S2, 2016
Project Aim:	To test the methods, speed and accuracy of 3d laser scanning against close range terrestrial photogrammetry

Programme: Issue A, 15th March 2016

1. Research for any existing literature relevant to the project topic title.

2. Search for some suitable sites to conduct the field work.

3. Based off Research prepare work instruction and safety documentation.

4. Conduct the field surveys with respect to best practice techniques for each form of survey.

5. Analyse Field data and compare results.

6. Conduct Time/cost/benefit analysis of each survey method.

Appendix B

Site A-Blk11 convergence

test report from Pix4D

Quality Report

Generated with Discovery version 2.1.49

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	blk11_test2_convergence
Processed	2016-04-14 19:40:03
Average Ground Sampling Distance (GSD)	undefined
Time for Initial Processing (without report)	08m:47s

Quality Check

Images	median of 70908 keypoints per image	
Dataset	33 out of 33 images calibrated (100%), all images enabled	
Camera Optimization	0.67% relative difference between initial and optimized internal camera parameters	
Matching	median of 26025.9 matches per calibrated image	
Georeferencing	no, no 3D GCP	

Calibration Details

Number of Calibrated Images	33 out of 33
Number of Geolocated Images	0 out of 33

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions

The preview is not generated for images without geolocation.

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	844643
Number of 3D Points for Bundle Block Adjustment	337922
Mean Reprojection Error [pixels]	0.118103

Internal Camera Parameters

ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB). Sensor Dimensions: 35.000 [mm] x 23.359 [mm]

EXIF ID: ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	7360.000 [pixel] 35.000 [mm]	3680.000 [pixel] 17.500 [mm]	2456.000 [pixel] 11.679 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	7409.729 [pixel] 35.236 [mm]	3680.684 [pixel] 17.503 [mm]	2443.788 [pixel] 11.621 [mm]	0.055	-0.261	0.089	-0.000	0.000

	The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	70908	26026
Min	49728	11111
Max	83392	37360
Mean	69989	25595

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	241534
In 3 Images	55563
In 4 Images	22048
In 5 Images	10137
In 6 Images	5392
In 7 Images	2390
In 8 Images	797
In 9 Images	59
In 10 Images	2

2D Keypoint Matches

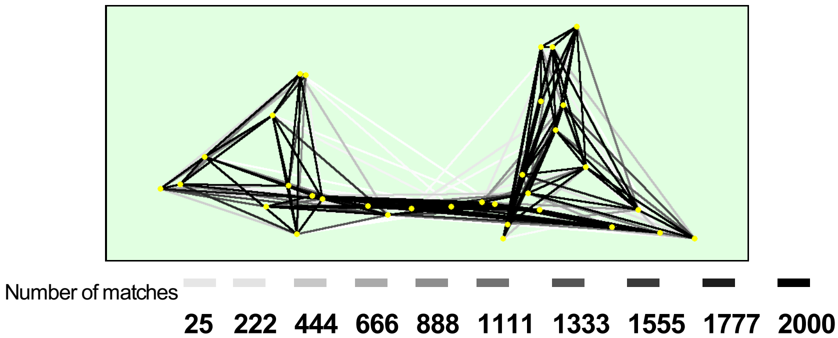


Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

Processing Options

Hardware	CPU: Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz RAM: 16GB GPU: NVIDIA GeForce GTX 550 Ti (Driver: 10.18.13.5382)
Operating System	Windows 10 Home, 64-bit
Camera Model Name	ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB)
Output Coordinate System	Arbitrary (m)
Detected template:	3D Models

Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Free Flight or Terrestrial
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard, Internal Parameters Optimization: All, External Parameters Optimization: All, Rematch: Auto yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	3
3D Textured Mesh Generation	yes, Maximum Number of Triangles: 1000000, Texture Size: 8192x8192
Advanced: Matching Window Size	9x9 pixels
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Advanced: Limit Camera Depth Automatically	yes
Time for Point Cloud Densification	13m:12s
Time for 3D Textured Mesh Generation	04m:46s

Results

Number of Generated Tiles	1
Number of 3D Densified Points	10000506
Average Density (per m^3)	244.96

Appendix C

Site A-Blk11 conventional surveying least squares adjustment report from Elfy V2.4

****

Elfy - [E:\UNI\uni class's\year 7 (2016)\project_semester 1\Field work\elfy\blk11-usq1.elf]   Version 2.4.0.39
Traverse Reductions
Date: 01/09/2016
Time: 1:42:35 PM

****

-> Refraction corrections applied for orthometric height differences
-> Coefficient of refraction of light, k = 0.13

* TRAVERSE ROUNDS FOUND * - Line (1)
====================== Observations From : AB1 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T104	48 44 18	+02	228 44 20	48 44 19.0	0 00 00.0	+00.0	+00.0	0.0
T150	148 15 17	-03	328 15 14	148 15 15.5	99 30 56.5	+00.0	+00.0	0.0
T97	250 17 22	+03	70 17 25	250 17 23.5	201 33 04.5	+00.0	+00.0	0.0
T310	252 08 00	-04	72 07 56	252 07 58.0	203 23 39.0	+00.0	+00.0	0.0
T98	317 17 36	+00	137 17 36	317 17 36.0	268 33 17.0	+00.0	+00.0	0.0
1A	56 13 20	-05	236 13 15	56 13 17.5	7 28 58.5	+00.0	+00.0	0.0
1C	104 12 45	+05	284 12 50	104 12 47.5	55 28 28.5	+00.0	+00.0	0.0
1D	175 54 43	+02	355 54 45	175 54 44.0	127 10 25.0	+00.0	+00.0	0.0
1E	213 41 00	-06	33 40 54	213 40 57.0	164 56 38.0	+00.0	+00.0	0.0
1F	242 04 09	-02	62 04 07	242 04 08.0	193 19 49.0	+00.0	+00.0	0.0
1G	251 14 46	-06	71 14 40	251 14 43.0	202 30 24.0	+00.0	+00.0	0.0
1H	321 54 04	+04	141 54 08	321 54 06.0	273 09 47.0	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T104	0 00 00.0
T150	99 30 56.5
T97	201 33 04.5
T310	203 23 39.0
T98	268 33 17.0
1A	7 28 58.5
1C	55 28 28.5
1D	127 10 25.0
1E	164 56 38.0
1F	193 19 49.0
1G	202 30 24.0
1H	273 09 47.0

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T104	91 58 38	-06	268 01 16	91 58 41.0	27.659	27.658	27.6420
T150	85 05 29	+00	274 54 31	85 05 29.0	16.314	16.313	16.2537
T97	88 46 37	+00	271 13 23	88 46 37.0	27.837	27.836	27.8302
T310	75 25 53	-01	284 34 06	75 25 53.5	28.560	28.559	27.6412
T98	89 55 32	-01	270 04 27	89 55 32.5	35.156	35.156	35.1560
1A	76 14 08	+00	283 45 52	76 14 08.0	26.910	26.912	26.1382
1C	95 20 47	-02	264 39 11	95 20 48.0	16.758	16.758	16.6851
1D	91 48 03	+00	268 11 57	91 48 03.0	16.885	16.886	16.8772
1E	75 26 05	+00	284 33 55	75 26 05.0	26.303	26.301	25.4567
1F	95 48 37	+04	264 11 27	95 48 35.0	15.400	15.399	15.3204

1G	75 32 15	-01	284 27 44	75 32 15.5	28.728	28.728	27.8177
1H	90 11 32	-07	269 48 21	90 11 35.5	38.250	38.247	38.2483

Grand Means

Target	VA ° ' "	Slope Dist m	Horiz. Dist m	Occ. Stn Ht	Target Height	Ht Diff m
T104	91 58 41.0	27.6585	27.6420	0.000	0.000	-0.955
T150	85 05 29.0	16.3135	16.2537	0.000	0.000	1.396
T97	88 46 37.0	27.8365	27.8302	0.000	0.000	0.594
T310	75 25 53.5	28.5595	27.6412	0.000	0.000	7.184
T98	89 55 32.5	35.1560	35.1560	0.000	0.000	0.046
1A	76 14 08.0	26.9110	26.1382	0.000	0.000	6.403
1C	95 20 48.0	16.7580	16.6851	0.000	0.000	-1.562
1D	91 48 03.0	16.8855	16.8772	0.000	0.000	-0.531
1E	75 26 05.0	26.3020	25.4567	0.000	0.000	6.615
1F	95 48 35.0	15.3995	15.3204	0.000	0.000	-1.559
1G	75 32 15.5	28.7280	27.8177	0.000	0.000	7.175
1H	90 11 35.5	38.2485	38.2483	0.000	0.000	-0.129

* TRAVERSE ROUNDS FOUND * - Line (26)

======================= Observations From : AB1 ==========================

* DIRECTIONS *

Target	FL ° ' "	Diff "	FR ° ' "	Mean ° ' "	Reduced Mean ° ' "	v'	v	v²
*** Warning! Difference between FL & FR Directions exceed tolerance ***								
T101	356 30 46	-08	176 30 38	356 30 42.0	0 00 00.0	+00.0	+00.0	0.0
1I	325 41 39	+13	145 41 52	325 41 45.5	329 11 03.5	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means ° ' "
T101	0 00 00.0
1I	329 11 03.5

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL ° ' "	Diff "	FR ° ' "	Mean ° ' "	SDist(FL) m	SDist(FR) m	H.Dist m
T101	90 30 37	-02	269 29 21	90 30 38.0	112.693	112.692	112.6880
1I	124 33 43	-11	235 26 06	124 33 48.5	2.954	2.953	2.4322

Grand Means

Target	VA ° ' "	Slope Dist m	Horiz. Dist m	Occ. Stn Ht	Target Height	Ht Diff m
T101	90 30 38.0	112.6925	112.6880	0.000	0.000	-1.003
1I	124 33 48.5	2.9535	2.4322	0.000	0.000	-1.676

* TRAVERSE ROUNDS FOUND * - Line (31)

======================= Observations From : AB1 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T101	356 30 34	+01	176 30 35	356 30 34.5	0 00 00.0	+00.0	+00.0	0.0
1C	104 12 28	+02	284 12 30	104 12 29.0	107 41 54.5	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T101	0 00 00.0
1C	107 41 54.5

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T101	90 30 37	-05	269 29 18	90 30 39.5	112.692	112.691	112.6870
1C	95 22 04	+02	264 37 58	95 22 03.0	16.779	16.780	16.7059

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T101	90 30 39.5	112.6915	112.6870	0.000	0.000	-1.004
1C	95 22 03.0	16.7795	16.7059	0.000	0.000	-1.570

* TRAVERSE ROUNDS FOUND * - Line (36)

======================== Observations From : AB2 ===========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T315	239 30 27	-02	59 30 25	239 30 26.0	0 00 00.0	+00.0	+00.0	0.0
T104	279 45 43	+03	99 45 46	279 45 44.5	40 15 18.5	+00.0	+00.0	0.0
T150	332 54 10	+00	152 54 10	332 54 10.0	93 23 44.0	+00.0	+00.0	0.0
T98	73 55 09	+01	253 55 10	73 55 09.5	194 24 43.5	+00.0	+00.0	0.0
T101	165 47 21	+03	345 47 24	165 47 22.5	286 16 56.5	+00.0	+00.0	0.0
1A	286 09 18	-06	106 09 12	286 09 15.0	46 38 49.0	+00.0	+00.0	0.0
1C	317 14 36	+03	137 14 39	317 14 37.5	77 44 11.5	+00.0	+00.0	0.0
1D	343 06 28	+00	163 06 28	343 06 28.0	103 36 02.0	+00.0	+00.0	0.0
1E	1 22 52	+01	181 22 53	1 22 52.5	121 52 26.5	+00.0	+00.0	0.0
1F	5 27 00	+01	185 27 01	5 27 00.5	125 56 34.5	+00.0	+00.0	0.0
1G	21 09 45	-02	201 09 43	21 09 44.0	141 39 18.0	+00.0	+00.0	0.0
1J	220 53 55	+00	40 53 55	220 53 55.0	341 23 29.0	+00.0	+00.0	0.0
1K	201 20 16	-03	21 20 13	201 20 14.5	321 49 48.5	+00.0	+00.0	0.0
1L	118 07 33	-11	298 07 22	118 07 27.5	238 37 01.5	+00.0	+00.0	0.0
1M	122 59 59	+00	302 59 59	122 59 59.0	243 29 33.0	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T315	0 00 00.0
T104	40 15 18.5
T150	93 23 44.0

T98	194 24 43.5
T101	286 16 56.5
1A	46 38 49.0
1C	77 44 11.5
1D	103 36 02.0
1E	121 52 26.5
1F	125 56 34.5
1G	141 39 18.0
1J	341 23 29.0
1K	321 49 48.5
1L	238 37 01.5
1M	243 29 33.0

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T315	75 58 23	-03	284 01 34	75 58 24.5	23.686	23.686	22.9798
T104	90 49 27	-06	269 10 27	90 49 30.0	25.453	25.454	25.4509
T150	87 21 00	-06	272 38 54	87 21 03.0	42.920	42.920	42.8741
T98	88 16 10	-05	271 43 45	88 16 12.5	20.989	20.989	20.9794
T101	90 16 49	-04	269 43 07	90 16 51.0	85.085	85.084	85.0835
1A	75 54 30	-02	284 05 28	75 54 31.0	28.717	28.714	27.8514
1C	91 31 19	-06	268 28 35	91 31 22.0	36.939	36.936	36.9245
1D	89 55 32	+00	270 04 28	89 55 32.0	44.510	44.510	44.5100
1E	81 47 35	+01	278 12 26	81 47 34.5	50.453	50.452	49.9358
1F	91 33 50	+03	268 26 13	91 33 48.5	36.266	36.266	36.2525
1G	79 50 13	+00	280 09 47	79 50 13.0	43.991	43.995	43.3027
1J	91 21 06	-03	268 38 51	91 21 07.5	25.756	25.758	25.7498
1K	92 35 34	+01	267 24 27	92 35 33.5	34.688	34.690	34.6535
1L	75 47 10	+01	284 12 51	75 47 09.5	26.761	26.758	25.9403
1M	92 43 35	-04	267 16 21	92 43 37.0	27.720	27.718	27.6876

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T315	75 58 24.5	23.6860	22.9798	0.000	0.000	5.741
T104	90 49 30.0	25.4535	25.4509	0.000	0.000	-0.366
T150	87 21 03.0	42.9200	42.8741	0.000	0.000	1.984
T98	88 16 12.5	20.9890	20.9794	0.000	0.000	0.634
T101	90 16 51.0	85.0845	85.0835	0.000	0.000	-0.417
1A	75 54 31.0	28.7155	27.8514	0.000	0.000	6.991
1C	91 31 22.0	36.9375	36.9245	0.000	0.000	-0.981
1D	89 55 32.0	44.5100	44.5100	0.000	0.000	0.058
1E	81 47 34.5	50.4525	49.9358	0.000	0.000	7.202
1F	91 33 48.5	36.2660	36.2525	0.000	0.000	-0.989
1G	79 50 13.0	43.9930	43.3027	0.000	0.000	7.763
1J	91 21 07.5	25.7570	25.7498	0.000	0.000	-0.608
1K	92 35 33.5	34.6890	34.6535	0.000	0.000	-1.569
1L	75 47 09.5	26.7595	25.9403	0.000	0.000	6.571
1M	92 43 37.0	27.7190	27.6876	0.000	0.000	-1.319

* TRAVERSE ROUNDS FOUND * - Line (67)

======================= Observations From : AB3 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T150	211 05 07	+04	31 05 11	211 05 09.0	0 00 00.0	+00.0	+00.0	0.0
T99	297 03 31	+03	117 03 34	297 03 32.5	85 58 23.5	+00.0	+00.0	0.0
T101	34 09 35	+11	214 09 46	34 09 40.5	183 04 31.5	+00.0	+00.0	0.0
T103	131 53 25	+12	311 53 37	131 53 31.0	280 48 22.0	+00.0	+00.0	0.0
1K	166 09 56	+10	346 10 06	166 10 01.0	315 04 52.0	+00.0	+00.0	0.0

1J	182 22 21	+08	2 22 29	182 22 25.0	331 17 16.0	+00.0	+00.0	0.0
1L	254 53 39	-01	74 53 38	254 53 38.5	43 48 29.5	+00.0	+00.0	0.0
1M	257 38 33	+04	77 38 37	257 38 35.0	46 33 26.0	+00.0	+00.0	0.0
1N	285 39 49	+00	105 39 49	285 39 49.0	74 34 40.0	+00.0	+00.0	0.0
1O	343 19 27	-01	163 19 26	343 19 26.5	132 14 17.5	+00.0	+00.0	0.0
1P	358 26 01	-05	178 25 56	358 25 58.5	147 20 49.5	+00.0	+00.0	0.0
1Q	17 01 16	-03	197 01 13	17 01 14.5	165 56 05.5	+00.0	+00.0	0.0
1R	36 49 49	-02	216 49 47	36 49 48.0	185 44 39.0	+00.0	+00.0	0.0
1S	59 46 05	-02	239 46 03	59 46 04.0	208 40 55.0	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T150	0 00 00.0
T99	85 58 23.5
T101	183 04 31.5
T103	280 48 22.0
1K	315 04 52.0
1J	331 17 16.0
1L	43 48 29.5
1M	46 33 26.0
1N	74 34 40.0
1O	132 14 17.5
1P	147 20 49.5
1Q	165 56 05.5
1R	185 44 39.0
1S	208 40 55.0

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T150	88 26 06	+02	271 33 56	88 26 05.0	85.808	85.808	85.7760
T99	87 46 47	-01	272 13 12	87 46 47.5	18.268	18.267	18.2538
T101	90 04 43	-02	269 55 15	90 04 44.0	41.502	41.501	41.5015
T103	90 00 55	-05	269 59 00	90 00 57.5	17.347	17.348	17.3475
1K	92 52 15	+00	267 07 45	92 52 15.0	24.134	24.138	24.1057
1J	90 24 21	-05	269 35 34	90 24 23.5	34.855	34.853	34.8531
1L	78 16 45	-03	281 43 12	78 16 46.5	34.118	34.120	33.4076
1M	91 46 20	-01	268 13 39	91 46 20.5	31.000	31.000	30.9852
1N	87 36 32	+02	272 23 30	87 36 31.0	19.773	19.772	19.7553
1O	94 17 53	-07	265 42 00	94 17 56.5	20.674	20.674	20.6158
1P	76 39 41	-02	283 20 17	76 39 42.0	26.085	26.084	25.3809
1Q	88 56 54	-02	271 03 04	88 56 55.0	40.385	40.382	40.3767
1R	89 55 29	-02	270 04 29	89 55 30.0	41.743	41.743	41.7430
1S	90 00 18	-02	269 59 40	90 00 19.0	36.129	36.133	36.1310

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T150	88 26 05.0	85.8080	85.7760	0.000	0.000	2.344
T99	87 46 47.5	18.2675	18.2538	0.000	0.000	0.708
T101	90 04 44.0	41.5015	41.5015	0.000	0.000	-0.057
T103	90 00 57.5	17.3475	17.3475	0.000	0.000	-0.005
1K	92 52 15.0	24.1360	24.1057	0.000	0.000	-1.209
1J	90 24 23.5	34.8540	34.8531	0.000	0.000	-0.247
1L	78 16 46.5	34.1190	33.4076	0.000	0.000	6.931
1M	91 46 20.5	31.0000	30.9852	0.000	0.000	-0.959
1N	87 36 31.0	19.7725	19.7553	0.000	0.000	0.825
1O	94 17 56.5	20.6740	20.6158	0.000	0.000	-1.550
1P	76 39 42.0	26.0845	25.3809	0.000	0.000	6.018

1Q	88 56 55.0	40.3835	40.3767	0.000	0.000	0.741
1R	89 55 30.0	41.7430	41.7430	0.000	0.000	0.055
1S	90 00 19.0	36.1310	36.1310	0.000	0.000	-0.003

* TRAVERSE ROUNDS FOUND * - Line (96)

======================= Observations From : AB4 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T100	60 02 00	-01	240 01 59	60 01 59.5	0 00 00.0	+00.0	+00.0	0.0
T101	143 58 42	+00	323 58 42	143 58 42.0	83 56 42.5	+00.0	+00.0	0.0
T102	239 35 49	-02	59 35 47	239 35 48.0	179 33 48.5	+00.0	+00.0	0.0
T150	327 25 49	-03	147 25 46	327 25 47.5	267 23 48.0	+00.0	+00.0	0.0
1N	4 40 57	+01	184 40 58	4 40 57.5	304 38 58.0	+00.0	+00.0	0.0
1O	31 39 18	+00	211 39 18	31 39 18.0	331 37 18.5	+00.0	+00.0	0.0
1P	53 37 18	-04	233 37 14	53 37 16.0	353 35 16.5	+00.0	+00.0	0.0
1Q	109 22 42	+03	289 22 45	109 22 43.5	49 20 44.0	+00.0	+00.0	0.0
1R	149 42 31	+03	329 42 34	149 42 32.5	89 40 33.0	+00.0	+00.0	0.0
1S	202 07 58	+05	22 08 03	202 08 00.5	142 06 01.0	+00.0	+00.0	0.0
1K	306 00 48	+02	126 00 50	306 00 49.0	245 58 49.5	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T100	0 00 00.0
T101	83 56 42.5
T102	179 33 48.5
T150	267 23 48.0
1N	304 38 58.0
1O	331 37 18.5
1P	353 35 16.5
1Q	49 20 44.0
1R	89 40 33.0
1S	142 06 01.0
1K	245 58 49.5

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T100	87 56 33	+01	272 03 28	87 56 32.5	16.085	16.084	16.0741
T101	90 19 15	-03	269 40 42	90 19 16.5	19.425	19.425	19.4247
T102	90 21 30	-01	269 38 29	90 21 30.5	14.407	14.406	14.4062
T150	88 46 59	+01	271 13 02	88 46 58.5	107.867	107.867	107.8427
1N	88 44 08	+04	271 15 56	88 44 06.0	35.005	35.007	34.9975
1O	94 36 05	+00	265 23 55	94 36 05.0	19.961	19.961	19.8967
1P	70 12 58	+00	289 47 02	70 12 58.0	17.627	17.626	16.5861
1Q	88 08 48	-10	271 51 02	88 08 53.0	21.338	21.337	21.3264
1R	89 59 28	-04	270 00 28	89 59 30.0	19.550	19.549	19.5495
1S	90 10 58	-01	269 49 01	90 10 58.5	17.397	17.398	17.3974
1K	91 44 10	-05	268 15 45	91 44 12.5	41.598	41.596	41.5779

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T100	87 56 32.5	16.0845	16.0741	0.000	0.000	0.578
T101	90 19 16.5	19.4250	19.4247	0.000	0.000	-0.109

T102	90 21 30.5	14.4065	14.4062	0.000	0.000	-0.090
T150	88 46 58.5	107.8670	107.8427	0.000	0.000	2.292
1N	88 44 06.0	35.0060	34.9975	0.000	0.000	0.773
1O	94 36 05.0	19.9610	19.8967	0.000	0.000	-1.601
1P	70 12 58.0	17.6265	16.5861	0.000	0.000	5.966
1Q	88 08 53.0	21.3375	21.3264	0.000	0.000	0.690
1R	89 59 30.0	19.5495	19.5495	0.000	0.000	0.003
1S	90 10 58.5	17.3975	17.3974	0.000	0.000	-0.056
1K	91 44 12.5	41.5970	41.5779	0.000	0.000	-1.261

****

Elfy - [E:\UNI\uni class's\year 7 (2016)\project_semester 1\Field work\elfy\blk11-usq1.elf] Version 2.4.0.39
2D Least Squares Adjustment
Date: 01/09/2016
Time: 1:45:25 PM

****

2D Parametric Least Squares Adjustment Results

There are: 44 coordinate parameters.
: 6 orientation paramenters.
: 55 directions.
: 55 horizontal distances.

Total number of unknowns = 50
Total number of observations = 110

Default Standard Deviations are:
: 1.5 mm for horizontal distances.
: 1.0 ppm for horizontal distances.
: 1.0 secs for Directions.
: 1.0 mm for instrument centring errors.
: 1.0 mm for target centring errors.

Iteration: 1 had a maximum coordinate shift of 6.3mm for Point 1C
Iteration: 2 had a maximum coordinate shift of 0.0mm for Point 1C

GROUP VARIANCE FACTORS:

Obs Type	sum(v/s)²	Sum of Redundancies	Group VF
Directions	11.84	26.69	0.44
Horiz Distances	24.70	33.31	0.74

After iteration 2, Variance Factor = 0.61

Adjusted Coordinates after iteration 2

Point ID	Status	Local East(m)	Local North(m)	Std Dev's & Error Ellipses (mm) E	N	S-Maj	S-Min	Brg°
T150	FIXED	333689.4720	6249006.8310					
T97	FIXED	333682.5690	6248972.4860					
T104	FIXED	333658.3730	6249021.3090					
T98	FIXED	333647.6100	6248977.3430					
T101	FIXED	333562.3960	6249000.4580					
T315	FIXED	333641.5670	6249020.5330					
T99	FIXED	333606.4010	6248982.9570					
T103	FIXED	333605.9870	6249018.2560					
T102	FIXED	333581.6760	6249016.8240					
T100	FIXED	333581.6470	6248986.3470					
AB1		333675.0762	6248999.2852	0.5	0.6	0.6	0.5	180
AB2		333647.4523	6248998.3214	0.5	0.5	0.5	0.5	3
AB3		333603.8922	6249001.0359	0.5	0.6	0.6	0.5	179
AB4		333581.7200	6249002.4196	0.6	0.7	0.7	0.6	1
T310	FIXED	333681.6590	6248972.4370					
1A		333662.1297	6249021.9912	1.2	1.2	1.2	1.2	37
1C		333680.3207	6249015.1462	1.1	1.2	1.2	1.1	5
1D		333691.9527	6248999.2860	1.2	1.2	1.2	1.2	173
1E		333695.1988	6248983.6946	1.2	1.2	1.2	1.2	7

1F	333681.2718	6248985.2715	1.1	1.2	1.2	1.1	176
1G	333682.1205	6248972.3745	1.2	1.2	1.2	1.1	20
1H	333643.3714	6248977.8905	1.6	1.7	1.7	1.6	171
1I	333672.9746	6248998.0611	1.6	1.5	1.6	1.5	53
1J	333633.2585	6249019.8061	1.1	1.1	1.1	1.1	153
1K	333619.7728	6249019.1711	1.0	0.9	1.0	0.9	63
1L	333629.5074	6248979.5909	1.1	1.1	1.1	1.1	80
1M	333626.6687	6248980.0294	1.1	1.1	1.1	1.1	106
1N	333610.4202	6248982.3910	1.2	1.2	1.2	1.1	136
1O	333591.0971	6248984.8714	1.1	1.2	1.2	1.1	162
1P	333583.4972	6248985.9292	1.1	1.2	1.2	1.1	172
1Q	333565.4782	6248988.5994	1.2	1.2	1.2	1.2	179
1R	333562.1710	6249002.3979	1.2	1.2	1.2	1.2	180
1S	333571.0954	6249016.1959	1.2	1.2	1.2	1.2	176

Coordinate Database has been updated with the adjusted coords.

Measurement = observed value
a-c = arc to chord correction
v = residual = correction
s = input standard deviation of observation, incl. centring and ppm where appl.
r = redundancy number for observation

Residuals after iteration 2

Type	From	To	a-c	Measurement	v	s	v/s	r
DIRECTION	AB1	T104	0.0"	0 0 0.0	-9.2"	10.6"	-0.9	0.63
DIRECTION	AB1	T150	0.0"	99 30 56.5	-10.5"	18.0"	-0.6	0.74
DIRECTION	AB1	T97	0.0"	201 33 4.5	11.4"	10.5"	1.1	0.76
DIRECTION	AB1	T310	0.0"	203 23 39.0	15.8"	10.6"	1.5	0.77
DIRECTION	AB1	T98	0.0"	268 33 17.0	-2.0"	8.4"	-0.2	0.66
DIRECTION	AB1	1A	0.0"	7 28 58.5	3.6"	11.2"	0.3	0.38
DIRECTION	AB1	1D	0.0"	127 10 25.0	-5.3"	17.3"	-0.3	0.43
DIRECTION	AB1	1E	0.0"	164 56 38.0	-4.2"	11.5"	-0.4	0.41
DIRECTION	AB1	1F	0.0"	193 19 49.0	-21.4"	19.1"	-1.1	0.43
DIRECTION	AB1	1G	0.0"	202 30 24.0	-2.2"	10.5"	-0.2	0.41
DIRECTION	AB1	1H	0.0"	273 9 47.0	0.0"	7.7"	0.0	0.00
DIRECTION	AB1	T101	0.0"	0 0 0.0	0.0"	2.8"	0.0	0.00
DIRECTION	AB1	1I	0.0"	329 11 3.5	0.0"	119.9"	0.0	0.00
DIRECTION	AB1	T101	0.0"	0 0 0.0	-0.1"	2.8"	-0.1	0.01
DIRECTION	AB1	1C	0.0"	107 41 54.5	5.9"	17.5"	0.3	0.43
DIRECTION	AB2	T315	0.0"	0 0 0.0	9.5"	12.7"	0.7	0.85
DIRECTION	AB2	T104	0.0"	40 15 18.5	-4.6"	11.5"	-0.4	0.84
DIRECTION	AB2	T150	0.0"	93 23 44.0	-3.7"	6.9"	-0.5	0.74
DIRECTION	AB2	T98	0.0"	194 24 43.5	0.9"	13.9"	0.1	0.83
DIRECTION	AB2	T101	0.0"	286 16 56.5	-1.4"	3.6"	-0.4	0.42
DIRECTION	AB2	1A	0.0"	46 38 49.0	-4.9"	10.5"	-0.5	0.42
DIRECTION	AB2	1C	0.0"	77 44 11.5	-3.1"	8.0"	-0.4	0.43
DIRECTION	AB2	1D	0.0"	103 36 2.0	2.1"	6.6"	0.3	0.43
DIRECTION	AB2	1E	0.0"	121 52 26.5	3.5"	5.9"	0.6	0.42
DIRECTION	AB2	1F	0.0"	125 56 34.5	0.2"	8.1"	0.0	0.43
DIRECTION	AB2	1G	0.0"	141 39 18.0	1.8"	6.8"	0.3	0.42
DIRECTION	AB2	1J	0.0"	341 23 29.0	3.7"	11.4"	0.3	0.41
DIRECTION	AB2	1K	0.0"	321 49 48.5	6.8"	8.5"	0.8	0.54
DIRECTION	AB2	1L	0.0"	238 37 1.5	-3.8"	11.3"	-0.3	0.41
DIRECTION	AB2	1M	0.0"	243 29 33.0	-3.5"	10.6"	-0.3	0.41
DIRECTION	AB3	T150	0.0"	0 0 0.0	-1.0"	3.5"	-0.3	0.40
DIRECTION	AB3	T99	0.0"	85 58 23.5	-0.2"	16.0"	0.0	0.83
DIRECTION	AB3	T101	0.0"	183 4 31.5	1.3"	7.1"	0.2	0.66
DIRECTION	AB3	T103	0.0"	280 48 22.0	12.5"	16.8"	0.7	0.82
DIRECTION	AB3	1K	0.0"	315 4 52.0	2.0"	12.1"	0.2	0.56

DIRECTION	AB3	1J	0.0"	331 17 16.0	0.7"	8.4"	0.1	0.41
DIRECTION	AB3	1L	0.0"	43 48 29.5	5.0"	8.8"	0.6	0.41
DIRECTION	AB3	1M	0.0"	46 33 26.0	4.9"	9.5"	0.5	0.41
DIRECTION	AB3	1N	0.0"	74 34 40.0	-2.1"	14.8"	-0.1	0.43
DIRECTION	AB3	1O	0.0"	132 14 17.5	-3.1"	14.2"	-0.2	0.42
DIRECTION	AB3	1P	0.0"	147 20 49.5	-3.5"	11.5"	-0.3	0.42
DIRECTION	AB3	1Q	0.0"	165 56 5.5	-1.9"	7.3"	-0.3	0.42
DIRECTION	AB3	1R	0.0"	185 44 39.0	-2.4"	7.1"	-0.3	0.42
DIRECTION	AB3	1S	0.0"	208 40 55.0	-0.1"	8.1"	0.0	0.42
DIRECTION	AB4	T100	0.0"	0 0 0.0	3.6"	18.2"	0.2	0.81
DIRECTION	AB4	T101	0.0"	83 56 42.5	-2.6"	15.1"	-0.2	0.70
DIRECTION	AB4	T102	0.0"	179 33 48.5	7.7"	20.3"	0.4	0.81
DIRECTION	AB4	T150	0.0"	267 23 48.0	-1.3"	2.9"	-0.4	0.22
DIRECTION	AB4	1N	0.0"	304 38 58.0	2.8"	8.4"	0.3	0.43
DIRECTION	AB4	1O	0.0"	331 37 18.5	2.4"	14.7"	0.2	0.43
DIRECTION	AB4	1P	0.0"	353 35 16.5	6.6"	17.6"	0.4	0.43
DIRECTION	AB4	1Q	0.0"	49 20 44.0	2.3"	13.7"	0.2	0.42
DIRECTION	AB4	1R	0.0"	89 40 33.0	4.9"	15.0"	0.3	0.41
DIRECTION	AB4	1S	0.0"	142 6 1.0	0.4"	16.8"	0.0	0.42
DIRECTION	AB4	1K	0.0"	245 58 49.5	1.5"	7.1"	0.2	0.54
H DISTANCE	AB1	T104		27.6420	-0.6mm	1.5mm	-0.4	0.87
H DISTANCE	AB1	T150		16.2537	-0.2mm	1.5mm	-0.1	0.88
H DISTANCE	AB1	T97		27.8302	-3.2mm	1.5mm	-2.1	0.86
H DISTANCE	AB1	T310		27.6412	2.2mm	1.5mm	1.5	0.86
H DISTANCE	AB1	T98		35.1560	-1.3mm	1.5mm	-0.8	0.88
H DISTANCE	AB1	1A		26.1382	-0.6mm	1.5mm	-0.4	0.48
H DISTANCE	AB1	1D		16.8772	-0.8mm	1.5mm	-0.5	0.45
H DISTANCE	AB1	1E		25.4567	-1.1mm	1.5mm	-0.7	0.46
H DISTANCE	AB1	1F		15.3204	1.8mm	1.5mm	1.2	0.47
H DISTANCE	AB1	1G		27.8177	-0.2mm	1.5mm	-0.2	0.47
H DISTANCE	AB1	1H		38.2483	0.0mm	1.5mm	0.0	0.00
H DISTANCE	AB1	T101		112.6880	-1.7mm	1.6mm	-1.0	0.90
H DISTANCE	AB1	1I		2.4322	0.0mm	1.5mm	0.0	0.00
H DISTANCE	AB1	T101		112.6870	-0.7mm	1.6mm	-0.4	0.90
H DISTANCE	AB1	1C		16.7059	-0.3mm	1.5mm	-0.2	0.46
H DISTANCE	AB2	T315		22.9798	-1.7mm	1.5mm	-1.1	0.89
H DISTANCE	AB2	T104		25.4509	-1.1mm	1.5mm	-0.7	0.89
H DISTANCE	AB2	T150		42.8741	-1.4mm	1.5mm	-0.9	0.89
H DISTANCE	AB2	T98		20.9794	-0.5mm	1.5mm	-0.3	0.89
H DISTANCE	AB2	T101		85.0835	-0.4mm	1.6mm	-0.2	0.90
H DISTANCE	AB2	1A		27.8514	-0.2mm	1.5mm	-0.1	0.44
H DISTANCE	AB2	1C		36.9245	-0.2mm	1.5mm	-0.1	0.48
H DISTANCE	AB2	1D		44.5100	0.8mm	1.5mm	0.5	0.47
H DISTANCE	AB2	1E		49.9358	0.9mm	1.5mm	0.6	0.47
H DISTANCE	AB2	1F		36.2525	-2.6mm	1.5mm	-1.7	0.48
H DISTANCE	AB2	1G		43.3027	0.0mm	1.5mm	0.0	0.47
H DISTANCE	AB2	1J		25.7498	0.1mm	1.5mm	0.1	0.47
H DISTANCE	AB2	1K		34.6535	0.0mm	1.5mm	0.0	0.61
H DISTANCE	AB2	1L		25.9403	-1.0mm	1.5mm	-0.6	0.47
H DISTANCE	AB2	1M		27.6876	-0.9mm	1.5mm	-0.6	0.47
H DISTANCE	AB3	T150		85.7760	-0.2mm	1.6mm	-0.1	0.88
H DISTANCE	AB3	T99		18.2538	-1.7mm	1.5mm	-1.1	0.86
H DISTANCE	AB3	T101		41.5015	-1.3mm	1.5mm	-0.8	0.87
H DISTANCE	AB3	T103		17.3475	-0.4mm	1.5mm	-0.3	0.86
H DISTANCE	AB3	1K		24.1057	-0.1mm	1.5mm	-0.1	0.62
H DISTANCE	AB3	1J		34.8531	-0.5mm	1.5mm	-0.3	0.48
H DISTANCE	AB3	1L		33.4076	-0.6mm	1.5mm	-0.4	0.47
H DISTANCE	AB3	1M		30.9852	-0.6mm	1.5mm	-0.4	0.47
H DISTANCE	AB3	1N		19.7553	-0.6mm	1.5mm	-0.4	0.46
H DISTANCE	AB3	1O		20.6158	-0.1mm	1.5mm	-0.1	0.48

H DISTANCE	AB3	1P	25.3809	-0.4mm	1.5mm	-0.3	0.48
H DISTANCE	AB3	1Q	40.3767	0.3mm	1.5mm	0.2	0.47
H DISTANCE	AB3	1R	41.7430	0.4mm	1.5mm	0.3	0.47
H DISTANCE	AB3	1S	36.1310	0.1mm	1.5mm	0.0	0.47
H DISTANCE	AB4	T100	16.0741	-1.3mm	1.5mm	-0.9	0.82
H DISTANCE	AB4	T101	19.4247	-1.4mm	1.5mm	-0.9	0.85
H DISTANCE	AB4	T102	14.4062	-1.7mm	1.5mm	-1.1	0.81
H DISTANCE	AB4	T150	107.8427	-0.5mm	1.6mm	-0.3	0.87
H DISTANCE	AB4	1N	34.9975	0.3mm	1.5mm	0.2	0.47
H DISTANCE	AB4	1O	19.8967	-0.3mm	1.5mm	-0.2	0.48
H DISTANCE	AB4	1P	16.5861	-0.2mm	1.5mm	-0.1	0.47
H DISTANCE	AB4	1Q	21.3264	-0.4mm	1.5mm	-0.3	0.45
H DISTANCE	AB4	1R	19.5495	-0.4mm	1.5mm	-0.3	0.45
H DISTANCE	AB4	1S	17.3974	0.0mm	1.5mm	0.0	0.46
H DISTANCE	AB4	1K	41.5779	-1.2mm	1.5mm	-0.8	0.61

Largest Residuals

Type	Obs No.	Correction
Direction	9	-21.4"
Horizontal Distance	14	-3.2mm

```
********************************************************************************

Elfy - [E:\UNI\uni class's\year 7 (2016)\project_semester 1\Field work\elfy\blk11-
usq1.elf]   Version 2.4.0.39
1D Least Squares Adjustment
Date: 01/09/2016
Time: 7:14:44 PM

********************************************************************************

1D Parametric Least Squares Adjustment Results

--------------------------------------------------------------------------------
There are: 22 height parameters.
         : 54 height differences.

Total number of unknowns = 22
Total number of observations = 54

Default Standard Deviations are: 0.5 mm for height differences. (Spirit Level)
                               : 2.0 mm for height differences. (Trig. Heights)
--------------------------------------------------------------------------------

Iteration: 1 had a maximum height shift of 18.5mm for Point 1F

After iteration 1, Variance Factor = 0.05

Adjusted Heights after iteration 1
--------------------------------------------------------------------------------
  Point ID        Status          Height(m)     Stdev(mm)
--------------------------------------------------------------------------------
      T150         FIXED            12.3700
       T97         FIXED            11.5690
      T104         FIXED            10.0200
       T98         FIXED            11.0210
      T101         FIXED             9.9700

      T315         FIXED            16.1280
       T99         FIXED            10.7340
      T103         FIXED            10.0220
      T102         FIXED             9.9890
      T100         FIXED            10.6560

       AB1                          10.9746        0.7
       AB2                          10.3867        0.7
       AB3                          10.0265        0.7
       AB4                          10.0785        0.8
      T310         FIXED            18.1590

        1A                          17.3778        1.5
        1C                           9.4051        1.5
        1D                          10.4443        1.5
        1E                          17.5890        1.5
        1F                           9.3973        2.1

        1G                          18.1493        1.5
        1H                          10.8457        2.1
        1I                           9.2990        2.1
        1J                           9.7791        1.5
        1K                           8.8177        1.3

        1L                          16.9574        1.5
        1M                           9.0679        1.5
        1N                          10.8515        1.6
        1O                           8.4770        1.6
        1P                          16.0445        1.6

        1Q                          10.7679        1.6
        1R                          10.0814        1.6
        1S                          10.0232        1.6
--------------------------------------------------------------------------------
```

Coordinate Database has been updated with the adjusted levels

Measurement = observed value
v = residual = correction
s = input standard deviation of observation, incl. centring and ppm where appl.
r = redundancy number for observation
Type = method of observation, where: 'T' denotes trignometric observation
'S' denotes spirit level observation
'U' denotes unknown observation - manual entry

Residuals after iteration 1

Type	From	To	Measurement	v	s	v/s	r	Type
HT DIFF	AB1	T104	-0.9546	0.0mm	2.0mm	0.0	0.9	T
HT DIFF	AB1	T150	1.3959	-0.5mm	2.0mm	-0.2	0.9	T
HT DIFF	AB1	T97	0.5942	0.2mm	2.0mm	0.1	0.9	T
HT DIFF	AB1	T310	7.1838	0.6mm	2.0mm	0.3	0.9	T
HT DIFF	AB1	T98	0.0457	0.7mm	2.0mm	0.4	0.9	T
HT DIFF	AB1	1A	6.4030	0.2mm	2.0mm	0.1	0.5	T
HT DIFF	AB1	1D	-0.5306	0.3mm	2.0mm	0.2	0.5	T
HT DIFF	AB1	1E	6.6145	-0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB1	1G	7.1747	0.0mm	2.0mm	0.0	0.5	T
HT DIFF	AB1	1H	-0.1289	0.0mm	2.0mm	0.0	0.0	T
HT DIFF	AB1	T101	-1.0033	-1.3mm	2.0mm	-0.6	0.9	T
HT DIFF	AB1	1I	-1.6756	0.0mm	2.0mm	0.0	0.0	T
HT DIFF	AB1	T101	-1.0041	-0.5mm	2.0mm	-0.2	0.9	T
HT DIFF	AB1	1C	-1.5696	0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB2	T315	5.7408	0.5mm	2.0mm	0.3	0.9	T
HT DIFF	AB2	T104	-0.3664	-0.3mm	2.0mm	-0.1	0.9	T
HT DIFF	AB2	T150	1.9839	-0.6mm	2.0mm	-0.3	0.9	T
HT DIFF	AB2	T98	0.6336	0.7mm	2.0mm	0.4	0.9	T
HT DIFF	AB2	T101	-0.4165	-0.2mm	2.0mm	-0.1	0.9	T
HT DIFF	AB2	1A	6.9914	-0.2mm	2.0mm	-0.1	0.5	T
HT DIFF	AB2	1C	-0.9815	-0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB2	1D	0.0580	-0.3mm	2.0mm	-0.2	0.5	T
HT DIFF	AB2	1E	7.2023	0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB2	1F	-0.9894	0.0mm	2.0mm	0.0	0.0	T
HT DIFF	AB2	1G	7.7627	0.0mm	2.0mm	0.0	0.5	T
HT DIFF	AB2	1J	-0.6077	0.2mm	2.0mm	0.1	0.5	T
HT DIFF	AB2	1K	-1.5691	0.2mm	2.0mm	0.1	0.6	T
HT DIFF	AB2	1L	6.5707	0.0mm	2.0mm	0.0	0.5	T
HT DIFF	AB2	1M	-1.3187	-0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB3	T150	2.3444	-0.9mm	2.0mm	-0.5	0.9	T
HT DIFF	AB3	T99	0.7077	-0.2mm	2.0mm	-0.1	0.9	T
HT DIFF	AB3	T101	-0.0570	0.5mm	2.0mm	0.2	0.9	T
HT DIFF	AB3	T103	-0.0048	0.3mm	2.0mm	0.1	0.9	T
HT DIFF	AB3	1K	-1.2088	0.0mm	2.0mm	0.0	0.6	T
HT DIFF	AB3	1J	-0.2472	-0.2mm	2.0mm	-0.1	0.5	T
HT DIFF	AB3	1L	6.9309	0.0mm	2.0mm	0.0	0.5	T
HT DIFF	AB3	1M	-0.9587	0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB3	1N	0.8250	-0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB3	1O	-1.5497	0.2mm	2.0mm	0.1	0.5	T
HT DIFF	AB3	1P	6.0178	0.1mm	2.0mm	0.1	0.5	T
HT DIFF	AB3	1Q	0.7411	0.2mm	2.0mm	0.1	0.5	T
HT DIFF	AB3	1R	0.0548	0.0mm	2.0mm	0.0	0.5	T
HT DIFF	AB3	1S	-0.0032	-0.2mm	2.0mm	-0.1	0.5	T
HT DIFF	AB4	T100	0.5775	0.0mm	2.0mm	0.0	0.8	T
HT DIFF	AB4	T101	-0.1089	0.4mm	2.0mm	0.2	0.8	T
HT DIFF	AB4	T102	-0.0901	0.6mm	2.0mm	0.3	0.8	T
HT DIFF	AB4	T150	2.2919	-0.4mm	2.0mm	-0.2	0.8	T
HT DIFF	AB4	1N	0.7729	0.1mm	2.0mm	0.0	0.5	T
HT DIFF	AB4	1O	-1.6013	-0.2mm	2.0mm	-0.1	0.5	T

HT DIFF	AB4	1P	5.9661	-0.1mm	2.0mm	-0.1	0.5	T
HT DIFF	AB4	1Q	0.6896	-0.2mm	2.0mm	-0.1	0.5	T
HT DIFF	AB4	1R	0.0029	0.0mm	2.0mm	0.0	0.5	T
HT DIFF	AB4	1S	-0.0555	0.2mm	2.0mm	0.1	0.5	T
HT DIFF	AB4	1K	-1.2606	-0.2mm	2.0mm	-0.1	0.6	T

Largest Residuals

Type	Obs No.	Correction
Height Diff	41	-1.3mm

Appendix D

Site A-Blk11 minimally constrained report, 3 fixed points from Pix4D

Quality Report

Generated with Discovery version 2.1.61

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	cub_final
Processed	2016-09-01 19:44:17
Average Ground Sampling Distance (GSD)	0.28 cm / 0.11 in
Time for Initial Processing (without report)	28m:26s

Quality Check

Images	median of 67675 keypoints per image	
Dataset	310 out of 310 images calibrated (100%), all images enabled	
Camera Optimization	0.63% relative difference between initial and optimized internal camera parameters	
Matching	median of 34207.7 matches per calibrated image	
Georeferencing	yes, 3 GCPs (3 3D), mean RMS error = 0 m	

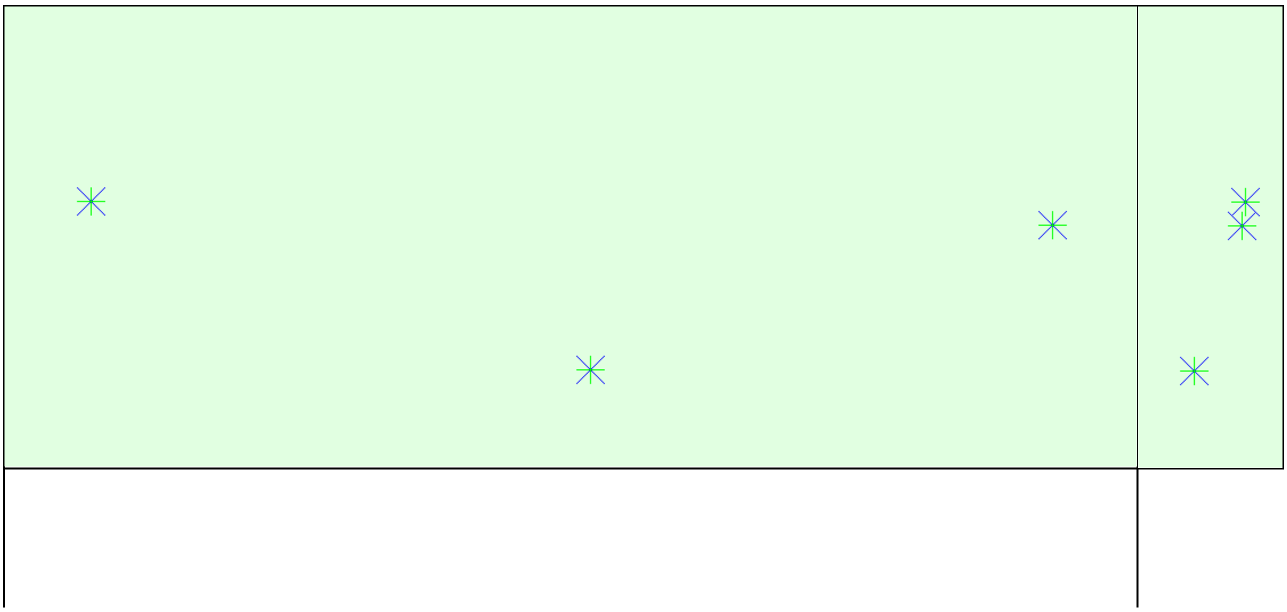
Calibration Details

Number of Calibrated Images	310 out of 310
Number of Geolocated Images	0 out of 310

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions



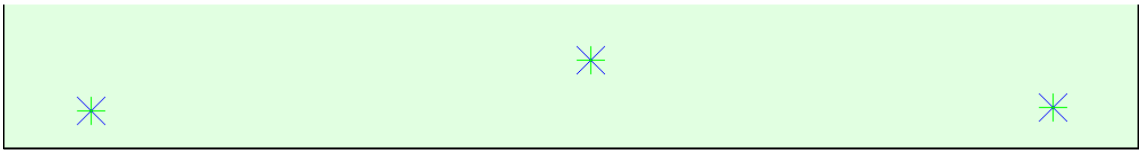


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	10625327
Number of 3D Points for Bundle Block Adjustment	3207977
Mean Reprojection Error [pixels]	0.139589

Internal Camera Parameters

ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB). Sensor Dimensions: 35.000 [mm] x 23.359 [mm]

EXIF ID: ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	7360.000 [pixel] 35.000 [mm]	3680.000 [pixel] 17.500 [mm]	2456.000 [pixel] 11.679 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	7406.888 [pixel] 35.223 [mm]	3693.252 [pixel] 17.563 [mm]	2445.331 [pixel] 11.629 [mm]	0.054	-0.245	0.031	-0.000	0.001

The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	67675	34208
Min	38047	13535
Max	87607	50311
Mean	65610	34275

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1769307
In 3 Images	579216
In 4 Images	291379
In 5 Images	177155
In 6 Images	114718
In 7 Images	79486
In 8 Images	56759
In 9 Images	40612
In 10 Images	29046
In 11 Images	20866
In 12 Images	14420
In 13 Images	10391

In 14 Images	7709
In 15 Images	5327
In 16 Images	3268
In 17 Images	2197
In 18 Images	1602
In 19 Images	1175
In 20 Images	847
In 21 Images	654
In 22 Images	475
In 23 Images	324
In 24 Images	262
In 25 Images	178
In 26 Images	154
In 27 Images	104
In 28 Images	91
In 29 Images	57
In 30 Images	52
In 31 Images	50
In 32 Images	27
In 33 Images	18
In 34 Images	15
In 35 Images	9
In 36 Images	8
In 37 Images	7
In 38 Images	3
In 39 Images	4
In 40 Images	1
In 41 Images	2
In 43 Images	1
In 44 Images	1

2D Keypoint Matches

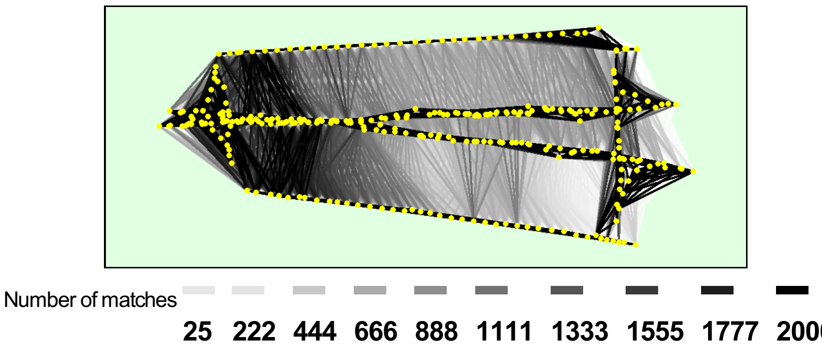


Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1D (3D)	0.001/ 0.002	-0.000	0.000	-0.000	0.209	15 / 15
1R (3D)	0.001/ 0.002	-0.000	0.000	-0.000	0.183	15 / 15
1L (3D)	0.001/ 0.002	0.000	-0.000	0.000	0.307	29 / 29
Mean [m]		-0.000057	-0.000040	0.000013		

Sigma [m]		0.000168	0.000138	0.000105		
RMS Error [m]		0.000177	0.000144	0.000105		

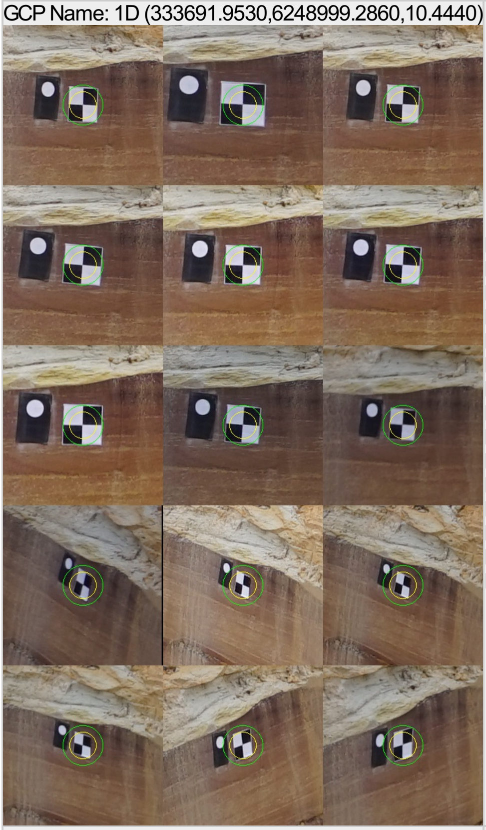
0 out of 13 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1A	0.0010/0.0020	-0.0053	0.0048	0.0311	0.2128	30 / 30
1S	0.0030/0.0030	0.0006	-0.0006	0.0029	0.2023	19 / 19
1K	0.0030/0.0030	-0.0061	0.0025	0.0324	0.2394	32 / 32
1J	0.0030/0.0030	-0.0088	0.0059	0.0325	0.1957	32 / 32
1E	0.0010/0.0020	0.0028	-0.0116	-0.0100	0.3249	13 / 13
1G	0.0030/0.0030	-0.0054	-0.0042	-0.0117	0.2986	16 / 16
1F	0.0030/0.0030	-0.0099	0.0015	0.0011	0.2253	19 / 19
1M	0.0030/0.0030	0.0012	0.0041	0.0011	0.3036	25 / 25
1N	0.0030/0.0030	0.0037	0.0025	0.0010	0.3365	24 / 24
1O	0.0030/0.0030	0.0064	-0.0005	0.0008	0.4707	24 / 24
1P	0.0030/0.0030	0.0096	-0.0020	0.0011	0.2344	17 / 17
1Q	0.0030/0.0030	0.0084	-0.0034	0.0033	0.3302	21 / 21
1I	0.0030/0.0030	-0.0107	0.0080	0.0105	0.1884	15 / 15
Mean [m]		-0.001047	0.000530	0.007398		
Sigma [m]		0.006771	0.004949	0.014513		
RMS Error [m]		0.006851	0.004977	0.016290		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

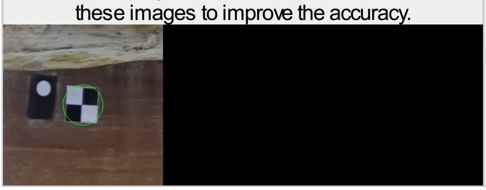
Georeference Verification

GCP Name: 1D (333691.9530,6248999.2860,10.4440)



DSC01423.JPG
DSC01424.JPG
DSC01425.JPG
DSC01426.JPG
DSC01427.JPG
DSC01428.JPG
DSC01429.JPG
DSC01430.JPG
DSC01434.JPG
DSC01592.JPG
DSC01593.JPG
DSC01594.JPG
DSC01595.JPG
DSC01596.JPG
DSC01597.JPG

GCP 1D was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.

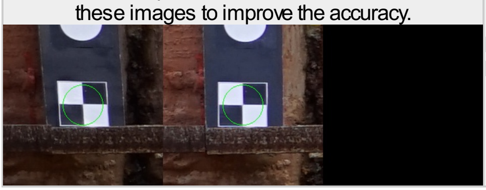


DSC01432.JPG

GCP Name: 1R (333562.1710,6249002.3980,10.0810)

DSC01528.JPG
DSC01530.JPG
DSC01531.JPG
DSC01532.JPG
DSC01533.JPG
DSC01534.JPG
DSC01535.JPG
DSC01536.JPG
DSC01537.JPG
DSC01538.JPG
DSC01539.JPG
DSC01555.JPG
DSC01633.JPG
DSC01635.JPG
DSC01636.JPG

GCP 1R was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.



DSC01527.JPG
DSC01529.JPG

GCP Name: 1L (333629.5070,6248979.5910,16.9570)

DSC01466.JPG
DSC01470.JPG

Figure 7: Images in which GCPs have been marked (yellow circle) and in which their computed 3D points have been projected (green circle). A green circle outside of the yellow circle indicates either an accuracy issue or a GCP issue.

Processing Options

Hardware	CPU: Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz RAM: 32GB GPU: NVIDIA GeForce GTX 550 Ti (Driver: 10.18.13.5382)
Operating System	Windows 10 Home, 64-bit
Camera Model Name	ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB)
Ground Control Point (GCP) Coordinate System	Arbitrary (m)
Output Coordinate System	Arbitrary (m)

Detected template:	No template available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Free Flight or Terrestrial
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard, Internal Parameters Optimization: All, External Parameters Optimization: All, Rematch: Auto yes

Appendix E

Site A-Blk11 minimally constrained report, 4 fixed points from Pix4D

Quality Report

Generated with Discovery version 2.1.61

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	cub_final
Processed	2016-09-01 21:04:19
Average Ground Sampling Distance (GSD)	0.28 cm / 0.11 in
Time for Initial Processing (without report)	28m:27s

Quality Check

Images	median of 67675 keypoints per image	✓
Dataset	310 out of 310 images calibrated (100%), all images enabled	✓
Camera Optimization	0.63% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 34213.9 matches per calibrated image	✓
Georeferencing	yes, 4 GCPs (4 3D), mean RMS error = 0 m	✓

Calibration Details

Number of Calibrated Images	310 out of 310
Number of Geolocated Images	0 out of 310

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions

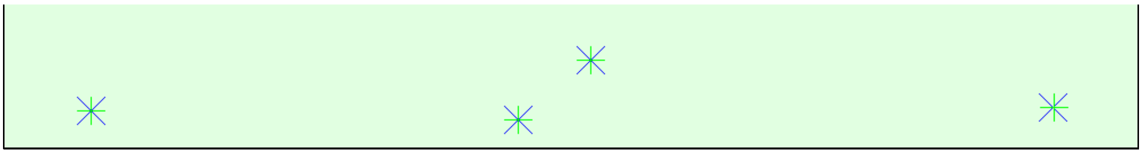


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	10625181
Number of 3D Points for Bundle Block Adjustment	3207900
Mean Reprojection Error [pixels]	0.139573

Internal Camera Parameters

ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB). Sensor Dimensions: 35.000 [mm] x 23.359 [mm]

EXIF ID: ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	7360.000 [pixel] 35.000 [mm]	3680.000 [pixel] 17.500 [mm]	2456.000 [pixel] 11.679 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	7406.966 [pixel] 35.223 [mm]	3693.491 [pixel] 17.564 [mm]	2442.286 [pixel] 11.614 [mm]	0.054	-0.245	0.031	-0.000	0.001

The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	67675	34214
Min	38047	13535
Max	87607	50312
Mean	65610	34275

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1769235
In 3 Images	579201
In 4 Images	291387
In 5 Images	177159
In 6 Images	114714
In 7 Images	79487
In 8 Images	56760
In 9 Images	40611
In 10 Images	29047
In 11 Images	20866
In 12 Images	14421
In 13 Images	10390

In 14 Images	7709
In 15 Images	5327
In 16 Images	3268
In 17 Images	2197
In 18 Images	1602
In 19 Images	1175
In 20 Images	847
In 21 Images	654
In 22 Images	475
In 23 Images	324
In 24 Images	262
In 25 Images	178
In 26 Images	154
In 27 Images	104
In 28 Images	91
In 29 Images	57
In 30 Images	52
In 31 Images	50
In 32 Images	27
In 33 Images	18
In 34 Images	15
In 35 Images	9
In 36 Images	8
In 37 Images	7
In 38 Images	3
In 39 Images	4
In 40 Images	1
In 41 Images	2
In 43 Images	1
In 44 Images	1

2D Keypoint Matches

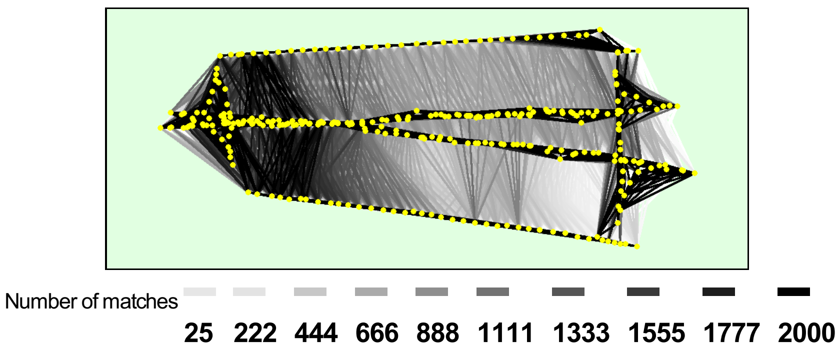


Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

Geolocation Details

Ground Control Points

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1D (3D)	0.001/ 0.002	-0.000	0.000	-0.000	0.201	15 / 15
1R (3D)	0.001/ 0.002	-0.000	0.000	-0.000	0.187	15 / 15
1K (3D)	0.001/ 0.001	-0.000	-0.000	0.000	0.249	32 / 32
1L (3D)	0.001/ 0.002	0.000	-0.000	0.000	0.315	29 / 29

Mean [m]		-0.000030	-0.000033	-0.000061		
Sigma [m]		0.000139	0.000108	0.000368		
RMS Error [m]		0.000142	0.000113	0.000373		

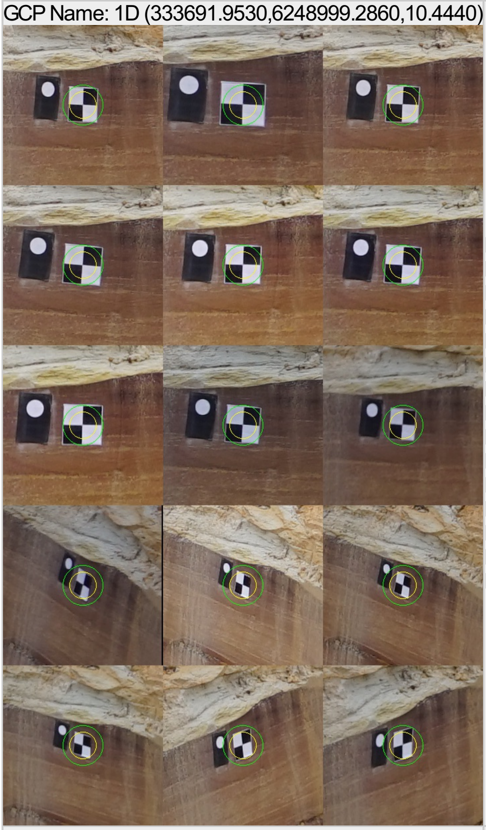
0 out of 12 check points have been labeled as inaccurate.

Check Point Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1A	0.0010/0.0020	-0.0032	0.0062	0.0006	0.2172	30 / 30
1S	0.0030/0.0030	0.0027	-0.0008	-0.0129	0.2004	19 / 19
1J	0.0030/0.0030	-0.0025	0.0031	-0.0002	0.2031	32 / 32
1E	0.0010/0.0020	-0.0007	-0.0025	0.0033	0.3267	13 / 13
1G	0.0030/0.0030	-0.0047	0.0021	0.0053	0.3034	16 / 16
1F	0.0030/0.0030	-0.0068	0.0018	0.0076	0.2239	19 / 19
1M	0.0030/0.0030	0.0011	-0.0029	0.0008	0.3069	25 / 25
1N	0.0030/0.0030	0.0032	-0.0025	0.0000	0.3387	24 / 24
1O	0.0030/0.0030	0.0050	-0.0064	0.0020	0.4666	24 / 24
1P	0.0030/0.0030	0.0109	-0.0002	0.0043	0.2339	17 / 17
1Q	0.0030/0.0030	0.0071	-0.0036	0.0125	0.3267	21 / 21
1I	0.0030/0.0030	-0.0072	0.0065	0.0033	0.1922	15 / 15
Mean [m]		0.000408	0.000082	0.002218		
Sigma [m]		0.005382	0.003788	0.005742		
RMS Error [m]		0.005397	0.003789	0.006155		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

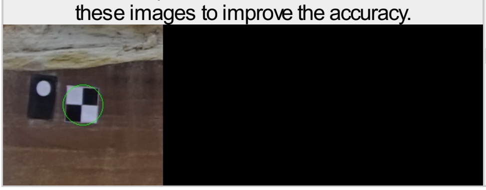
Georeference Verification

GCP Name: 1D (333691.9530,6248999.2860,10.4440)



DSC01423.JPG
DSC01424.JPG
DSC01425.JPG
DSC01426.JPG
DSC01427.JPG
DSC01428.JPG
DSC01429.JPG
DSC01430.JPG
DSC01434.JPG
DSC01592.JPG
DSC01593.JPG
DSC01594.JPG
DSC01595.JPG
DSC01596.JPG
DSC01597.JPG

GCP 1D was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.

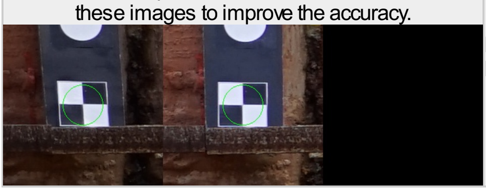


DSC01432.JPG

GCP Name: 1R (333562.1710,6249002.3980,10.0810)

DSC01528.JPG
DSC01530.JPG
DSC01531.JPG
DSC01532.JPG
DSC01533.JPG
DSC01534.JPG
DSC01535.JPG
DSC01536.JPG
DSC01537.JPG
DSC01538.JPG
DSC01539.JPG
DSC01555.JPG
DSC01633.JPG
DSC01635.JPG
DSC01636.JPG

GCP 1R was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.



DSC01527.JPG
DSC01529.JPG

GCP Name: 1K (333619.7730,6249019.1710,8.8180)

DSC01338.JPG
DSC01350.JPG
DSC01352.JPG
DSC01354.JPG
DSC01355.JPG
DSC01356.JPG
DSC01357.JPG
DSC01358.JPG
DSC01359.JPG
DSC01360.JPG
DSC01361.JPG
DSC01362.JPG
DSC01363.JPG
DSC01364.JPG
DSC01365.JPG
DSC01367.JPG
DSC01563.JPG
DSC01564.JPG
DSC01565.JPG
DSC01566.JPG
DSC01567.JPG
DSC01568.JPG
DSC01569.JPG
DSC01570.JPG
DSC01571.JPG
DSC01572.JPG
DSC01573.JPG
DSC01574.JPG
DSC01575.JPG
DSC01576.JPG
DSC01577.JPG
DSC01578.JPG

GCP Name: 1L (333629.5070,6248979.5910,16.9570)

DSC01466.JPG
DSC01470.JPG
DSC01472.JPG
DSC01473.JPG
DSC01474.JPG
DSC01475.JPG
DSC01476.JPG
DSC01477.JPG
DSC01478.JPG
DSC01479.JPG
DSC01480.JPG
DSC01481.JPG
DSC01483.JPG
DSC01485.JPG
DSC01487.JPG
DSC01607.JPG
DSC01608.JPG
DSC01609.JPG
DSC01610.JPG
DSC01612.JPG
DSC01613.JPG
DSC01614.JPG
DSC01615.JPG
DSC01616.JPG
DSC01617.JPG
DSC01618.JPG
DSC01619.JPG
DSC01620.JPG
DSC01621.JPG

Figure 7: Images in which GCPs have been marked (yellow circle) and in which their computed 3D points have been projected (green circle). A green circle outside of the yellow circle indicates either an accuracy issue or a GCP issue.

Processing Options

Hardware	CPU: Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz RAM: 32GB GPU: NVIDIA GeForce GTX 550 Ti (Driver: 10.18.13.5382)
Operating System	Windows 10 Home, 64-bit
Camera Model Name	ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB)
Ground Control Point (GCP) Coordinate System	Arbitrary (m)
Output Coordinate System	Arbitrary (m)

Detected template:	No template available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Free Flight or Terrestrial
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard, Internal Parameters Optimization: All, External Parameters Optimization: All, Rematch: Auto yes

Appendix F

Site A-Blk11 fully constrained

report from Pix4D

Quality Report

Generated with Discovery version 2.1.61

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	cub_final
Processed	2016-09-01 21:50:15
Average Ground Sampling Distance (GSD)	0.28 cm / 0.11 in
Time for Initial Processing (without report)	28m:31s

Quality Check

Images	median of 67675 keypoints per image	✓
Dataset	310 out of 310 images calibrated (100%), all images enabled	✓
Camera Optimization	0.63% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 34221.4 matches per calibrated image	✓
Georeferencing	yes, 16 GCPs (16 3D), mean RMS error = 0 m	✓

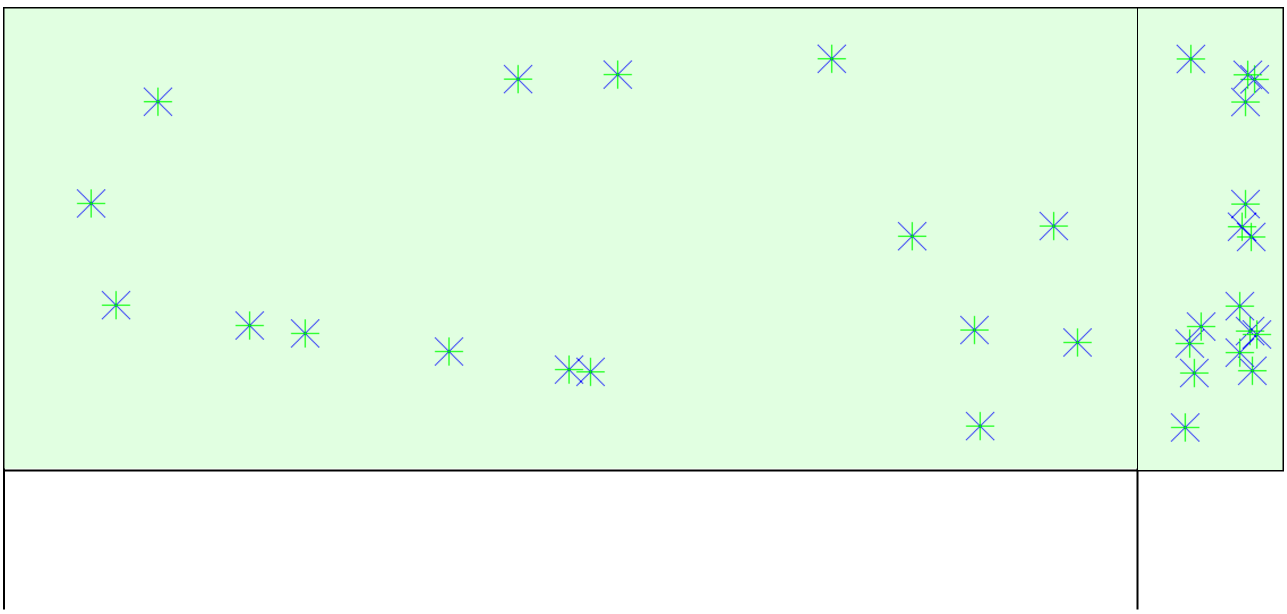
Calibration Details

Number of Calibrated Images	310 out of 310
Number of Geolocated Images	0 out of 310

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions



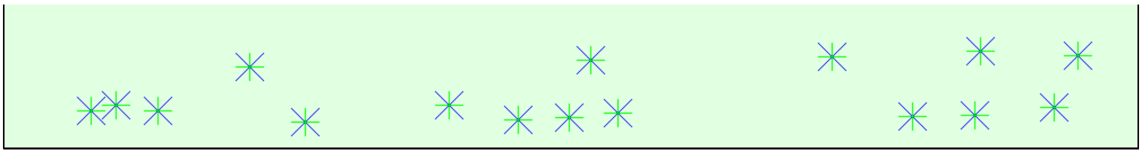


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	10624875
Number of 3D Points for Bundle Block Adjustment	3207750
Mean Reprojection Error [pixels]	0.1397

Internal Camera Parameters

ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB). Sensor Dimensions: 35.000 [mm] x 23.359 [mm]

EXIF ID: ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	7360.000 [pixel] 35.000 [mm]	3680.000 [pixel] 17.500 [mm]	2456.000 [pixel] 11.679 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	7406.741 [pixel] 35.222 [mm]	3695.020 [pixel] 17.571 [mm]	2442.336 [pixel] 11.614 [mm]	0.054	-0.246	0.033	-0.000	0.001

The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	67675	34221
Min	38047	13532
Max	87607	50311
Mean	65610	34274

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	1769087
In 3 Images	579203
In 4 Images	291381
In 5 Images	177161
In 6 Images	114714
In 7 Images	79489
In 8 Images	56758
In 9 Images	40613
In 10 Images	29043
In 11 Images	20867
In 12 Images	14422
In 13 Images	10390

In 14 Images	7708
In 15 Images	5328
In 16 Images	3269
In 17 Images	2196
In 18 Images	1603
In 19 Images	1174
In 20 Images	847
In 21 Images	654
In 22 Images	475
In 23 Images	324
In 24 Images	262
In 25 Images	178
In 26 Images	154
In 27 Images	104
In 28 Images	91
In 29 Images	57
In 30 Images	52
In 31 Images	50
In 32 Images	27
In 33 Images	18
In 34 Images	15
In 35 Images	9
In 36 Images	8
In 37 Images	7
In 38 Images	3
In 39 Images	4
In 40 Images	1
In 41 Images	2
In 43 Images	1
In 44 Images	1

2D Keypoint Matches

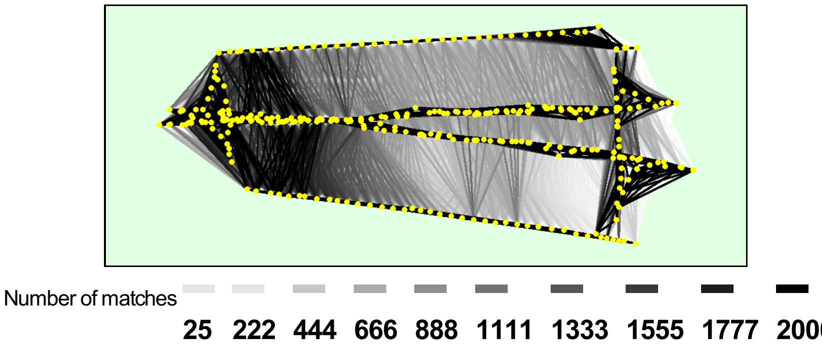


Figure 5: Top view of the image computed positions with a link between matching images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images.

Geolocation Details

Ground Control Points

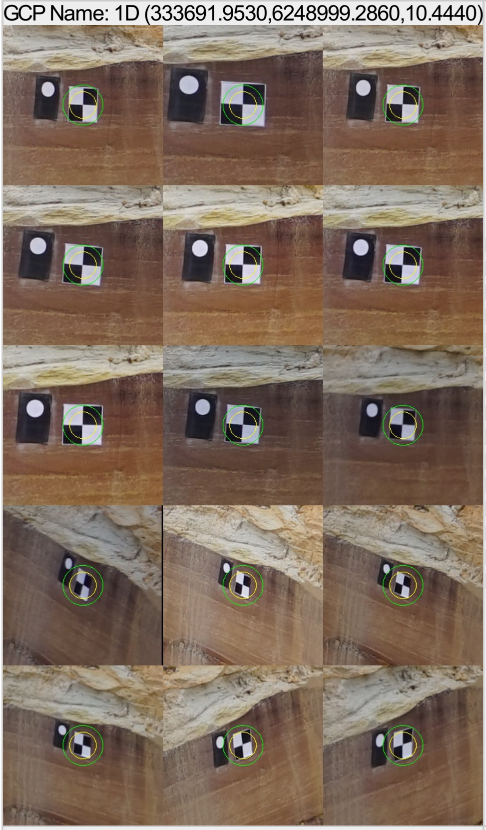
GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
1D (3D)	0.001/ 0.002	0.000	-0.000	-0.001	0.206	15 / 15
1A (3D)	0.001/ 0.002	-0.000	-0.000	0.000	0.219	30 / 30
1R (3D)	0.001/ 0.002	-0.001	0.001	-0.000	0.220	15 / 15
1S (3D)	0.001/ 0.002	-0.000	-0.000	-0.002	0.191	19 / 19

1K (3D)	0.001/ 0.001	-0.000	-0.000	0.001	0.265	32 / 32
1J (3D)	0.001/ 0.002	-0.000	0.000	-0.000	0.222	32 / 32
1L (3D)	0.001/ 0.002	-0.000	-0.000	0.000	0.297	29 / 29
1E (3D)	0.001/ 0.002	-0.000	-0.000	-0.001	0.337	13 / 13
1G (3D)	0.001/ 0.002	0.000	0.000	-0.001	0.300	16 / 16
1F (3D)	0.001/ 0.002	-0.000	0.000	0.003	0.241	19 / 19
1M (3D)	0.001/ 0.002	0.000	0.000	-0.000	0.293	25 / 25
1N (3D)	0.001/ 0.002	-0.000	0.000	-0.000	0.326	24 / 24
1O (3D)	0.001/ 0.002	-0.001	-0.000	-0.001	0.483	24 / 24
1P (3D)	0.001/ 0.002	0.001	-0.001	-0.000	0.234	17 / 17
1Q (3D)	0.001/ 0.002	0.001	-0.000	0.002	0.358	21 / 21
1I (3D)	0.002/ 0.002	-0.000	0.001	-0.000	0.193	15 / 15
Mean [m]		-0.000039	-0.000001	-0.000101		
Sigma [m]		0.000556	0.000437	0.001160		
RMS Error [m]		0.000558	0.000437	0.001164		

Localisation accuracy per GCP and mean errors in the three coordinate directions. The last column counts the number of calibrated images where the GCP has been automatically verified vs. manually marked.

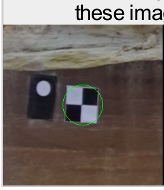
Georeference Verification

GCP Name: 1D (333691.9530,6248999.2860,10.4440)



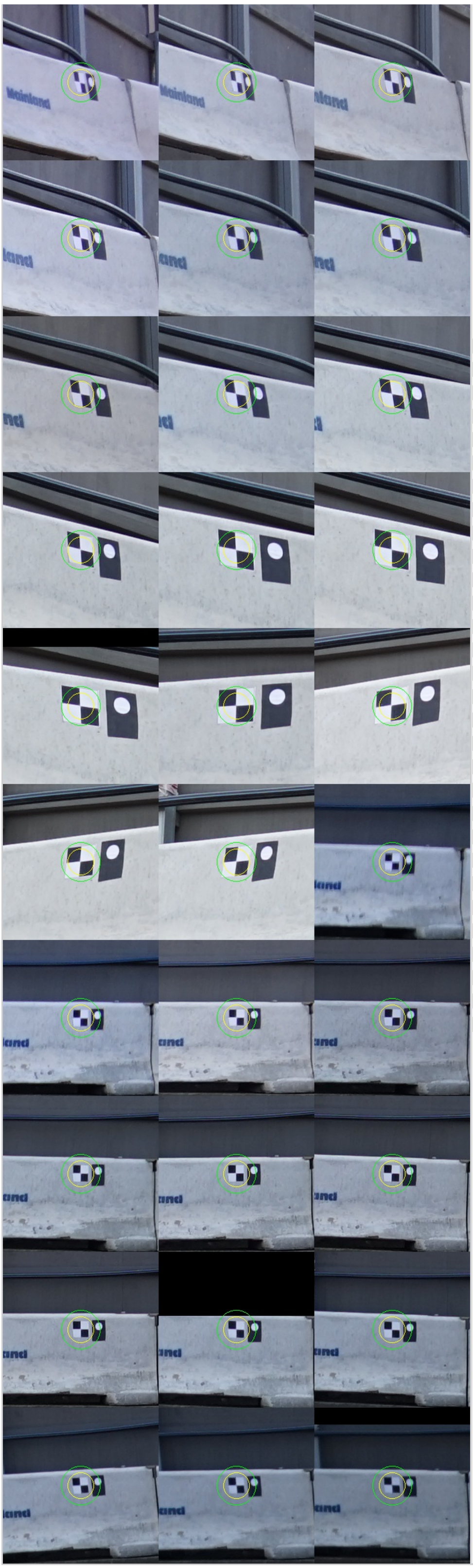
DSC01423.JPG
DSC01424.JPG
DSC01425.JPG
DSC01426.JPG
DSC01427.JPG
DSC01428.JPG
DSC01429.JPG
DSC01430.JPG
DSC01434.JPG
DSC01592.JPG
DSC01593.JPG
DSC01594.JPG
DSC01595.JPG
DSC01596.JPG
DSC01597.JPG

GCP 1D was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.



DSC01432.JPG

GCP Name: 1A (333662.1300,6249021.9910,17.3780)



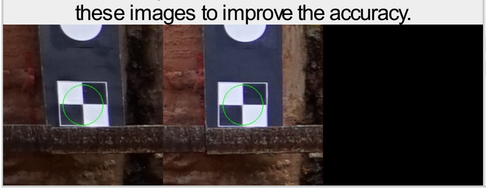
DSC01372.JPG
DSC01374.JPG
DSC01380.JPG
DSC01382.JPG
DSC01384.JPG
DSC01386.JPG
DSC01388.JPG
DSC01390.JPG
DSC01392.JPG
DSC01394.JPG
DSC01396.JPG
DSC01398.JPG
DSC01400.JPG
DSC01401.JPG
DSC01403.JPG
DSC01405.JPG
DSC01407.JPG
DSC01579.JPG
DSC01580.JPG
DSC01581.JPG
DSC01582.JPG
DSC01583.JPG
DSC01584.JPG
DSC01585.JPG
DSC01586.JPG
DSC01587.JPG
DSC01589.JPG
DSC01590.JPG
DSC01591.JPG
DSC01592.JPG

GCP Name: 1R (333562.1710,6249002.3980,10.0810)

DSC01528.JPG

DSC01530.JPG
DSC01531.JPG
DSC01532.JPG
DSC01533.JPG
DSC01534.JPG
DSC01535.JPG
DSC01536.JPG
DSC01537.JPG
DSC01538.JPG
DSC01539.JPG
DSC01555.JPG
DSC01633.JPG
DSC01635.JPG
DSC01636.JPG

GCP 1R was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.



DSC01527.JPG
DSC01529.JPG

GCP Name: 1S (333571.0950,6249016.1960,10.0230)

DSC01322.JPG
DSC01323.JPG
DSC01324.JPG
DSC01327.JPG
DSC01333.JPG
DSC01545.JPG
DSC01546.JPG

DSC01547.JPG
DSC01548.JPG
DSC01549.JPG
DSC01550.JPG
DSC01551.JPG
DSC01552.JPG
DSC01553.JPG
DSC01554.JPG
DSC01555.JPG
DSC01556.JPG
DSC01557.JPG
DSC01558.JPG

GCP Name: 1K (333619.7730,6249019.1710,8.8180)

DSC01338.JPG
DSC01350.JPG
DSC01352.JPG
DSC01354.JPG
DSC01355.JPG
DSC01356.JPG
DSC01357.JPG
DSC01358.JPG
DSC01359.JPG
DSC01360.JPG
DSC01361.JPG
DSC01362.JPG
DSC01363.JPG
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DSC01367.JPG
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DSC01570.JPG
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DSC01572.JPG
DSC01573.JPG
DSC01574.JPG
DSC01575.JPG
DSC01576.JPG
DSC01577.JPG
DSC01578.JPG

GCP Name: 1J (333633.2590,6249019.8060,9.7790)

DSC01356.JPG
DSC01358.JPG
DSC01360.JPG
DSC01362.JPG
DSC01364.JPG
DSC01365.JPG
DSC01366.JPG
DSC01367.JPG
DSC01368.JPG
DSC01369.JPG
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DSC01371.JPG
DSC01372.JPG
DSC01373.JPG
DSC01375.JPG
DSC01377.JPG
DSC01379.JPG
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DSC01570.JPG
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DSC01572.JPG
DSC01573.JPG
DSC01574.JPG
DSC01575.JPG
DSC01576.JPG
DSC01577.JPG
DSC01578.JPG
DSC01579.JPG
DSC01580.JPG
DSC01581.JPG
DSC01582.JPG

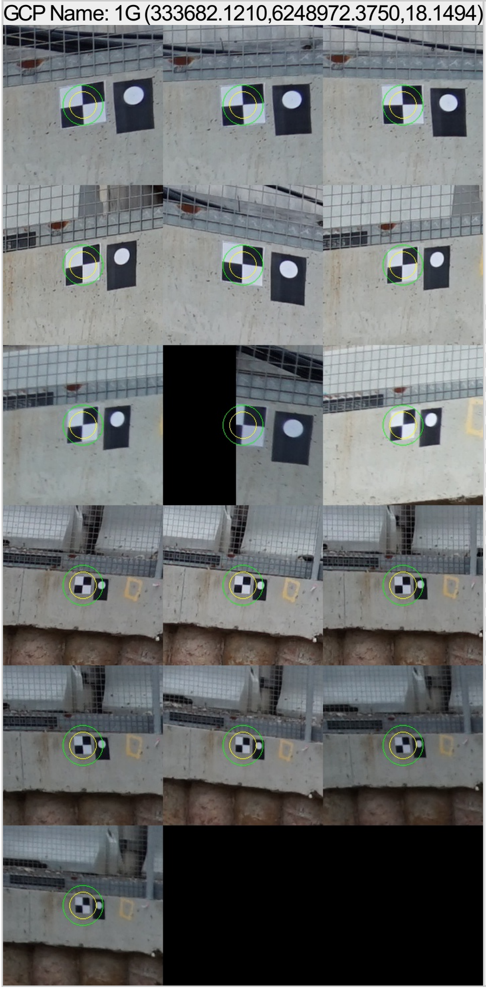
GCP Name: 1L (333629.5070,6248979.5910,16.9570)

DSC01466.JPG
DSC01470.JPG
DSC01472.JPG
DSC01473.JPG
DSC01474.JPG
DSC01475.JPG
DSC01476.JPG
DSC01477.JPG
DSC01478.JPG
DSC01479.JPG
DSC01480.JPG
DSC01481.JPG
DSC01483.JPG
DSC01485.JPG
DSC01487.JPG
DSC01607.JPG
DSC01608.JPG
DSC01609.JPG
DSC01610.JPG
DSC01612.JPG
DSC01613.JPG
DSC01614.JPG
DSC01615.JPG
DSC01616.JPG
DSC01617.JPG
DSC01618.JPG
DSC01619.JPG
DSC01620.JPG
DSC01621.JPG

GCP Name: 1E (333695.1990,6248983.6950,17.5890)

DSC01425.JPG
DSC01427.JPG
DSC01429.JPG
DSC01431.JPG
DSC01432.JPG
DSC01433.JPG
DSC01434.JPG
DSC01435.JPG
DSC01436.JPG
DSC01595.JPG
DSC01596.JPG
DSC01597.JPG
DSC01598.JPG

GCP Name: 1G (333682.1210,6248972.3750,18.1494)



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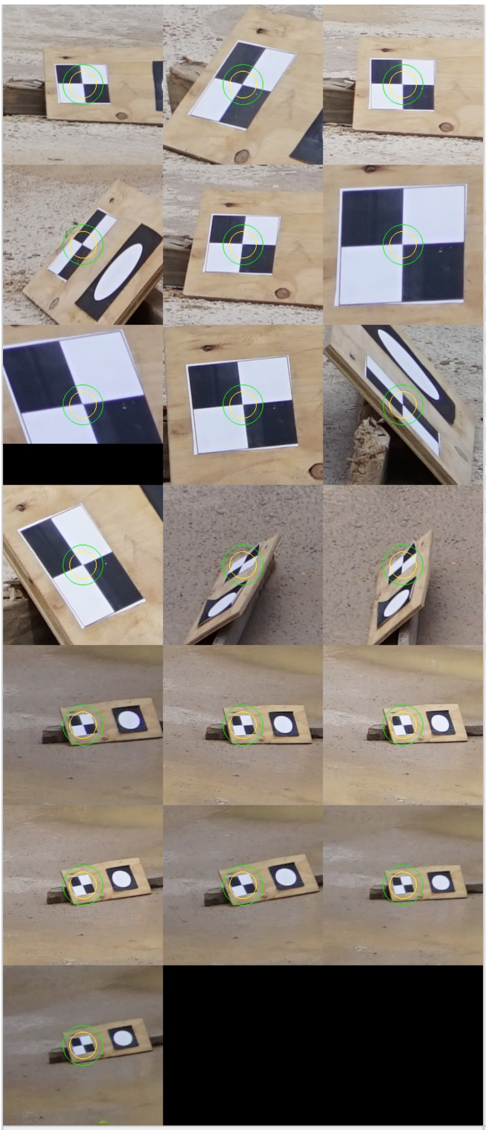
DSC01447.JPG
DSC01449.JPG
DSC01450.JPG
DSC01451.JPG
DSC01597.JPG
DSC01598.JPG
DSC01599.JPG
DSC01600.JPG
DSC01602.JPG
DSC01603.JPG
DSC01604.JPG

GCP Name: 1F (333681.2720,6248985.2720,9.3973)



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DSC01602.JPG
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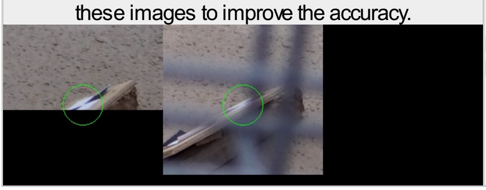
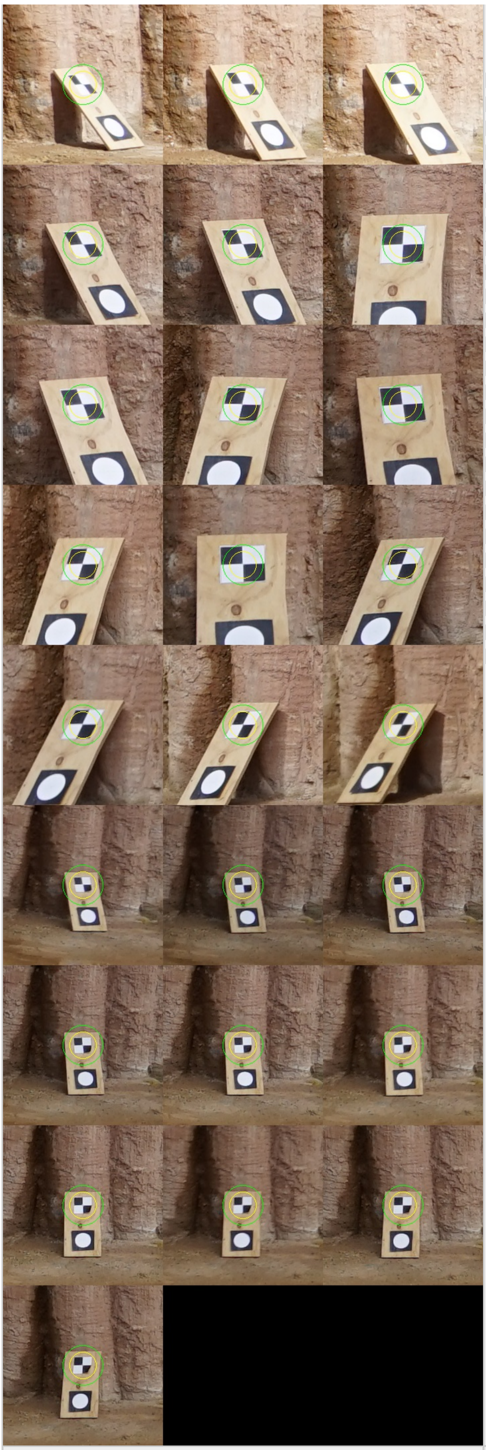
GCP 1F was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.



DSC01591.JPG
DSC01592.JPG

GCP Name: 1M (333626.6690,6248980.0290,9.0680)



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DSC01485.JPG
DSC01487.JPG
DSC01489.JPG
DSC01608.JPG
DSC01609.JPG
DSC01610.JPG
DSC01612.JPG
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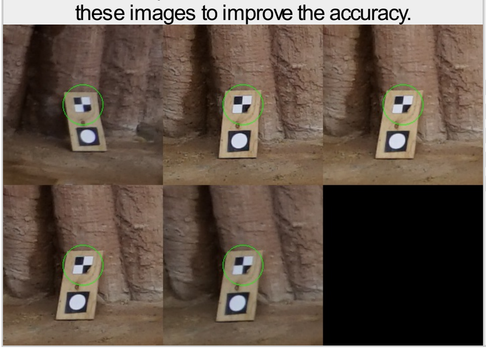
DSC01616.JPG
DSC01617.JPG
DSC01618.JPG

GCP 1M was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.



DSC01607.JPG
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DSC01621.JPG
DSC01622.JPG

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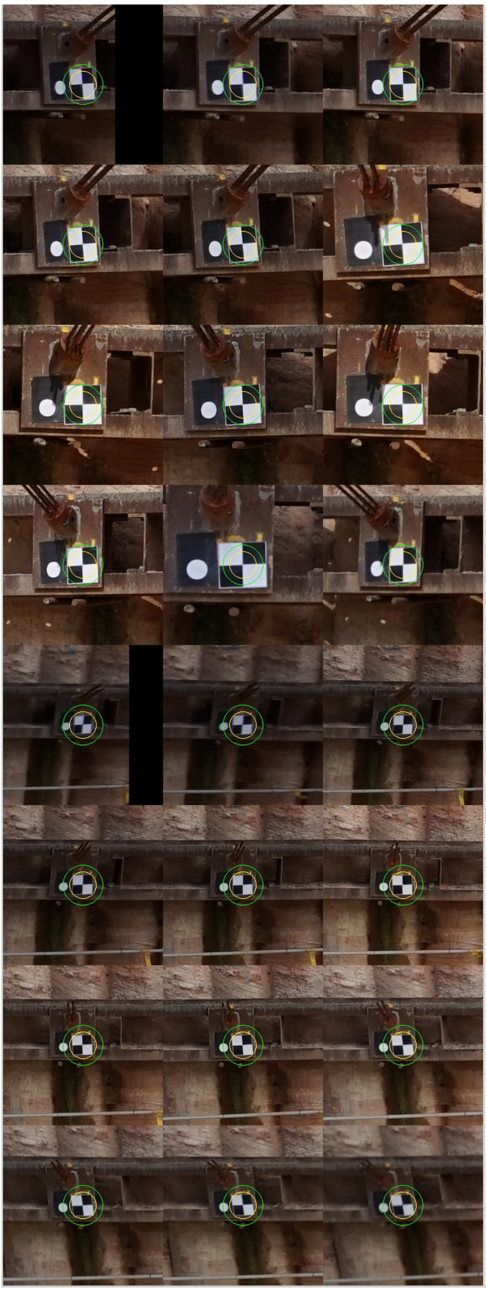

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DSC01621.JPG
DSC01622.JPG
DSC01623.JPG
DSC01624.JPG
DSC01625.JPG
DSC01626.JPG

GCP Name: 1O (333591.0970,6248984.8710,8.4770)

DSC01496.JPG
DSC01497.JPG

DSC01498.JPG
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DSC01500.JPG
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DSC01625.JPG
DSC01626.JPG
DSC01627.JPG
DSC01628.JPG
DSC01629.JPG
DSC01630.JPG
DSC01631.JPG

GCP Name: 1P (333583.4970,6248985.9290,16.0450)

DSC01498.JPG
DSC01500.JPG
DSC01501.JPG
DSC01502.JPG

DSC01503.JPG
DSC01504.JPG
DSC01505.JPG
DSC01506.JPG
DSC01507.JPG
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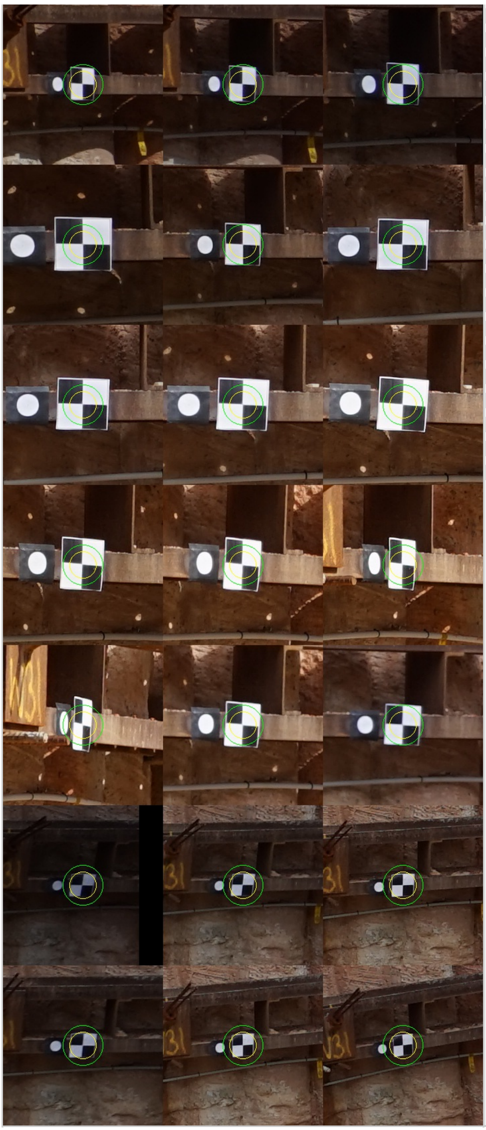
DSC01512.JPG
DSC01513.JPG
DSC01514.JPG
DSC01515.JPG

GCP 1P was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.

DSC01625.JPG
DSC01626.JPG
DSC01627.JPG
DSC01628.JPG
DSC01629.JPG
DSC01630.JPG

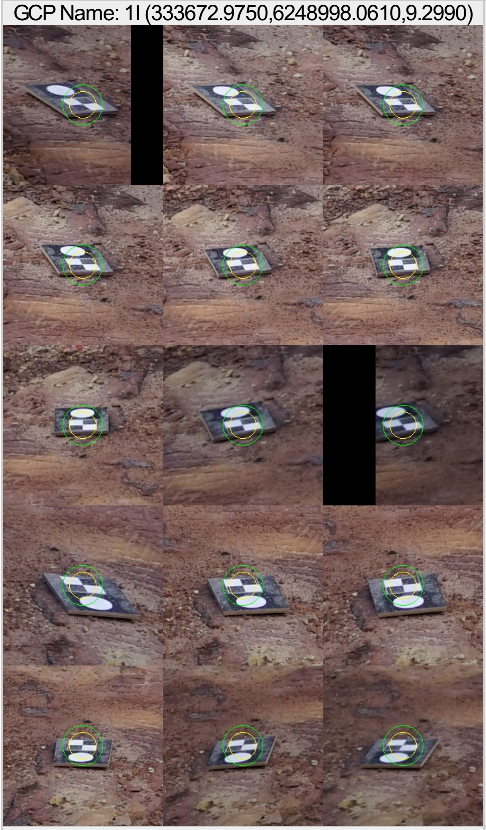
GCP Name: 1Q (333565.4780,6248988.5990,10.7680)

DSC01512.JPG



DSC01514.JPG
DSC01516.JPG
DSC01517.JPG
DSC01518.JPG
DSC01519.JPG
DSC01520.JPG
DSC01521.JPG
DSC01522.JPG
DSC01523.JPG
DSC01524.JPG
DSC01525.JPG
DSC01526.JPG
DSC01527.JPG
DSC01529.JPG
DSC01631.JPG
DSC01632.JPG
DSC01633.JPG
DSC01634.JPG
DSC01635.JPG
DSC01636.JPG

GCP Name: 1I (333672.9750,6248998.0610,9.2990)



DSC01586.JPG
DSC01587.JPG
DSC01588.JPG
DSC01589.JPG
DSC01590.JPG
DSC01591.JPG
DSC01592.JPG
DSC01593.JPG
DSC01594.JPG
DSC01598.JPG
DSC01599.JPG
DSC01600.JPG
DSC01602.JPG
DSC01603.JPG
DSC01604.JPG

GCP 1I was not marked on the following images (only up to 6 images shown). If the circle is too far away from the initial GCP position, also measure the GCP in these images to improve the accuracy.

Figure 7: Images in which GCPs have been marked (yellow circle) and in which their computed 3D points have been projected (green circle). A green circle outside of the yellow circle indicates either an accuracy issue or a GCP issue.

Processing Options

Hardware	CPU: Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz RAM: 32GB GPU: NVIDIA GeForce GTX 550 Ti (Driver: 10.18.13.5382)
Operating System	Windows 10 Home, 64-bit
Camera Model Name	ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB)
Ground Control Point (GCP) Coordinate System	Arbitrary (m)
Output Coordinate System	Arbitrary (m)
Detected template:	No template available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Free Flight or Terrestrial
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard, Internal Parameters Optimization: All, External Parameters Optimization: All, Rematch: Auto yes

Point Cloud Densification details

Processing Options

Image Scale	multiscale, 1/2 (Half image size, Default)
Point Density	Optimal
Minimum Number of Matches	6
3D Textured Mesh Generation	yes, Maximum Number of Triangles: 1000000, Texture Size: 8192x8192
Advanced: Matching Window Size	9x9 pixels
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Advanced: Limit Camera Depth Automatically	yes
Time for Point Cloud Densification	02h:21m:41s
Time for 3D Textured Mesh Generation	14m:40s

Results

Number of Generated Tiles	3
Number of 3D Densified Points	42933292
Average Density (per m^3)	59579.3

Appendix G

Site A-Blk11 minimally constrained report,

3 fixed points from Trimble Realworks

Registration Report (Target-Based)
Report by station

User Name: lbroome

Date: Sat Jun 18 16:23:53 2016
Project Name: blk11

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

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10 STATION(S) - **Mean Distance:** 0.0019 **Max Distance:** 0.0038
27 TARGET(S) - **Mean Distance:** 0.0023 **Max Distance:** 0.0071

Cub_blk11003 - 9 **Scanned Objects - Mean Distance:** 0.0014

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
027	060	2	0.0004 m	-0.0000 m	-0.0001 m	-0.0004 m	0.0007 m	18.8609 m
007	040	3	0.0006 m	-0.0000 m	0.0002 m	0.0005 m	0.0002 m	13.6981 m
001	034	3	0.0010 m	-0.0002 m	-0.0003 m	0.0010 m	0.0005 m	16.6783 m
Target13	--	--	--	--	--	--	0.0009 m	29.3030 m
005	038	3	0.0012 m	0.0003 m	0.0002 m	-0.0011 m	0.0002 m	11.9761 m
028	--	--	--	--	--	--	0.0016 m	16.6689 m
029	067	2	0.0037 m	0.0035 m	-0.0010 m	0.0003 m	0.0005 m	18.4479 m
Target108	--	--	--	--	--	--	0.0284 m	20.5818 m
Target110	--	--	--	--	--	--	0.0005 m	17.8934 m

Cub_blk11004 - 10 **Scanned Objects - Mean Distance:** 0.0017

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	041	4	0.0019 m	0.0006 m	0.0000 m	-0.0018 m	0.0002 m	13.1340 m
001	034	3	0.0007 m	0.0005 m	0.0004 m	0.0001 m	0.0002 m	11.3791 m
005	038	3	0.0007 m	0.0000 m	-0.0004 m	0.0005 m	0.0002 m	14.7748 m
027	060	2	0.0004 m	0.0000 m	0.0001 m	0.0004 m	0.0007 m	17.1625 m
006	039	3	0.0028 m	-0.0004 m	0.0005 m	-0.0028 m	0.0005 m	17.6535 m
002	035	3	0.0047 m	-0.0003 m	-0.0006 m	0.0046 m	0.0005 m	24.6605 m
004	037	4	0.0009 m	-0.0003 m	0.0003 m	0.0008 m	0.0008 m	17.2992 m
007	040	3	0.0011 m	0.0002 m	-0.0001 m	0.0011 m	0.0007 m	18.3876 m
003	036	4	0.0020 m	-0.0004 m	-0.0003 m	-0.0020 m	0.0003 m	7.6219 m
Target113	--	--	--	--	--	--	0.0011 m	32.4096 m

Cub_blk11005 - 11 **Scanned Objects - Mean Distance:** 0.0020

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	034	3	0.0011 m	-0.0004 m	-0.0001 m	-0.0011 m	0.0002 m	14.7169 m
Target29	--	--	--	--	--	--	0.0006 m	15.2313 m
002	035	3	0.0026 m	-0.0001 m	-0.0003 m	-0.0026 m	0.0002 m	14.9541 m
003	036	4	0.0028 m	0.0005 m	-0.0000 m	-0.0027 m	0.0002 m	8.6487 m
004	037	4	0.0007 m	-0.0002 m	-0.0001 m	-0.0007 m	0.0002 m	15.1173 m
005	038	3	0.0007 m	-0.0004 m	0.0002 m	0.0006 m	0.0009 m	20.1230 m
006	039	3	0.0047 m	-0.0000 m	-0.0005 m	0.0047 m	0.0008 m	28.7037 m
026	059	2	0.0008 m	0.0005 m	0.0005 m	0.0004 m	0.0007 m	19.1735 m
007	040	3	0.0017 m	-0.0002 m	-0.0001 m	-0.0016 m	0.0006 m	16.6008 m
008	041	4	0.0032 m	0.0003 m	0.0005 m	0.0032 m	0.0004 m	21.2096 m
Target38	--	--	--	--	--	--	0.0003 m	10.4394 m

Cub_blk11006 - 12 **Scanned Objects - Mean Distance:** 0.0019

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
002	035	3	0.0023 m	0.0004 m	0.0009 m	-0.0021 m	0.0002 m	12.9029 m
004	037	4	0.0006 m	0.0000 m	-0.0006 m	0.0001 m	0.0005 m	16.5745 m
024	057	2	0.0006 m	0.0004 m	-0.0003 m	-0.0002 m	0.0002 m	9.9631 m
023	056	4	0.0019 m	0.0004 m	0.0002 m	-0.0019 m	0.0003 m	12.9981 m
026	059	2	0.0008 m	-0.0005 m	-0.0005 m	-0.0004 m	0.0005 m	16.4011 m
003	036	4	0.0033 m	-0.0002 m	0.0007 m	0.0032 m	0.0004 m	28.0630 m
016	049	3	0.0013 m	0.0006 m	-0.0005 m	-0.0010 m	0.0002 m	12.5428 m
008	041	4	0.0012 m	-0.0007 m	-0.0005 m	-0.0008 m	0.0006 m	25.8709 m
032	065	2	0.0042 m	-0.0005 m	0.0008 m	0.0040 m	0.0007 m	19.2416 m
Target48	069	2	0.0031 m	-0.0030 m	0.0009 m	-0.0003 m	0.0002 m	15.1124 m
Target49	--	--	--	--	--	--	0.0003 m	14.8594 m
Target50	--	--	--	--	--	--	0.0011 m	6.0031 m

Cub_blk11007 - 9 **Scanned Objects - Mean Distance:** 0.0013

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	039	3	0.0020 m	0.0005 m	-0.0000 m	-0.0020 m	0.0006 m	16.2111 m
004	037	4	0.0007 m	0.0005 m	0.0004 m	-0.0002 m	0.0001 m	14.3400 m
003	036	4	0.0016 m	0.0001 m	-0.0004 m	0.0015 m	0.0008 m	24.5672 m
033	066	2	0.0026 m	-0.0001 m	0.0003 m	0.0026 m	0.0007 m	20.6194 m
023	056	4	0.0009 m	-0.0005 m	-0.0003 m	-0.0007 m	0.0003 m	14.9623 m
024	057	2	0.0006 m	-0.0004 m	0.0003 m	0.0002 m	0.0002 m	10.0177 m
008	041	4	0.0006 m	-0.0002 m	0.0000 m	-0.0005 m	0.0002 m	14.0090 m
Target114	--	--	--	--	--	--	0.0007 m	16.8532 m
Target115	--	--	--	--	--	--	0.0003 m	10.9254 m

Cub_blk11008 - 9 **Scanned Objects - Mean Distance:** 0.0017

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
033	066	2	0.0026 m	0.0001 m	-0.0003 m	-0.0026 m	0.0002 m	3.9097 m
Target59	--	--	--	--	--	--	0.0001 m	14.0003 m
019	052	2	0.0004 m	-0.0003 m	0.0001 m	0.0003 m	0.0002 m	12.3396 m
015	048	3	0.0037 m	-0.0005 m	0.0003 m	0.0037 m	0.0006 m	15.4087 m
018	051	4	0.0004 m	0.0003 m	-0.0003 m	0.0002 m	0.0001 m	10.9252 m
017	050	4	0.0003 m	0.0003 m	0.0001 m	-0.0002 m	0.0005 m	18.4628 m
016	049	3	0.0016 m	-0.0007 m	0.0003 m	0.0014 m	0.0007 m	21.5990 m
023	056	4	0.0027 m	0.0005 m	-0.0001 m	-0.0026 m	0.0005 m	15.0771 m
Target116	--	--	--	--	--	--	0.0006 m	15.0534 m

Cub_blk11009 - 10 **Scanned Objects - Mean Distance:** 0.0038

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
032	065	2	0.0042 m	0.0005 m	-0.0008 m	-0.0040 m	0.0002 m	14.5054 m
015	048	3	0.0054 m	0.0002 m	0.0006 m	0.0054 m	0.0007 m	27.4771 m
013	046	3	0.0078 m	-0.0019 m	-0.0005 m	-0.0076 m	0.0002 m	14.0592 m
016	049	3	0.0005 m	0.0002 m	0.0002 m	-0.0004 m	0.0002 m	12.3900 m
017	050	4	0.0023 m	-0.0001 m	0.0010 m	0.0020 m	0.0005 m	19.5390 m
031	064	2	0.0071 m	0.0006 m	-0.0009 m	-0.0070 m	0.0008 m	17.9076 m
018	051	4	0.0012 m	0.0009 m	-0.0006 m	0.0005 m	0.0002 m	13.7730 m
019	052	2	0.0004 m	0.0003 m	-0.0001 m	-0.0003 m	0.0002 m	11.7476 m
023	056	4	0.0052 m	-0.0004 m	0.0003 m	0.0052 m	0.0008 m	20.5282 m
Target75	--	--	--	--	--	--	0.0008 m	2.7768 m

Cub_blk11010 - 11 **Scanned Objects - Mean Distance:** 0.0022

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
031	064	2	0.0071 m	-0.0006 m	0.0009 m	0.0070 m	0.0005 m	15.7308 m
017	050	4	0.0022 m	-0.0002 m	-0.0008 m	-0.0021 m	0.0002 m	14.7879 m
014	047	2	0.0010 m	0.0006 m	-0.0005 m	-0.0006 m	0.0002 m	14.4129 m
009	042	2	0.0017 m	0.0004 m	-0.0001 m	-0.0016 m	0.0002 m	13.7715 m
018	051	4	0.0014 m	-0.0010 m	0.0003 m	0.0009 m	0.0004 m	21.8945 m
010	043	2	0.0027 m	0.0004 m	-0.0000 m	-0.0026 m	0.0002 m	12.1938 m
013	046	3	0.0013 m	0.0012 m	0.0005 m	0.0002 m	0.0002 m	6.4864 m
Target84	--	--	--	--	--	--	0.0002 m	3.1901 m
Target85	068	2	0.0006 m	-0.0005 m	0.0001 m	-0.0000 m	0.0005 m	16.8581 m
Target86	--	--	--	--	--	--	0.0004 m	17.2175 m
Target87	--	--	--	--	--	--	0.0008 m	2.6538 m

Cub_blk11011 - 11 **Scanned Objects - Mean Distance:** 0.0034

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
009	042	2	0.0017 m	-0.0004 m	0.0001 m	0.0016 m	0.0002 m	10.8005 m
010	043	2	0.0027 m	-0.0004 m	0.0000 m	0.0026 m	0.0002 m	14.8592 m
017	050	4	0.0004 m	0.0000 m	-0.0003 m	0.0003 m	0.0002 m	10.5412 m
Target91	--	--	--	--	--	--	0.0006 m	16.4939 m
018	051	4	0.0016 m	-0.0001 m	0.0006 m	-0.0015 m	0.0005 m	19.1121 m
013	046	3	0.0075 m	0.0006 m	-0.0000 m	0.0074 m	0.0008 m	24.5760 m
014	047	2	0.0010 m	-0.0006 m	0.0005 m	0.0006 m	0.0002 m	8.1190 m
015	048	3	0.0091 m	0.0003 m	-0.0008 m	-0.0090 m	0.0002 m	6.0769 m
Target96	--	--	--	--	--	--	0.0024 m	3.4937 m
Target117	--	--	--	--	--	--	0.0008 m	17.4382 m
Target118	--	--	--	--	--	--	0.0055 m	5.5745 m

BLK11-USQ1 - 19 **Scanned Objects - Mean Distance:** 0.0000

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1A	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1B	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1C	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1D	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1E	068	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1F	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1G	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1H	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1I	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1J	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1K	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1L	069	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1M	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1N	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1O	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1P	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1Q	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1R	067	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1S	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--

Report by target

User Name: lbroome

Date: Sat Jun 18 16:23:53 2016
Project Name: blk11

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

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10 STATION(S) - Mean Distance: 0.0019 **Max Distance:** 0.0038
27 TARGET(S) - Mean Distance: 0.0023 **Max Distance:** 0.0071

034 - 3 **Scanned Objects - Mean Distance:** 0.0009 **- Mean Position** X=333597.2034 Y=6249001.6208 Z=8.4071

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	Cub_blk11004	0.0007 m	0.0005 m	0.0004 m	0.0001 m	0.0002 m	11.3791 m
001	Cub_blk11005	0.0011 m	-0.0004 m	-0.0001 m	-0.0011 m	0.0002 m	14.7169 m
001	Cub_blk11003	0.0010 m	-0.0002 m	-0.0003 m	0.0010 m	0.0005 m	16.6783 m

035 - 3 **Scanned Objects - Mean Distance:** 0.0032 **- Mean Position** X=333623.3951 Y=6248989.7821 Z=8.8508

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
002	Cub_blk11004	0.0047 m	-0.0003 m	-0.0006 m	0.0046 m	0.0005 m	24.6605 m
002	Cub_blk11005	0.0026 m	-0.0001 m	-0.0003 m	-0.0026 m	0.0002 m	14.9541 m
002	Cub_blk11006	0.0023 m	0.0004 m	0.0009 m	-0.0021 m	0.0002 m	12.9029 m

036 – 4 **Scanned Objects – Mean Distance:** 0.0024 **– Mean Position** X=333609.8308 Y=6249001.0905 Z=8.4036

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
003	Cub_blk11004	0.0020 m	-0.0004 m	-0.0003 m	-0.0020 m	0.0003 m	7.6219 m
003	Cub_blk11005	0.0028 m	0.0005 m	-0.0000 m	-0.0027 m	0.0002 m	8.6487 m
003	Cub_blk11006	0.0033 m	-0.0002 m	0.0007 m	0.0032 m	0.0004 m	28.0630 m
003	Cub_blk11007	0.0016 m	0.0001 m	-0.0004 m	0.0015 m	0.0008 m	24.5672 m

037 – 4 **Scanned Objects – Mean Distance:** 0.0007 **– Mean Position** X=333621.9626 Y=6248999.9275 Z=8.7536

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
004	Cub_blk11004	0.0009 m	-0.0003 m	0.0003 m	0.0008 m	0.0008 m	17.2992 m
004	Cub_blk11005	0.0007 m	-0.0002 m	-0.0001 m	-0.0007 m	0.0002 m	15.1173 m
004	Cub_blk11006	0.0006 m	0.0000 m	-0.0006 m	0.0001 m	0.0005 m	16.5745 m
004	Cub_blk11007	0.0007 m	0.0005 m	0.0004 m	-0.0002 m	0.0001 m	14.3400 m

038 – 3 **Scanned Objects – Mean Distance:** 0.0009 **– Mean Position** X=333592.3730 Y=6249004.2190 Z=8.4124

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
005	Cub_blk11004	0.0007 m	0.0000 m	-0.0004 m	0.0005 m	0.0002 m	14.7748 m
005	Cub_blk11005	0.0007 m	-0.0004 m	0.0002 m	0.0006 m	0.0009 m	20.1230 m
005	Cub_blk11003	0.0012 m	0.0003 m	0.0002 m	-0.0011 m	0.0002 m	11.9761 m

039 – 3 **Scanned Objects – Mean Distance:** 0.0032 **– Mean Position** X=333620.3344 Y=6249018.9279 Z=9.6984

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	Cub_blk11004	0.0028 m	-0.0004 m	0.0005 m	-0.0028 m	0.0005 m	17.6535 m
006	Cub_blk11005	0.0047 m	-0.0000 m	-0.0005 m	0.0047 m	0.0008 m	28.7037 m
006	Cub_blk11007	0.0020 m	0.0005 m	-0.0000 m	-0.0020 m	0.0006 m	16.2111 m

040 - 3 **Scanned Objects - Mean Distance:** 0.0011 **- Mean Position** X=333592.5905 Y=6248996.0322 Z=8.4155

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
007	Cub_blk11004	0.0011 m	0.0002 m	-0.0001 m	0.0011 m	0.0007 m	18.3876 m
007	Cub_blk11005	0.0017 m	-0.0002 m	-0.0001 m	-0.0016 m	0.0006 m	16.6008 m
007	Cub_blk11003	0.0006 m	-0.0000 m	0.0002 m	0.0005 m	0.0002 m	13.6981 m

041 - 4 **Scanned Objects - Mean Distance:** 0.0017 **- Mean Position** X=333619.2928 Y=6249011.0295 Z=8.7539

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	Cub_blk11004	0.0019 m	0.0006 m	0.0000 m	-0.0018 m	0.0002 m	13.1340 m
008	Cub_blk11005	0.0032 m	0.0003 m	0.0005 m	0.0032 m	0.0004 m	21.2096 m
008	Cub_blk11006	0.0012 m	-0.0007 m	-0.0005 m	-0.0008 m	0.0006 m	25.8709 m
008	Cub_blk11007	0.0006 m	-0.0002 m	0.0000 m	-0.0005 m	0.0002 m	14.0090 m

042 - 2 **Scanned Objects - Mean Distance:** 0.0017 **- Mean Position** X=333684.0088 Y=6249001.0657 Z=9.4262

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
009	Cub_blk11010	0.0017 m	0.0004 m	-0.0001 m	-0.0016 m	0.0002 m	13.7715 m
009	Cub_blk11011	0.0017 m	-0.0004 m	0.0001 m	0.0016 m	0.0002 m	10.8005 m

043 - 2 **Scanned Objects - Mean Distance:** 0.0027 **- Mean Position** X=333686.8566 Y=6248998.0575 Z=9.4334

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
010	Cub_blk11010	0.0027 m	0.0004 m	-0.0000 m	-0.0026 m	0.0002 m	12.1938 m
010	Cub_blk11011	0.0027 m	-0.0004 m	0.0000 m	0.0026 m	0.0002 m	14.8592 m

046 - 3 **Scanned Objects - Mean Distance:** 0.0055 **- Mean Position** X=333674.2892 Y=6248985.9319 Z=9.4373

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
013	Cub_blk11010	0.0013 m	0.0012 m	0.0005 m	0.0002 m	0.0002 m	6.4864 m
013	Cub_blk11011	0.0075 m	0.0006 m	-0.0000 m	0.0074 m	0.0008 m	24.5760 m
013	Cub_blk11009	0.0078 m	-0.0019 m	-0.0005 m	-0.0076 m	0.0002 m	14.0592 m

047 - 2 **Scanned Objects - Mean Distance:** 0.0010 **- Mean Position** X=333679.0382 Y=6249002.1704 Z=9.4284

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
014	Cub_blk11010	0.0010 m	0.0006 m	-0.0005 m	-0.0006 m	0.0002 m	14.4129 m
014	Cub_blk11011	0.0010 m	-0.0006 m	0.0005 m	0.0006 m	0.0002 m	8.1190 m

048 - 3 **Scanned Objects - Mean Distance:** 0.0061 **- Mean Position** X=333672.5002 Y=6249011.0744 Z=9.3280

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
015	Cub_blk11008	0.0037 m	-0.0005 m	0.0003 m	0.0037 m	0.0006 m	15.4087 m
015	Cub_blk11009	0.0054 m	0.0002 m	0.0006 m	0.0054 m	0.0007 m	27.4771 m
015	Cub_blk11011	0.0091 m	0.0003 m	-0.0008 m	-0.0090 m	0.0002 m	6.0769 m

049 - 3 **Scanned Objects - Mean Distance:** 0.0011 **- Mean Position** X=333648.4698 Y=6248989.9386 Z=8.7509

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
016	Cub_blk11008	0.0016 m	-0.0007 m	0.0003 m	0.0014 m	0.0007 m	21.5990 m
016	Cub_blk11009	0.0005 m	0.0002 m	0.0002 m	-0.0004 m	0.0002 m	12.3900 m
016	Cub_blk11006	0.0013 m	0.0006 m	-0.0005 m	-0.0010 m	0.0002 m	12.5428 m

050 – 4 **Scanned Objects – Mean Distance:** 0.0013 **– Mean Position** X=333673.4301 Y=6249000.9020 Z=9.4161

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
017	Cub_blk11008	0.0003 m	0.0003 m	0.0001 m	-0.0002 m	0.0005 m	18.4628 m
017	Cub_blk11009	0.0023 m	-0.0001 m	0.0010 m	0.0020 m	0.0005 m	19.5390 m
017	Cub_blk11010	0.0022 m	-0.0002 m	-0.0008 m	-0.0021 m	0.0002 m	14.7879 m
017	Cub_blk11011	0.0004 m	0.0000 m	-0.0003 m	0.0003 m	0.0002 m	10.5412 m

051 – 4 **Scanned Objects – Mean Distance:** 0.0012 **– Mean Position** X=333662.2055 Y=6249000.0462 Z=8.8298

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
018	Cub_blk11008	0.0004 m	0.0003 m	-0.0003 m	0.0002 m	0.0001 m	10.9252 m
018	Cub_blk11009	0.0012 m	0.0009 m	-0.0006 m	0.0005 m	0.0002 m	13.7730 m
018	Cub_blk11010	0.0014 m	-0.0010 m	0.0003 m	0.0009 m	0.0004 m	21.8945 m
018	Cub_blk11011	0.0016 m	-0.0001 m	0.0006 m	-0.0015 m	0.0005 m	19.1121 m

052 – 2 **Scanned Objects – Mean Distance:** 0.0004 **– Mean Position** X=333656.2335 Y=6248997.4243 Z=8.8318

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
019	Cub_blk11008	0.0004 m	-0.0003 m	0.0001 m	0.0003 m	0.0002 m	12.3396 m
019	Cub_blk11009	0.0004 m	0.0003 m	-0.0001 m	-0.0003 m	0.0002 m	11.7476 m

056 – 4 **Scanned Objects – Mean Distance:** 0.0027 **– Mean Position** X=333645.3202 Y=6249000.4738 Z=8.7432

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
023	Cub_blk11006	0.0019 m	0.0004 m	0.0002 m	-0.0019 m	0.0003 m	12.9981 m
023	Cub_blk11007	0.0009 m	-0.0005 m	-0.0003 m	-0.0007 m	0.0003 m	14.9623 m
023	Cub_blk11008	0.0027 m	0.0005 m	-0.0001 m	-0.0026 m	0.0005 m	15.0771 m
023	Cub_blk11009	0.0052 m	-0.0004 m	0.0003 m	0.0052 m	0.0008 m	20.5282 m

057 – 2 **Scanned Objects – Mean Distance:** 0.0006 **– Mean Position** X=333638.8847 Y=6249000.8867 Z=8.8088

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
024	Cub_blk11006	0.0006 m	0.0004 m	-0.0003 m	-0.0002 m	0.0002 m	9.9631 m
024	Cub_blk11007	0.0006 m	-0.0004 m	0.0003 m	0.0002 m	0.0002 m	10.0177 m

059 – 2 **Scanned Objects – Mean Distance:** 0.0008 **– Mean Position** X=333623.7268 Y=6248980.6904 Z=10.7473

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
026	Cub_blk11005	0.0008 m	0.0005 m	0.0005 m	0.0004 m	0.0007 m	19.1735 m
026	Cub_blk11006	0.0008 m	-0.0005 m	-0.0005 m	-0.0004 m	0.0005 m	16.4011 m

060 – 2 **Scanned Objects – Mean Distance:** 0.0004 **– Mean Position** X=333592.3177 Y=6249017.3043 Z=9.6110

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
027	Cub_blk11003	0.0004 m	-0.0000 m	-0.0001 m	-0.0004 m	0.0007 m	18.8609 m
027	Cub_blk11004	0.0004 m	0.0000 m	0.0001 m	0.0004 m	0.0007 m	17.1625 m

064 – 2 **Scanned Objects – Mean Distance:** 0.0071 **– Mean Position** X=333673.0017 Y=6248973.9669 Z=11.5961

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
031	Cub_blk11009	0.0071 m	0.0006 m	-0.0009 m	-0.0070 m	0.0008 m	17.9076 m
031	Cub_blk11010	0.0071 m	-0.0006 m	0.0009 m	0.0070 m	0.0005 m	15.7308 m

065 – 2 **Scanned Objects – Mean Distance:** 0.0042 **– Mean Position** X=333649.1036 Y=6248977.2569 Z=11.0336

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
032	Cub_blk11006	0.0042 m	-0.0005 m	0.0008 m	0.0040 m	0.0007 m	19.2416 m
032	Cub_blk11009	0.0042 m	0.0005 m	-0.0008 m	-0.0040 m	0.0002 m	14.5054 m

066 - 2 **Scanned Objects - Mean Distance:** 0.0026 **- Mean Position** X=333653.5866 Y=6249009.9778 Z=8.8366

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
033	Cub_blk11007	0.0026 m	-0.0001 m	0.0003 m	0.0026 m	0.0007 m	20.6194 m
033	Cub_blk11008	0.0026 m	0.0001 m	-0.0003 m	-0.0026 m	0.0002 m	3.9097 m

067 - 2 **Scanned Objects - Mean Distance:** 0.0037 **- Mean Position** X=333562.1708 Y=6249002.3980 Z=10.0817

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1R	BLK11-USQ1	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
029	Cub_blk11003	0.0037 m	0.0035 m	-0.0010 m	0.0003 m	0.0005 m	18.4479 m

068 - 2 **Scanned Objects - Mean Distance:** 0.0006 **- Mean Position** X=333695.1988 Y=6248983.6940 Z=17.5890

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1E	BLK11-USQ1	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target85	Cub_blk11010	0.0006 m	-0.0005 m	0.0001 m	-0.0000 m	0.0005 m	16.8581 m

069 - 2 **Scanned Objects - Mean Distance:** 0.0031 **- Mean Position** X=333629.5074 Y=6248979.5900 Z=16.9582

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1L	BLK11-USQ1	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target48	Cub_blk11006	0.0031 m	-0.0030 m	0.0009 m	-0.0003 m	0.0002 m	15.1124 m

Appendix H

Site A-Blk11 fully constrained

report from Trimble Realworks

Registration Report (Target-Based)
Report by station

User Name: lbroome

Date: Sun Jun 19 08:45:23 2016
Project Name: blk11

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

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10 STATION(S) - Mean Distance: 0.002 **Max Distance:** 0.004
39 TARGET(S) - Mean Distance: 0.003 **Max Distance:** 0.012

Cub_blk11003 - 11 **Scanned Objects - Mean Distance:** 0.002

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
027	060	2	0.000 m	-0.000 m	-0.000 m	-0.000 m	0.001 m	18.861 m
007	040	3	0.001 m	-0.000 m	0.000 m	0.001 m	0.000 m	13.698 m
001	034	3	0.001 m	-0.000 m	-0.000 m	0.001 m	0.000 m	16.678 m
Target13	--	--	--	--	--	--	0.001 m	29.303 m
005	038	3	0.001 m	0.000 m	0.000 m	-0.001 m	0.000 m	11.976 m
028	078	2	0.002 m	0.002 m	-0.001 m	0.000 m	0.002 m	16.669 m
Target16	--	--	--	--	--	--	0.001 m	2.978 m
029	077	2	0.005 m	0.002 m	0.001 m	0.004 m	0.000 m	18.448 m
030	--	--	--	--	--	--	0.000 m	17.066 m
Target107	076	2	0.002 m	0.001 m	0.001 m	0.001 m	0.031 m	20.579 m
Target108	075	2	0.004 m	-0.003 m	0.003 m	-0.002 m	0.000 m	17.893 m

Cub_blk11004 - 9 **Scanned Objects - Mean Distance:** 0.002

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	041	4	0.002 m	0.001 m	0.000 m	-0.002 m	0.000 m	13.134 m
001	034	3	0.001 m	0.001 m	0.000 m	0.000 m	0.000 m	11.379 m
005	038	3	0.001 m	0.000 m	-0.000 m	0.001 m	0.000 m	14.775 m
027	060	2	0.000 m	0.000 m	0.000 m	0.000 m	0.001 m	17.162 m
006	039	3	0.003 m	-0.000 m	0.001 m	-0.003 m	0.000 m	17.653 m
002	035	3	0.005 m	-0.000 m	-0.001 m	0.005 m	0.000 m	24.660 m
004	037	4	0.001 m	-0.000 m	0.000 m	0.001 m	0.001 m	17.299 m
007	040	3	0.001 m	0.000 m	-0.000 m	0.001 m	0.001 m	18.388 m
003	036	4	0.002 m	-0.000 m	-0.000 m	-0.002 m	0.000 m	7.622 m

Cub_blk11005 - 11 **Scanned Objects - Mean Distance:** 0.002

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	034	3	0.001 m	-0.000 m	-0.000 m	-0.001 m	0.000 m	14.717 m
Target29	--	--	--	--	--	--	0.001 m	15.231 m
002	035	3	0.003 m	-0.000 m	-0.000 m	-0.003 m	0.000 m	14.954 m
003	036	4	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	8.649 m
004	037	4	0.001 m	-0.000 m	-0.000 m	-0.001 m	0.000 m	15.117 m
005	038	3	0.001 m	-0.000 m	0.000 m	0.001 m	0.001 m	20.123 m
006	039	3	0.005 m	-0.000 m	-0.000 m	0.005 m	0.001 m	28.704 m
026	059	2	0.001 m	0.000 m	0.000 m	0.000 m	0.001 m	19.173 m
007	040	3	0.002 m	-0.000 m	-0.000 m	-0.002 m	0.001 m	16.601 m
008	041	4	0.003 m	0.000 m	0.000 m	0.003 m	0.000 m	21.210 m
Target38	074	2	0.004 m	0.001 m	-0.001 m	-0.003 m	0.000 m	10.439 m

Cub_blk11006 - 12 **Scanned Objects - Mean Distance:** 0.002

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
002	035	3	0.002 m	0.000 m	0.001 m	-0.002 m	0.000 m	12.903 m
004	037	4	0.001 m	0.000 m	-0.001 m	0.000 m	0.000 m	16.574 m
024	057	2	0.001 m	0.000 m	-0.000 m	-0.000 m	0.000 m	9.963 m
023	056	4	0.002 m	0.000 m	0.000 m	-0.002 m	0.000 m	12.998 m
026	059	2	0.001 m	-0.000 m	-0.000 m	-0.000 m	0.000 m	16.401 m
003	036	4	0.003 m	-0.000 m	0.001 m	0.003 m	0.000 m	28.063 m
016	049	3	0.001 m	0.001 m	-0.001 m	-0.001 m	0.000 m	12.543 m
008	041	4	0.001 m	-0.001 m	-0.001 m	-0.001 m	0.001 m	25.871 m
032	065	2	0.004 m	-0.001 m	0.001 m	0.004 m	0.001 m	19.242 m
Target48	072	2	0.005 m	-0.004 m	0.002 m	-0.001 m	0.000 m	15.112 m
Target49	073	2	0.003 m	0.000 m	-0.002 m	0.000 m	0.000 m	14.859 m
Target50	--	--	--	--	--	--	0.001 m	6.003 m

Cub_blk11007 - 9 **Scanned Objects - Mean Distance:** 0.002

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	039	3	0.002 m	0.000 m	-0.000 m	-0.002 m	0.001 m	16.211 m
004	037	4	0.001 m	0.000 m	0.000 m	-0.000 m	0.000 m	14.340 m
003	036	4	0.002 m	0.000 m	-0.000 m	0.002 m	0.001 m	24.567 m
033	066	2	0.003 m	-0.000 m	0.000 m	0.003 m	0.001 m	20.619 m
023	056	4	0.001 m	-0.000 m	-0.000 m	-0.001 m	0.000 m	14.962 m
024	057	2	0.001 m	-0.000 m	0.000 m	0.000 m	0.000 m	10.018 m
008	041	4	0.001 m	-0.000 m	0.000 m	-0.001 m	0.000 m	14.009 m
Target109	079	2	0.003 m	0.002 m	-0.002 m	-0.002 m	0.001 m	16.853 m
Target110	080	2	0.004 m	0.001 m	-0.003 m	-0.002 m	0.001 m	10.926 m

Cub_blk11008 - 9 **Scanned Objects - Mean Distance:** 0.003

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
033	066	2	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	3.910 m
Target59	--	--	--	--	--	--	0.000 m	14.000 m
019	052	2	0.000 m	-0.000 m	0.000 m	0.000 m	0.000 m	12.340 m
015	048	3	0.004 m	-0.001 m	0.000 m	0.004 m	0.001 m	15.409 m
018	051	4	0.000 m	0.000 m	-0.000 m	0.000 m	0.000 m	10.925 m
017	050	4	0.000 m	0.000 m	0.000 m	-0.000 m	0.000 m	18.463 m
016	049	3	0.002 m	-0.001 m	0.000 m	0.001 m	0.001 m	21.599 m
023	056	4	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	15.077 m
Target111	081	2	0.009 m	-0.004 m	-0.005 m	0.006 m	0.001 m	15.053 m

Cub_blk11009 - 10 **Scanned Objects - Mean Distance:** 0.004

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
032	065	2	0.004 m	0.001 m	-0.001 m	-0.004 m	0.000 m	14.505 m
015	048	3	0.005 m	0.000 m	0.001 m	0.005 m	0.001 m	27.477 m
013	046	3	0.008 m	-0.002 m	-0.000 m	-0.008 m	0.000 m	14.059 m
016	049	3	0.000 m	0.000 m	0.000 m	-0.000 m	0.000 m	12.390 m
017	050	4	0.002 m	-0.000 m	0.001 m	0.002 m	0.001 m	19.539 m
031	064	2	0.007 m	0.001 m	-0.001 m	-0.007 m	0.001 m	17.908 m
018	051	4	0.001 m	0.001 m	-0.001 m	0.000 m	0.000 m	13.773 m
019	052	2	0.000 m	0.000 m	-0.000 m	-0.000 m	0.000 m	11.748 m
023	056	4	0.005 m	-0.000 m	0.000 m	0.005 m	0.001 m	20.528 m
Target75	--	--	--	--	--	--	0.001 m	2.777 m

Cub_blk11010 - 12 Scanned Objects - Mean Distance: 0.004

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
031	064	2	0.007 m	-0.001 m	0.001 m	0.007 m	0.000 m	15.731 m
017	050	4	0.002 m	-0.000 m	-0.001 m	-0.002 m	0.000 m	14.788 m
014	047	2	0.001 m	0.001 m	-0.000 m	-0.001 m	0.000 m	14.413 m
009	042	2	0.002 m	0.000 m	-0.000 m	-0.002 m	0.000 m	13.772 m
018	051	4	0.001 m	-0.001 m	0.000 m	0.001 m	0.000 m	21.895 m
010	043	2	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	12.194 m
Target82	--	--	--	--	--	--	0.001 m	6.571 m
013	046	3	0.001 m	0.001 m	0.000 m	0.000 m	0.000 m	6.486 m
Target84	070	2	0.012 m	-0.003 m	0.002 m	-0.012 m	0.000 m	3.190 m
Target85	069	2	0.005 m	-0.002 m	0.003 m	0.003 m	0.000 m	16.858 m
Target86	071	2	0.009 m	0.006 m	0.002 m	0.006 m	0.000 m	17.218 m
Target87	--	--	--	--	--	--	0.001 m	2.654 m

Cub_blk11011 - 11 Scanned Objects - Mean Distance: 0.004

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
009	042	2	0.002 m	-0.000 m	0.000 m	0.002 m	0.000 m	10.800 m
010	043	2	0.003 m	-0.000 m	0.000 m	0.003 m	0.000 m	14.859 m
017	050	4	0.000 m	0.000 m	-0.000 m	0.000 m	0.000 m	10.541 m
Target91	--	--	--	--	--	--	0.001 m	16.494 m
018	051	4	0.002 m	-0.000 m	0.001 m	-0.002 m	0.000 m	19.112 m
013	046	3	0.007 m	0.001 m	-0.000 m	0.007 m	0.001 m	24.576 m
014	047	2	0.001 m	-0.001 m	0.000 m	0.001 m	0.000 m	8.119 m
015	048	3	0.009 m	0.000 m	-0.001 m	-0.009 m	0.000 m	6.077 m
Target96	--	--	--	--	--	--	0.002 m	3.494 m
Target113	068	2	0.006 m	-0.002 m	-0.003 m	0.005 m	0.001 m	17.438 m
Target114	067	2	0.006 m	0.002 m	0.002 m	-0.005 m	0.004 m	5.575 m

BLK11-USQ1 - 19 **Scanned Objects - Mean Distance:** 0.000

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1A	081	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1B	--	--	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1C	067	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1D	068	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1E	069	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1F	070	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1G	071	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1H	--	--	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1I	--	--	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1J	080	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1K	079	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1L	072	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1M	073	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1N	074	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1O	--	--	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1P	075	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1Q	076	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1R	077	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--
1S	078	2	0.000 m	0.000 m	0.000 m	0.000 m	--	--

Report by target

User Name: lbroome

Date: Sun Jun 19 08:45:23 2016
Project Name: blk11

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

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10 STATION(S) - Mean Distance: 0.002 **Max Distance:** 0.004
39 TARGET(S) - Mean Distance: 0.003 **Max Distance:** 0.012

034 - 3 **Scanned Objects - Mean Distance:** 0.001 - **Mean Position** X=333597.202 Y=6249001.624 Z=8.413

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	Cub_blk11004	0.001 m	0.001 m	0.000 m	0.000 m	0.000 m	11.379 m
001	Cub_blk11005	0.001 m	-0.000 m	-0.000 m	-0.001 m	0.000 m	14.717 m
001	Cub_blk11003	0.001 m	-0.000 m	-0.000 m	0.001 m	0.000 m	16.678 m

035 - 3 **Scanned Objects - Mean Distance:** 0.003 - **Mean Position** X=333623.394 Y=6248989.786 Z=8.853

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
002	Cub_blk11004	0.005 m	-0.000 m	-0.001 m	0.005 m	0.000 m	24.660 m
002	Cub_blk11005	0.003 m	-0.000 m	-0.000 m	-0.003 m	0.000 m	14.954 m
002	Cub_blk11006	0.002 m	0.000 m	0.001 m	-0.002 m	0.000 m	12.903 m

036 - 4 **Scanned Objects - Mean Distance:** 0.002 **- Mean Position** X=333609.829 Y=6249001.094 Z=8.409

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
003	Cub_blk11004	0.002 m	-0.000 m	-0.000 m	-0.002 m	0.000 m	7.622 m
003	Cub_blk11005	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	8.649 m
003	Cub_blk11006	0.003 m	-0.000 m	0.001 m	0.003 m	0.000 m	28.063 m
003	Cub_blk11007	0.002 m	0.000 m	-0.000 m	0.002 m	0.001 m	24.567 m

037 - 4 **Scanned Objects - Mean Distance:** 0.001 **- Mean Position** X=333621.961 Y=6248999.932 Z=8.760

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
004	Cub_blk11004	0.001 m	-0.000 m	0.000 m	0.001 m	0.001 m	17.299 m
004	Cub_blk11005	0.001 m	-0.000 m	-0.000 m	-0.001 m	0.000 m	15.117 m
004	Cub_blk11006	0.001 m	0.000 m	-0.001 m	0.000 m	0.000 m	16.574 m
004	Cub_blk11007	0.001 m	0.000 m	0.000 m	-0.000 m	0.000 m	14.340 m

038 - 3 **Scanned Objects - Mean Distance:** 0.001 **- Mean Position** X=333592.372 Y=6249004.222 Z=8.419

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
005	Cub_blk11004	0.001 m	0.000 m	-0.000 m	0.001 m	0.000 m	14.775 m
005	Cub_blk11005	0.001 m	-0.000 m	0.000 m	0.001 m	0.001 m	20.123 m
005	Cub_blk11003	0.001 m	0.000 m	0.000 m	-0.001 m	0.000 m	11.976 m

039 - 3 **Scanned Objects - Mean Distance:** 0.003 **- Mean Position** X=333620.332 Y=6249018.932 Z=9.711

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	Cub_blk11004	0.003 m	-0.000 m	0.001 m	-0.003 m	0.000 m	17.653 m
006	Cub_blk11005	0.005 m	-0.000 m	-0.000 m	0.005 m	0.001 m	28.704 m
006	Cub_blk11007	0.002 m	0.000 m	-0.000 m	-0.002 m	0.001 m	16.211 m

040 - 3 **Scanned Objects - Mean Distance:** 0.001 **- Mean Position** X=333592.589 Y=6248996.036 Z=8.419

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
007	Cub_blk11004	0.001 m	0.000 m	-0.000 m	0.001 m	0.001 m	18.388 m
007	Cub_blk11005	0.002 m	-0.000 m	-0.000 m	-0.002 m	0.001 m	16.601 m
007	Cub_blk11003	0.001 m	-0.000 m	0.000 m	0.001 m	0.000 m	13.698 m

041 - 4 **Scanned Objects - Mean Distance:** 0.002 **- Mean Position** X=333619.291 Y=6249011.034 Z=8.764

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	Cub_blk11004	0.002 m	0.001 m	0.000 m	-0.002 m	0.000 m	13.134 m
008	Cub_blk11005	0.003 m	0.000 m	0.000 m	0.003 m	0.000 m	21.210 m
008	Cub_blk11006	0.001 m	-0.001 m	-0.001 m	-0.001 m	0.001 m	25.871 m
008	Cub_blk11007	0.001 m	-0.000 m	0.000 m	-0.001 m	0.000 m	14.009 m

042 - 2 **Scanned Objects - Mean Distance:** 0.002 **- Mean Position** X=333684.007 Y=6249001.072 Z=9.436

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
009	Cub_blk11010	0.002 m	0.000 m	-0.000 m	-0.002 m	0.000 m	13.772 m
009	Cub_blk11011	0.002 m	-0.000 m	0.000 m	0.002 m	0.000 m	10.800 m

043 - 2 **Scanned Objects - Mean Distance:** 0.003 **- Mean Position** X=333686.855 Y=6248998.064 Z=9.442

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
010	Cub_blk11010	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	12.194 m
010	Cub_blk11011	0.003 m	-0.000 m	0.000 m	0.003 m	0.000 m	14.859 m

046 – 3 **Scanned Objects - Mean Distance:** 0.006 - **Mean Position** X=333674.288 Y=6248985.938 Z=9.441

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
013	Cub_blk11010	0.001 m	0.001 m	0.000 m	0.000 m	0.000 m	6.486 m
013	Cub_blk11011	0.007 m	0.001 m	-0.000 m	0.007 m	0.001 m	24.576 m
013	Cub_blk11009	0.008 m	-0.002 m	-0.000 m	-0.008 m	0.000 m	14.059 m

047 – 2 **Scanned Objects - Mean Distance:** 0.001 - **Mean Position** X=333679.037 Y=6249002.176 Z=9.438

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
014	Cub_blk11010	0.001 m	0.001 m	-0.000 m	-0.001 m	0.000 m	14.413 m
014	Cub_blk11011	0.001 m	-0.001 m	0.000 m	0.001 m	0.000 m	8.119 m

048 – 3 **Scanned Objects - Mean Distance:** 0.006 - **Mean Position** X=333672.498 Y=6249011.080 Z=9.341

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
015	Cub_blk11008	0.004 m	-0.001 m	0.000 m	0.004 m	0.001 m	15.409 m
015	Cub_blk11009	0.005 m	0.000 m	0.001 m	0.005 m	0.001 m	27.477 m
015	Cub_blk11011	0.009 m	0.000 m	-0.001 m	-0.009 m	0.000 m	6.077 m

049 – 3 **Scanned Objects - Mean Distance:** 0.001 - **Mean Position** X=333648.469 Y=6248989.944 Z=8.754

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
016	Cub_blk11008	0.002 m	-0.001 m	0.000 m	0.001 m	0.001 m	21.599 m
016	Cub_blk11009	0.000 m	0.000 m	0.000 m	-0.000 m	0.000 m	12.390 m
016	Cub_blk11006	0.001 m	0.001 m	-0.001 m	-0.001 m	0.000 m	12.543 m

050 - 4 Scanned Objects - Mean Distance: 0.001 - Mean Position X=333673.429 Y=6249000.908 Z=9.425

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
017	Cub_blk11008	0.000 m	0.000 m	0.000 m	-0.000 m	0.000 m	18.463 m
017	Cub_blk11009	0.002 m	-0.000 m	0.001 m	0.002 m	0.001 m	19.539 m
017	Cub_blk11010	0.002 m	-0.000 m	-0.001 m	-0.002 m	0.000 m	14.788 m
017	Cub_blk11011	0.000 m	0.000 m	-0.000 m	0.000 m	0.000 m	10.541 m

051 - 4 Scanned Objects - Mean Distance: 0.001 - Mean Position X=333662.204 Y=6249000.052 Z=8.838

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
018	Cub_blk11008	0.000 m	0.000 m	-0.000 m	0.000 m	0.000 m	10.925 m
018	Cub_blk11009	0.001 m	0.001 m	-0.001 m	0.000 m	0.000 m	13.773 m
018	Cub_blk11010	0.001 m	-0.001 m	0.000 m	0.001 m	0.000 m	21.895 m
018	Cub_blk11011	0.002 m	-0.000 m	0.001 m	-0.002 m	0.000 m	19.112 m

052 - 2 Scanned Objects - Mean Distance: 0.000 - Mean Position X=333656.232 Y=6248997.430 Z=8.838

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
019	Cub_blk11008	0.000 m	-0.000 m	0.000 m	0.000 m	0.000 m	12.340 m
019	Cub_blk11009	0.000 m	0.000 m	-0.000 m	-0.000 m	0.000 m	11.748 m

056 - 4 Scanned Objects - Mean Distance: 0.003 - Mean Position X=333645.319 Y=6249000.479 Z=8.750

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
023	Cub_blk11006	0.002 m	0.000 m	0.000 m	-0.002 m	0.000 m	12.998 m
023	Cub_blk11007	0.001 m	-0.000 m	-0.000 m	-0.001 m	0.000 m	14.962 m
023	Cub_blk11008	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	15.077 m
023	Cub_blk11009	0.005 m	-0.000 m	0.000 m	0.005 m	0.001 m	20.528 m

057 – 2 **Scanned Objects – Mean Distance:** 0.001 **– Mean Position** X=333638.883 Y=6249000.891 Z=8.816

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
024	Cub_blk11006	0.001 m	0.000 m	-0.000 m	-0.000 m	0.000 m	9.963 m
024	Cub_blk11007	0.001 m	-0.000 m	0.000 m	0.000 m	0.000 m	10.018 m

059 – 2 **Scanned Objects – Mean Distance:** 0.001 **– Mean Position** X=333623.726 Y=6248980.694 Z=10.746

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
026	Cub_blk11005	0.001 m	0.000 m	0.000 m	0.000 m	0.001 m	19.173 m
026	Cub_blk11006	0.001 m	-0.000 m	-0.000 m	-0.000 m	0.000 m	16.401 m

060 – 2 **Scanned Objects – Mean Distance:** 0.000 **– Mean Position** X=333592.316 Y=6249017.307 Z=9.622

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
027	Cub_blk11003	0.000 m	-0.000 m	-0.000 m	-0.000 m	0.001 m	18.861 m
027	Cub_blk11004	0.000 m	0.000 m	0.000 m	0.000 m	0.001 m	17.162 m

064 – 2 **Scanned Objects – Mean Distance:** 0.007 **– Mean Position** X=333673.001 Y=6248973.972 Z=11.595

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
031	Cub_blk11009	0.007 m	0.001 m	-0.001 m	-0.007 m	0.001 m	17.908 m
031	Cub_blk11010	0.007 m	-0.001 m	0.001 m	0.007 m	0.000 m	15.731 m

065 – 2 **Scanned Objects – Mean Distance:** 0.004 **– Mean Position** X=333649.103 Y=6248977.261 Z=11.032

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
032	Cub_blk11006	0.004 m	-0.001 m	0.001 m	0.004 m	0.001 m	19.242 m
032	Cub_blk11009	0.004 m	0.001 m	-0.001 m	-0.004 m	0.000 m	14.505 m

066 – 2 **Scanned Objects - Mean Distance:** 0.003 **- Mean Position** X=333653.585 Y=6249009.983 Z=8.848

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
033	Cub_blk11007	0.003 m	-0.000 m	0.000 m	0.003 m	0.001 m	20.619 m
033	Cub_blk11008	0.003 m	0.000 m	-0.000 m	-0.003 m	0.000 m	3.910 m

067 – 2 **Scanned Objects - Mean Distance:** 0.006 **- Mean Position** X=333680.319 Y=6249015.140 Z=9.407

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1C	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target114	Cub_blk11011	0.006 m	0.002 m	0.002 m	-0.005 m	0.004 m	5.575 m

068 – 2 **Scanned Objects - Mean Distance:** 0.006 **- Mean Position** X=333691.953 Y=6248999.286 Z=10.444

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1D	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target113	Cub_blk11011	0.006 m	-0.002 m	-0.003 m	0.005 m	0.001 m	17.438 m

069 – 2 **Scanned Objects - Mean Distance:** 0.005 **- Mean Position** X=333695.199 Y=6248983.694 Z=17.589

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1E	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target85	Cub_blk11010	0.005 m	-0.002 m	0.003 m	0.003 m	0.000 m	16.858 m

070 – 2 **Scanned Objects - Mean Distance:** 0.012 **- Mean Position** X=333681.272 Y=6248985.271 Z=9.406

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1F	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target84	Cub_blk11010	0.012 m	-0.003 m	0.002 m	-0.012 m	0.000 m	3.190 m

071 - 2 **Scanned Objects - Mean Distance:** 0.009 - **Mean Position** X=333682.120 Y=6248972.374 Z=18.149

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1G	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target86	Cub_blk11010	0.009 m	0.006 m	0.002 m	0.006 m	0.000 m	17.218 m

072 - 2 **Scanned Objects - Mean Distance:** 0.005 - **Mean Position** X=333629.507 Y=6248979.590 Z=16.958

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1L	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target48	Cub_blk11006	0.005 m	-0.004 m	0.002 m	-0.001 m	0.000 m	15.112 m

073 - 2 **Scanned Objects - Mean Distance:** 0.003 - **Mean Position** X=333626.669 Y=6248980.029 Z=9.069

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1M	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target49	Cub_blk11006	0.003 m	0.000 m	-0.002 m	0.000 m	0.000 m	14.859 m

074 - 2 **Scanned Objects - Mean Distance:** 0.004 - **Mean Position** X=333610.420 Y=6248982.391 Z=10.852

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1N	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target38	Cub_blk11005	0.004 m	0.001 m	-0.001 m	-0.003 m	0.000 m	10.439 m

075 - 2 **Scanned Objects - Mean Distance:** 0.004 - **Mean Position** X=333583.497 Y=6248985.929 Z=16.045

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1P	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target108	Cub_blk11003	0.004 m	-0.003 m	0.003 m	-0.002 m	0.000 m	17.893 m

076 – 2 **Scanned Objects - Mean Distance:** 0.002 - **Mean Position** X=333565.478 Y=6248988.599 Z=10.768

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1Q	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target107	Cub_blk11003	0.002 m	0.001 m	0.001 m	0.001 m	0.031 m	20.579 m

077 – 2 **Scanned Objects - Mean Distance:** 0.005 - **Mean Position** X=333562.171 Y=6249002.398 Z=10.082

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1R	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
029	Cub_blk11003	0.005 m	0.002 m	0.001 m	0.004 m	0.000 m	18.448 m

078 – 2 **Scanned Objects - Mean Distance:** 0.002 - **Mean Position** X=333571.095 Y=6249016.196 Z=10.024

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1S	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
028	Cub_blk11003	0.002 m	0.002 m	-0.001 m	0.000 m	0.002 m	16.669 m

079 – 2 **Scanned Objects - Mean Distance:** 0.003 - **Mean Position** X=333619.773 Y=6249019.171 Z=8.818

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1K	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target109	Cub_blk11007	0.003 m	0.002 m	-0.002 m	-0.002 m	0.001 m	16.853 m

080 – 2 **Scanned Objects - Mean Distance:** 0.004 - **Mean Position** X=333633.259 Y=6249019.806 Z=9.780

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1J	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target110	Cub_blk11007	0.004 m	0.001 m	-0.003 m	-0.002 m	0.001 m	10.926 m

081 - 2 **Scanned Objects - Mean Distance:** 0.009 **- Mean Position** X=333662.130 Y=6249021.991 Z=17.378

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1A	BLK11-USQ1	0.000 m	0.000 m	0.000 m	0.000 m	--	--
Target111	Cub_blk11008	0.009 m	-0.004 m	-0.005 m	0.006 m	0.001 m	15.053 m

Appendix I

Site B-The Office conventional surveying

least squares Adjustment from Elfy V2.4

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Elfy - [E:\UNI\uni class's\year 7 (2016)\project_semester 1\Field work\elfy\PYMBLE-USQ2.elf]   Version 2.4.0.39
Traverse Reductions
Date: 02/09/2016
Time: 3:53:24 PM

****

-> Refraction corrections applied for orthometric height differences
-> Coefficient of refraction of light, k = 0.13

* TRAVERSE ROUNDS FOUND * - Line (1)
======================= Observations From :   A1 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T1	323 38 25	-06	143 38 19	323 38 22.0	0 00 00.0	+00.0	+00.0	0.0
T2	340 06 51	+00	160 06 51	340 06 51.0	16 28 29.0	+00.0	+00.0	0.0
T3	123 30 40	+02	303 30 42	123 30 41.0	159 52 19.0	+00.0	+00.0	0.0
T4	166 40 00	+02	346 40 02	166 40 01.0	203 01 39.0	+00.0	+00.0	0.0
6B	152 53 45	+00	332 53 45	152 53 45.0	189 15 23.0	+00.0	+00.0	0.0
7B	75 07 18	+05	255 07 23	75 07 20.5	111 28 58.5	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T1	0 00 00.0
T2	16 28 29.0
T3	159 52 19.0
T4	203 01 39.0
6B	189 15 23.0
7B	111 28 58.5

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T1	89 15 09	+11	270 45 02	89 15 03.5	43.185	43.185	43.1813
T2	89 03 18	+09	270 56 51	89 03 13.5	42.856	42.856	42.8502
T3	87 31 12	-04	272 28 44	87 31 14.0	17.198	17.198	17.1819
T4	93 18 57	+03	266 41 06	93 18 55.5	18.411	18.412	18.3807
6B	95 05 11	-07	264 54 42	95 05 14.5	17.794	17.794	17.7239
7B	85 41 46	+01	274 18 15	85 41 45.5	8.687	8.686	8.6620

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T1	89 15 03.5	43.1850	43.1813	0.000	0.000	0.565
T2	89 03 13.5	42.8560	42.8502	0.000	0.000	0.708
T3	87 31 14.0	17.1980	17.1819	0.000	0.000	0.744
T4	93 18 55.5	18.4115	18.3807	0.000	0.000	-1.065
6B	95 05 14.5	17.7940	17.7239	0.000	0.000	-1.578
7B	85 41 45.5	8.6865	8.6620	0.000	0.000	0.652

* TRAVERSE ROUNDS FOUND * - Line (14)
======================= Observations From : A2 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T1	329 58 32	-11	149 58 21	329 58 26.5	0 00 00.0	+00.0	+00.0	0.0
T2	343 44 13	-02	163 44 11	343 44 12.0	13 45 45.5	+00.0	+00.0	0.0
T3	114 36 08	+01	294 36 09	114 36 08.5	144 37 42.0	+00.0	+00.0	0.0
T4	192 47 07	+01	12 47 08	192 47 07.5	222 48 41.0	+00.0	+00.0	0.0
6B	170 36 45	-06	350 36 39	170 36 42.0	200 38 15.5	+00.0	+00.0	0.0
7B	25 16 16	+04	205 16 20	25 16 18.0	55 17 51.5	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T1	0 00 00.0
T2	13 45 45.5
T3	144 37 42.0
T4	222 48 41.0
6B	200 38 15.5
7B	55 17 51.5

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T1	89 23 07	+07	270 37 00	89 23 03.5	51.735	51.735	51.7320
T2	89 13 02	+08	270 47 06	89 12 58.0	51.008	51.009	51.0037
T3	85 30 32	+07	274 29 35	85 30 28.5	9.385	9.386	9.3567
T4	95 25 08	-02	264 34 50	95 25 09.0	11.370	11.370	11.3192
6B	99 27 27	+02	260 32 35	99 27 26.0	9.659	9.659	9.5277
7B	86 03 24	-12	273 56 24	86 03 30.0	9.356	9.355	9.3334

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T1	89 23 03.5	51.7350	51.7320	0.000	0.000	0.556
T2	89 12 58.0	51.0085	51.0037	0.000	0.000	0.698
T3	85 30 28.5	9.3855	9.3567	0.000	0.000	0.735
T4	95 25 09.0	11.3700	11.3192	0.000	0.000	-1.074
6B	99 27 26.0	9.6590	9.5277	0.000	0.000	-1.587
7B	86 03 30.0	9.3555	9.3334	0.000	0.000	0.643

* TRAVERSE ROUNDS FOUND * - Line (27)
======================= Observations From : A3 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T1	294 15 39	+00	114 15 39	294 15 39.0	0 00 00.0	+00.0	+00.0	0.0
T2	317 23 31	+00	137 23 31	317 23 31.0	23 07 52.0	+00.0	+00.0	0.0
T3	94 51 13	-02	274 51 11	94 51 12.0	160 35 33.0	+00.0	+00.0	0.0
T4	119 37 35	-05	299 37 30	119 37 32.5	185 21 53.5	+00.0	+00.0	0.0
8B	34 23 28	+07	214 23 35	34 23 31.5	100 07 52.5	+00.0	+00.0	0.0
1B	355 55 49	+03	175 55 52	355 55 50.5	61 40 11.5	+00.0	+00.0	0.0

Sum	+00.0	+00.0

Sum	00.0

Target	Grand Means ° ' "
T1	0 00 00.0
T2	23 07 52.0
T3	160 35 33.0
T4	185 21 53.5
8B	100 07 52.5
1B	61 40 11.5

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL ° ' "	Diff "	FR ° ' "	Mean ° ' "	SDist(FL) m	SDist(FR) m	H.Dist m
T1	89 01 32	+03	270 58 31	89 01 30.5	29.943	29.943	29.9387
T2	88 48 23	+02	271 11 39	88 48 22.0	31.242	31.242	31.2352
T3	88 42 29	+01	271 17 32	88 42 28.5	30.543	30.543	30.5352
T4	92 05 39	+03	267 54 24	92 05 37.5	30.674	30.674	30.6535
8B	92 23 25	+02	267 36 37	92 23 24.0	12.754	12.753	12.7424
1B	66 31 20	+02	293 28 42	66 31 19.0	16.559	16.558	15.1877

Grand Means

Target	VA ° ' "	Slope Dist m	Horiz. Dist m	Occ. Stn Ht	Target Height	Ht Diff m
T1	89 01 30.5	29.9430	29.9387	0.000	0.000	0.510
T2	88 48 22.0	31.2420	31.2352	0.000	0.000	0.651
T3	88 42 28.5	30.5430	30.5352	0.000	0.000	0.689
T4	92 05 37.5	30.6740	30.6535	0.000	0.000	-1.121
8B	92 23 24.0	12.7535	12.7424	0.000	0.000	-0.532
1B	66 31 19.0	16.5585	15.1877	0.000	0.000	6.597

* TRAVERSE ROUNDS FOUND * - Line (40)

======================= Observations From : A4 ===========================

* DIRECTIONS *

Target	FL ° ' "	Diff "	FR ° ' "	Mean ° ' "	Reduced Mean ° ' "	v'	v	v²
T1	177 52 21	-03	357 52 18	177 52 19.5	0 00 00.0	+00.0	+00.0	0.0
T2	209 04 02	-04	29 03 58	209 04 10.0	31 11 40.5	+00.0	+00.0	0.0
T3	348 09 10	-01	168 09 09	348 09 09.5	170 16 50.0	+00.0	+00.0	0.0
T4	7 54 10	-08	187 54 02	7 54 06.0	190 01 46.5	+00.0	+00.0	0.0
8B	313 51 25	+05	133 51 30	313 51 27.5	135 59 08.0	+00.0	+00.0	0.0
1B	274 48 47	+09	94 48 56	274 48 51.5	96 56 32.0	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means ° ' "
T1	0 00 00.0
T2	31 11 40.5
T3	170 16 50.0
T4	190 01 46.5
8B	135 59 08.0

1B	96 56 32.0

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T1	88 38 21	+03	271 21 42	88 38 19.5	22.100	22.100	22.0938
T2	88 22 32	+12	271 37 40	88 22 26.0	23.501	23.501	23.4915
T3	88 55 52	+01	271 04 09	88 55 51.5	37.721	37.722	37.7149
T4	91 38 17	+01	268 21 44	91 38 16.5	38.663	38.663	38.6472
8B	91 57 55	+02	268 02 07	91 57 54.0	15.059	15.060	15.0506
1B	61 05 34	+02	298 54 28	61 05 33.0	13.679	13.679	11.9746

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T1	88 38 19.5	22.1000	22.0938	0.000	0.000	0.525
T2	88 22 26.0	23.5010	23.4915	0.000	0.000	0.667
T3	88 55 51.5	37.7215	37.7149	0.000	0.000	0.704
T4	91 38 16.5	38.6630	38.6472	0.000	0.000	-1.105
8B	91 57 54.0	15.0595	15.0506	0.000	0.000	-0.516
1B	61 05 33.0	13.6790	11.9746	0.000	0.000	6.612

* TRAVERSE ROUNDS FOUND * - Line (53)

======================= Observations From : A5 ===========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T1	174 28 02	-01	354 28 01	174 28 01.5	0 00 00.0	+00.0	+00.0	0.0
T2	217 36 41	-02	37 36 39	217 36 40.0	43 08 38.5	+00.0	+00.0	0.0
T3	350 55 52	+10	170 56 02	350 55 57.0	176 27 55.5	+00.0	+00.0	0.0
T4	7 45 32	+02	187 45 34	7 45 33.0	193 17 31.5	+00.0	+00.0	0.0
1B	304 11 29	+01	124 11 30	304 11 29.5	129 43 28.0	+00.0	+00.0	0.0
2B	234 29 00	-06	54 28 54	234 28 57.0	60 00 55.5	+00.0	+00.0	0.0
3B	199 26 35	+02	19 26 37	199 26 36.0	24 58 34.5	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T1	0 00 00.0
T2	43 08 38.5
T3	176 27 55.5
T4	193 17 31.5
1B	129 43 28.0
2B	60 00 55.5
3B	24 58 34.5

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T1	88 09 07	+03	271 50 56	88 09 05.5	15.576	15.576	15.5679
T2	87 54 05	+04	272 05 59	87 54 03.0	17.591	17.591	17.5792
T3	89 06 52	+04	270 53 12	89 06 50.0	44.068	44.068	44.0627
T4	91 25 37	+03	268 34 26	91 25 35.5	45.284	45.284	45.2700

1B	64 03 37	-02	295 56 21	64 03 38.0	15.064	15.065	13.5469
2B	82 44 38	+00	277 15 22	82 44 38.0	16.350	16.349	16.2186
3B	88 47 28	+04	271 12 36	88 47 26.0	15.597	15.598	15.5940

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T1	88 09 05.5	15.5760	15.5679	0.000	0.000	0.502
T2	87 54 03.0	17.5910	17.5792	0.000	0.000	0.644
T3	89 06 50.0	44.0680	44.0627	0.000	0.000	0.682
T4	91 25 35.5	45.2840	45.2700	0.000	0.000	-1.127
1B	64 03 38.0	15.0645	13.5469	0.000	0.000	6.590
2B	82 44 38.0	16.3495	16.2186	0.000	0.000	2.065
3B	88 47 26.0	15.5975	15.5940	0.000	0.000	0.329

* TRAVERSE ROUNDS FOUND * - Line (68)

======================= Observations From : A6 ==========================

* DIRECTIONS *

Target	FL	Diff	FR	Mean	Reduced Mean	v'	v	v²
	° ' "	"	° ' "	° ' "	° ' "			
T1	80 57 54	-10	260 57 44	80 57 49.0	0 00 00.0	+00.0	+00.0	0.0
T2	158 01 55	+04	338 01 59	158 01 57.0	77 04 08.0	+00.0	+00.0	0.0
T3	299 34 53	+05	119 34 58	299 34 55.5	218 37 06.5	+00.0	+00.0	0.0
T4	313 48 44	+02	133 48 46	313 48 45.0	232 50 56.0	+00.0	+00.0	0.0
2B	194 03 45	+00	14 03 45	194 03 45.0	113 05 56.0	+00.0	+00.0	0.0
3B	118 06 16	-02	298 06 14	118 06 15.0	37 08 26.0	+00.0	+00.0	0.0
					Sum	+00.0	+00.0	
							Sum	00.0

Target	Grand Means
	° ' "
T1	0 00 00.0
T2	77 04 08.0
T3	218 37 06.5
T4	232 50 56.0
2B	113 05 56.0
3B	37 08 26.0

* VERTICAL ANGLES AND SLOPE DISTANCES *

Target	FL	Diff	FR	Mean	SDist(FL)	SDist(FR)	H.Dist
	° ' "	"	° ' "	° ' "	m	m	m
T1	87 15 18	+04	272 44 46	87 15 16.0	11.012	11.012	10.9994
T2	85 31 27	+04	274 28 37	85 31 25.0	8.579	8.580	8.5533
T3	89 12 01	+00	270 47 59	89 12 01.0	50.622	50.622	50.6171
T4	91 11 14	+06	268 48 52	91 11 11.0	53.257	53.257	53.2456
2B	75 17 05	+03	284 42 58	75 17 03.5	8.228	8.228	7.9581
3B	87 20 25	+04	272 39 39	87 20 23.0	7.635	7.635	7.6268

Grand Means

Target	VA	Slope Dist	Horiz. Dist	Occ. Stn Ht	Target Height	Ht Diff
	° ' "	m	m			m
T1	87 15 16.0	11.0120	10.9994	0.000	0.000	0.527
T2	85 31 25.0	8.5795	8.5533	0.000	0.000	0.670

T3	89 12 01.0	50.6220	50.6171	0.000	0.000	0.707
T4	91 11 11.0	53.2570	53.2456	0.000	0.000	-1.102
2B	75 17 03.5	8.2280	7.9581	0.000	0.000	2.090
3B	87 20 23.0	7.6350	7.6268	0.000	0.000	0.354

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Elfy - [E:\UNI\uni class's\year 7 (2016)\project_semester 1\Field work\elfy\PYMBLE-USQ2.elf]   Version 2.4.0.39
2D Least Squares Adjustment
Date: 02/09/2016
Time: 3:53:59 PM

****

Generation of Approximate Starting Coordinates by Least Squares

Point ID	East (m)	North (m)
T2	512.15	2041.09
T3	505.91	1983.87
T4	492.81	1983.08
A2	500.43	1991.45
A3	497.86	2013.32
A4	499.83	2021.09
A5	500.84	2027.64
A6	506.73	2034.48
6B	497.15	1982.51
7B	508.06	1996.83
8B	510.21	2010.19
1B	511.71	2019.55
2B	514.43	2036.48
3B	506.65	2042.11

2D Parametric Least Squares Adjustment Results

There are: 30 coordinate parameters.
: 6 orientation paramenters.
: 37 directions.
: 1 azimuths.
: 37 horizontal distances.

Total number of unknowns = 36
Total number of observations = 75

Default Standard Deviations are:
: 1.5 mm for horizontal distances.
: 1.0 ppm for horizontal distances.
: 1.0 secs for Directions.
: 1.0 mm for instrument centring errors.
: 1.0 mm for target centring errors.

Iteration: 1 had a maximum coordinate shift of 0.1mm for Point A5
Iteration: 2 had a maximum coordinate shift of 0.0mm for Point 2B

GROUP VARIANCE FACTORS:

Obs Type	sum(v/s)²	Sum of Redundancies	Group VF
Directions	1.66	16.93	0.10
Azimuths	0.00	0.00	NaN
Horiz Distances	2.01	22.07	0.09

After iteration 2, Variance Factor = 0.09

Adjusted Coordinates after iteration 2

Point ID	Status	Local East (m)	Local North (m)	Std Dev's & Error Ellipses (mm) E	N	S-Maj	S-Min	Brg°
A1	FIXED	500.0000	2000.0000					

T1	500.0000	2043.1815	1.4	0.9	1.4	0.9	90
T2	512.1517	2041.0904	1.6	1.0	1.7	0.9	109
T3	505.9126	1983.8672	1.2	0.9	1.2	0.9	75
T4	492.8099	1983.0838	1.2	0.9	1.2	0.9	109
A2	500.4325	1991.4512	1.0	0.9	1.0	0.9	90
A3	497.8552	2013.3196	0.9	1.0	1.0	0.9	8
A4	499.8309	2021.0885	1.0	1.0	1.1	1.0	81
A5	500.8365	2027.6363	1.2	1.0	1.2	1.0	90
A6	506.7263	2034.4784	1.4	1.0	1.5	1.0	105
6B	497.1491	1982.5070	1.3	1.2	1.3	1.2	97
7B	508.0606	1996.8283	1.2	1.1	1.2	1.1	49
8B	510.2058	2010.1851	1.3	1.4	1.4	1.3	160
1B	511.7060	2019.5506	1.2	1.2	1.3	1.1	138
2B	514.4280	2036.4845	1.8	1.5	1.8	1.3	116
3B	506.6520	2042.1051	1.9	1.4	1.9	1.4	101

Coordinate Database has been updated with the adjusted coords.

Measurement = observed value
a-c = arc to chord correction
v = residual = correction
s = input standard deviation of observation, incl. centring and ppm where appl.
r = redundancy number for observation

Residuals after iteration 2

Type	From	To	a-c	Measurement	v	s	v/s	r
AZIMUTH	A1	T1	0.0"	0 0 0.0	0.0"	6.8"	0.0	0.00
DIRECTION	A1	T1	0.0"	0 0 0.0	0.3"	6.8"	0.0	0.42
DIRECTION	A1	T2	0.0"	16 28 29.0	-0.3"	6.9"	0.0	0.43
DIRECTION	A1	T3	0.0"	159 52 19.0	1.4"	17.0"	0.1	0.54
DIRECTION	A1	T4	0.0"	203 1 39.0	0.9"	15.9"	0.1	0.51
DIRECTION	A1	6B	0.0"	189 15 23.0	0.7"	16.5"	0.0	0.35
DIRECTION	A1	7B	0.0"	111 28 58.5	-13.6"	33.7"	-0.4	0.39
DIRECTION	A2	T1	0.0"	0 0 0.0	0.0"	5.7"	0.0	0.42
DIRECTION	A2	T2	0.0"	13 45 45.5	-0.1"	5.8"	0.0	0.43
DIRECTION	A2	T3	0.0"	144 37 42.0	-3.9"	31.2"	-0.1	0.55
DIRECTION	A2	T4	0.0"	222 48 41.0	2.8"	25.8"	0.1	0.52
DIRECTION	A2	6B	0.0"	200 38 15.5	-1.8"	30.6"	-0.1	0.35
DIRECTION	A2	7B	0.0"	55 17 51.5	4.7"	31.3"	0.2	0.40
DIRECTION	A3	T1	0.0"	0 0 0.0	0.1"	9.8"	0.0	0.48
DIRECTION	A3	T2	0.0"	23 7 52.0	0.9"	9.4"	0.1	0.50
DIRECTION	A3	T3	0.0"	160 35 33.0	-3.5"	9.6"	-0.4	0.48
DIRECTION	A3	T4	0.0"	185 21 53.5	1.5"	9.6"	0.2	0.44
DIRECTION	A3	8B	0.0"	100 7 52.5	3.1"	22.9"	0.1	0.40
DIRECTION	A3	1B	0.0"	61 40 11.5	1.7"	19.2"	0.1	0.52
DIRECTION	A4	T1	0.0"	0 0 0.0	1.4"	13.2"	0.1	0.47
DIRECTION	A4	T2	0.0"	31 11 40.5	-1.5"	12.5"	-0.1	0.50
DIRECTION	A4	T3	0.0"	170 16 50.0	5.0"	7.8"	0.6	0.48
DIRECTION	A4	T4	0.0"	190 1 46.5	-3.7"	7.6"	-0.5	0.44
DIRECTION	A4	8B	0.0"	135 59 8.0	-3.9"	19.4"	-0.2	0.40
DIRECTION	A4	1B	0.0"	96 56 32.0	-4.3"	24.4"	-0.2	0.53
DIRECTION	A5	T1	0.0"	0 0 0.0	-1.2"	18.8"	-0.1	0.55
DIRECTION	A5	T2	0.0"	43 8 38.5	1.1"	16.6"	0.1	0.58
DIRECTION	A5	T3	0.0"	176 27 55.5	-3.1"	6.7"	-0.5	0.46
DIRECTION	A5	T4	0.0"	193 17 31.5	2.6"	6.5"	0.4	0.42
DIRECTION	A5	1B	0.0"	129 43 28.0	2.1"	21.6"	0.1	0.52
DIRECTION	A5	2B	0.0"	60 0 55.5	-0.6"	18.0"	0.0	0.39
DIRECTION	A5	3B	0.0"	24 58 34.5	1.9"	18.7"	0.1	0.37
DIRECTION	A6	T1	0.0"	0 0 0.0	-3.7"	26.5"	-0.1	0.54
DIRECTION	A6	T2	0.0"	77 4 8.0	-3.3"	34.1"	-0.1	0.55

DIRECTION	A6	T3	0.0"	218 37 6.5	1.1"	5.8"	0.2	0.44
DIRECTION	A6	T4	0.0"	232 50 56.0	-0.6"	5.6"	-0.1	0.40
DIRECTION	A6	2B	0.0"	113 5 56.0	-3.8"	36.7"	-0.1	0.39
DIRECTION	A6	3B	0.0"	37 8 26.0	-1.6"	38.3"	0.0	0.37
H DISTANCE	A1	T1		43.1813	0.2mm	1.5mm	0.1	0.67
H DISTANCE	A1	T2		42.8502	-0.6mm	1.5mm	-0.4	0.68
H DISTANCE	A1	T3		17.1819	0.3mm	1.5mm	0.2	0.66
H DISTANCE	A1	T4		18.3807	0.1mm	1.5mm	0.1	0.67
H DISTANCE	A1	6B		17.7239	-0.1mm	1.5mm	-0.1	0.42
H DISTANCE	A1	7B		8.6620	0.1mm	1.5mm	0.1	0.44
H DISTANCE	A2	T1		51.7320	0.1mm	1.6mm	0.1	0.68
H DISTANCE	A2	T2		51.0037	0.2mm	1.6mm	0.1	0.68
H DISTANCE	A2	T3		9.3567	0.1mm	1.5mm	0.1	0.65
H DISTANCE	A2	T4		11.3192	-0.3mm	1.5mm	-0.2	0.65
H DISTANCE	A2	6B		9.5277	0.1mm	1.5mm	0.1	0.42
H DISTANCE	A2	7B		9.3334	-0.6mm	1.5mm	-0.4	0.43
H DISTANCE	A3	T1		29.9387	0.2mm	1.5mm	0.1	0.67
H DISTANCE	A3	T2		31.2352	-0.4mm	1.5mm	-0.3	0.67
H DISTANCE	A3	T3		30.5352	-0.6mm	1.5mm	-0.4	0.67
H DISTANCE	A3	T4		30.6535	0.3mm	1.5mm	0.2	0.67
H DISTANCE	A3	8B		12.7424	-0.3mm	1.5mm	-0.2	0.43
H DISTANCE	A3	1B		15.1877	0.1mm	1.5mm	0.1	0.57
H DISTANCE	A4	T1		22.0938	-0.2mm	1.5mm	-0.1	0.67
H DISTANCE	A4	T2		23.4915	0.6mm	1.5mm	0.4	0.67
H DISTANCE	A4	T3		37.7149	0.0mm	1.5mm	0.0	0.68
H DISTANCE	A4	T4		38.6472	0.6mm	1.5mm	0.4	0.68
H DISTANCE	A4	8B		15.0506	0.1mm	1.5mm	0.1	0.43
H DISTANCE	A4	1B		11.9746	-0.3mm	1.5mm	-0.2	0.56
H DISTANCE	A5	T1		15.5679	-0.2mm	1.5mm	-0.1	0.69
H DISTANCE	A5	T2		17.5792	0.5mm	1.5mm	0.4	0.68
H DISTANCE	A5	T3		44.0627	-0.2mm	1.5mm	-0.2	0.70
H DISTANCE	A5	T4		45.2700	-0.3mm	1.5mm	-0.2	0.69
H DISTANCE	A5	1B		13.5469	0.2mm	1.5mm	0.1	0.56
H DISTANCE	A5	2B		16.2186	-0.7mm	1.5mm	-0.5	0.42
H DISTANCE	A5	3B		15.5940	-0.2mm	1.5mm	-0.1	0.42
H DISTANCE	A6	T1		10.9994	0.0mm	1.5mm	0.0	0.65
H DISTANCE	A6	T2		8.5533	-0.3mm	1.5mm	-0.2	0.66
H DISTANCE	A6	T3		50.6171	0.6mm	1.6mm	0.4	0.68
H DISTANCE	A6	T4		53.2456	-0.3mm	1.6mm	-0.2	0.68
H DISTANCE	A6	2B		7.9581	0.7mm	1.5mm	0.4	0.41
H DISTANCE	A6	3B		7.6268	0.3mm	1.5mm	0.2	0.42

Largest Residuals

Type	Obs No.	Correction
Direction	7	-13.6"
Horizontal Distance	62	-0.7mm

****

Elfy - [E:\UNI\uni class's\year 7 (2016)\project_semester 1\Field work\elfy\PYMBLE-USQ2.elf]   Version 2.4.0.39
1D Least Squares Adjustment
Date: 02/09/2016
Time: 3:54:20 PM

****

1D Parametric Least Squares Adjustment Results

There are: 15 height parameters.
         : 37 height differences.

Total number of unknowns = 15
Total number of observations = 37

Default Standard Deviations are: 0.5 mm for height differences. (Spirit Level)
                               : 2.0 mm for height differences. (Trig. Heights)

Iteration: 1 had a maximum height shift of 26.7m for Point 1B
Iteration: 2 had a maximum height shift of 0.0mm for Point 1B

After iteration 2, Variance Factor = 0.02

Adjusted Heights after iteration 2

Point ID	Status	Height (m)	Stdev (mm)
A1	FIXED	20.0000	
T1		20.5651	1.2
T2		20.7072	1.2
T3		20.7442	1.2
T4		18.9352	1.2
A2		20.0091	1.2
A3		20.0557	1.3
A4		20.0402	1.3
A5		20.0627	1.3
A6		20.0376	1.3
6B		18.4220	1.5
7B		20.6520	1.5
8B		19.5239	1.8
1B		26.6525	1.6
2B		22.1277	1.8
3B		20.3920	1.8

Coordinate Database has been updated with the adjusted levels

Measurement = observed value
v = residual = correction
s = input standard deviation of observation, incl. centring and ppm where appl.
r = redundancy number for observation
Type = method of observation, where: 'T' denotes trignometric observation
                                     'S' denotes spirit level observation
                                     'U' denotes unknown observation - manual entry

Residuals after iteration 2

Type	From	To	Measurement	v	s	v/s	r	Type
HT DIFF	A1	T1	0.5647	0.4mm	2.0mm	0.2	0.7	T
HT DIFF	A1	T2	0.7079	-0.7mm	2.0mm	-0.4	0.7	T
HT DIFF	A1	T3	0.7440	0.2mm	2.0mm	0.1	0.7	T
HT DIFF	A1	T4	-1.0648	0.0mm	2.0mm	0.0	0.7	T
HT DIFF	A1	6B	-1.5779	-0.1mm	2.0mm	0.0	0.4	T

HT DIFF	A1	7B	0.6519	0.1mm	2.0mm	0.1	0.4	T
HT DIFF	A2	T1	0.5561	-0.1mm	2.0mm	0.0	0.7	T
HT DIFF	A2	T2	0.6980	0.1mm	2.0mm	0.1	0.7	T
HT DIFF	A2	T3	0.7351	0.1mm	2.0mm	0.0	0.7	T
HT DIFF	A2	T4	-1.0738	0.0mm	2.0mm	0.0	0.7	T
HT DIFF	A2	6B	-1.5871	0.1mm	2.0mm	0.0	0.4	T
HT DIFF	A2	7B	0.6431	-0.1mm	2.0mm	-0.1	0.4	T
HT DIFF	A3	T1	0.5095	-0.1mm	2.0mm	-0.1	0.7	T
HT DIFF	A3	T2	0.6510	0.5mm	2.0mm	0.2	0.7	T
HT DIFF	A3	T3	0.6888	-0.3mm	2.0mm	-0.1	0.7	T
HT DIFF	A3	T4	-1.1206	0.1mm	2.0mm	0.1	0.7	T
HT DIFF	A3	8B	-0.5318	-0.1mm	2.0mm	0.0	0.4	T
HT DIFF	A3	1B	6.5969	-0.1mm	2.0mm	-0.1	0.6	T
HT DIFF	A4	T1	0.5250	-0.1mm	2.0mm	-0.1	0.7	T
HT DIFF	A4	T2	0.6669	0.1mm	2.0mm	0.0	0.7	T
HT DIFF	A4	T3	0.7039	0.1mm	2.0mm	0.1	0.7	T
HT DIFF	A4	T4	-1.1050	0.0mm	2.0mm	0.0	0.7	T
HT DIFF	A4	8B	-0.5164	0.1mm	2.0mm	0.0	0.4	T
HT DIFF	A4	1B	6.6124	-0.1mm	2.0mm	-0.1	0.6	T
HT DIFF	A5	T1	0.5024	0.0mm	2.0mm	0.0	0.7	T
HT DIFF	A5	T2	0.6444	0.1mm	2.0mm	0.0	0.7	T
HT DIFF	A5	T3	0.6816	-0.1mm	2.0mm	0.0	0.7	T
HT DIFF	A5	T4	-1.1272	-0.3mm	2.0mm	-0.1	0.7	T
HT DIFF	A5	1B	6.5895	0.3mm	2.0mm	0.1	0.5	T
HT DIFF	A5	2B	2.0650	0.0mm	2.0mm	0.0	0.4	T
HT DIFF	A5	3B	0.3292	0.0mm	2.0mm	0.0	0.4	T
HT DIFF	A6	T1	0.5275	0.0mm	2.0mm	0.0	0.7	T
HT DIFF	A6	T2	0.6696	0.0mm	2.0mm	0.0	0.7	T
HT DIFF	A6	T3	0.7067	-0.1mm	2.0mm	0.0	0.7	T
HT DIFF	A6	T4	-1.1025	0.1mm	2.0mm	0.1	0.7	T
HT DIFF	A6	2B	2.0901	0.0mm	2.0mm	0.0	0.4	T
HT DIFF	A6	3B	0.3544	0.0mm	2.0mm	0.0	0.4	T

Largest Residuals

Type	Obs No.	Correction
Height Diff	15	-0.7mm

Appendix J

Site B-The Office minimally constrained report, 3 fixed points from Pix4D

Quality Report

Generated with Pro version 2.2.25

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	office-final-2
Processed	2016-09-09 13:24:51
Camera Model Name(s)	ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB)
Average Ground Sampling Distance (GSD)	0.22 cm / 0.08 in
Time for Initial Processing (without report)	11m:11s

Quality Check

Images	median of 92033 keypoints per image	✓
Dataset	56 out of 56 images calibrated (100%), all images enabled	✓
Camera Optimization	0.59% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 21128.8 matches per calibrated image	✓
Georeferencing	yes, 3 GCPs (3 3D), mean RMS error = 0 m	✓

Calibration Details

Number of Calibrated Images	56 out of 56
Number of Geolocated Images	0 out of 56

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions

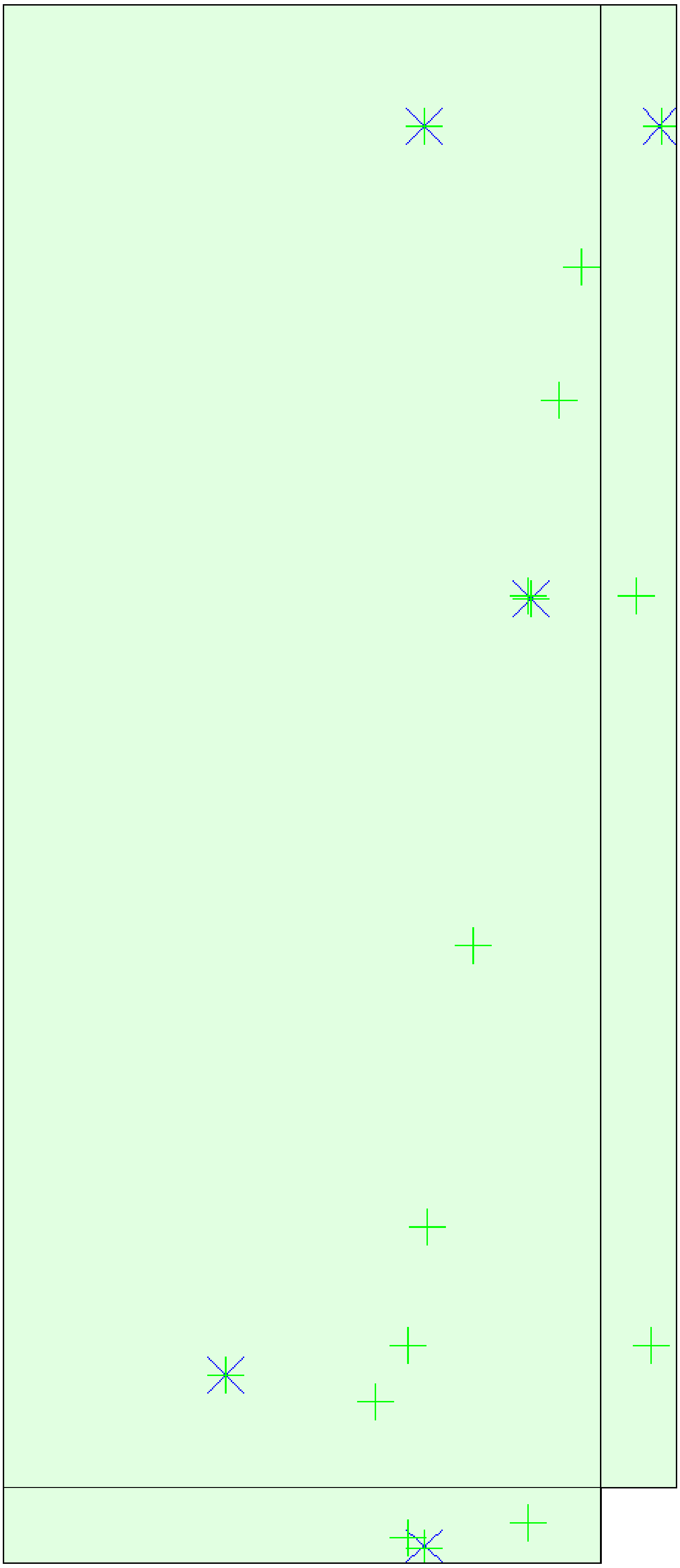


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.004	0.003	0.013	0.077	0.020	0.077
Sigma	0.001	0.000	0.006	0.048	0.007	0.062

Bundle Block Adjustment Details

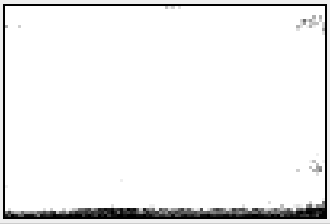
Number of 2D Keypoint Observations for Bundle Block Adjustment	1136332
Number of 3D Points for Bundle Block Adjustment	434122
Mean Reprojection Error [pixels]	0.195

Internal Camera Parameters

ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB). Sensor Dimensions: 35.000 [mm] x 23.359 [mm]

EXIF ID: ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	7360.000 [pixel] 35.000 [mm]	3680.000 [pixel] 17.500 [mm]	2456.000 [pixel] 11.679 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	7403.745 [pixel] 35.208 [mm]	3690.940 [pixel] 17.552 [mm]	2451.734 [pixel] 11.659 [mm]	0.055	-0.242	0.031	0.000	0.001
Uncertainties (Sigma)	1.212 [pixel] 0.006 [mm]	1.026 [pixel] 0.005 [mm]	1.277 [pixel] 0.006 [mm]	0.001	0.005	0.010	0.000	0.000



The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	92033	21129
Min	65544	4018
Max	97659	29153
Mean	86436	20292

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	310500
In 3 Images	62010
In 4 Images	26809
In 5 Images	14682
In 6 Images	8114
In 7 Images	4885
In 8 Images	2972
In 9 Images	1791
In 10 Images	1068
In 11 Images	664
In 12 Images	378
In 13 Images	152
In 14 Images	72
In 15 Images	22
In 16 Images	3

2D Keypoint Matches

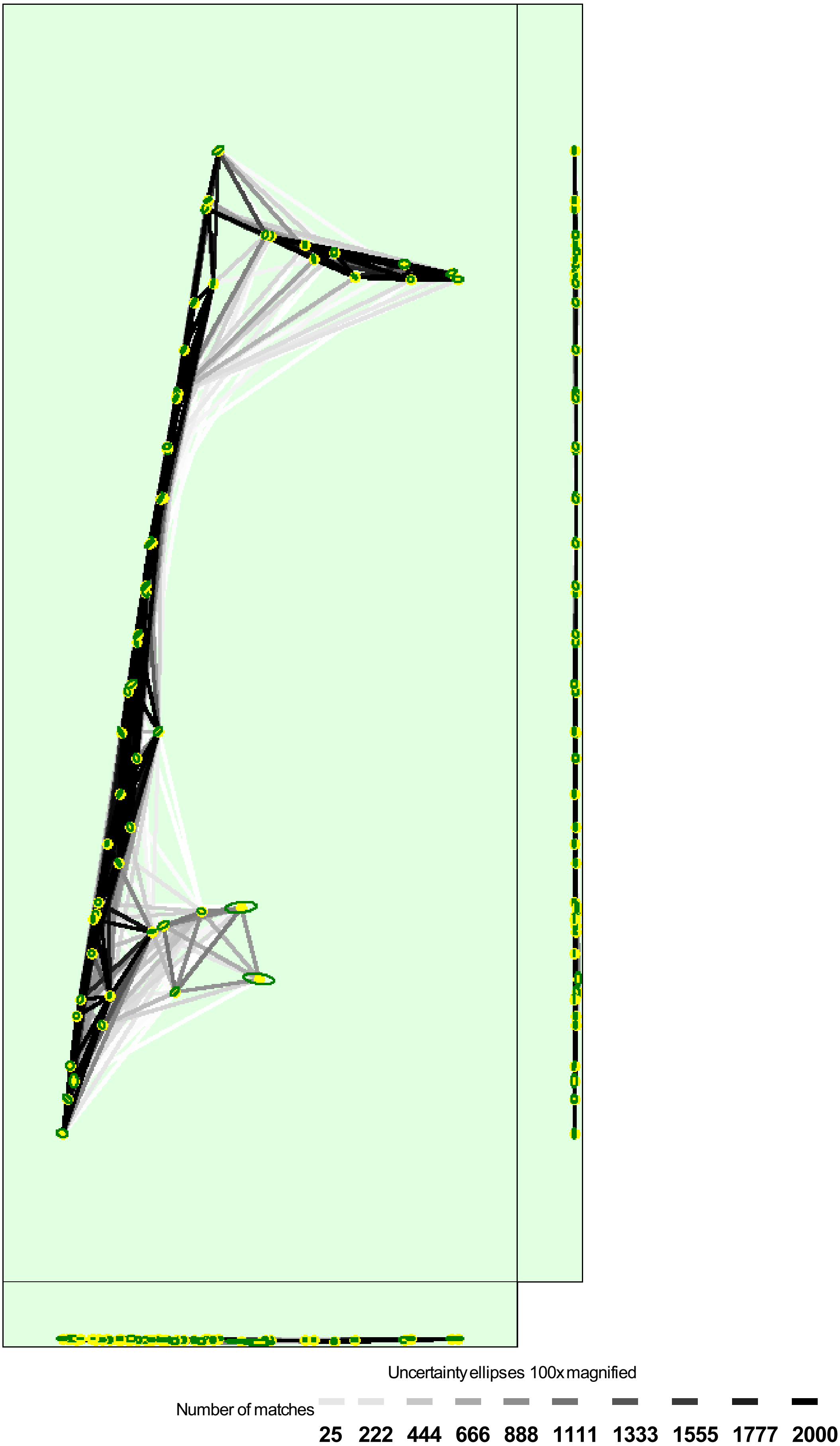


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]

Mean	0.002	0.002	0.001	0.024	0.011	0.021
Sigma	0.001	0.001	0.000	0.013	0.008	0.023

Manual Tie Points

MTP Name	Projection Error [pixel]	Verified/Marked
mtp7	0.376	12 / 12
mtp8	0.813	9 / 9
mtp9	0.283	6 / 6
mtp11	0.349	8 / 8
mtp12	0.354	10 / 10
mtp13	0.522	10 / 10
mtp14	0.315	8 / 8
mtp15	0.402	11 / 11

Projection errors for manual tie points.The last column counts the number of images where the manual tie point has been automatically verified vs. manually marked.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz RAM: 32GB GPU: NVIDIA GeForce GTX 550 Ti (Driver: 10.18.13.5382)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Ground Control Point (GCP) Coordinate System	Arbitrary (m)
Output Coordinate System	Arbitrary (m)

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Free Flight or Terrestrial
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Appendix K

Site B-The Office fully constrained
report from Pix4D

Quality Report

Generated with Pro version 2.2.25

Important: Click on the different icons for:

Help to analyze the results in the Quality Report

Additional information about the sections

Click here for additional tips to analyze the Quality Report

Summary

Project	office-final-2
Processed	2016-09-09 13:51:37
Camera Model Name(s)	ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB)
Average Ground Sampling Distance (GSD)	0.22 cm / 0.08 in
Time for Initial Processing (without report)	11m:09s

Quality Check

Images	median of 92033 keypoints per image	✓
Dataset	56 out of 56 images calibrated (100%), all images enabled	✓
Camera Optimization	0.62% relative difference between initial and optimized internal camera parameters	✓
Matching	median of 21140.4 matches per calibrated image	✓
Georeferencing	yes, 6 GCPs (6 3D), mean RMS error = 0 m	✓

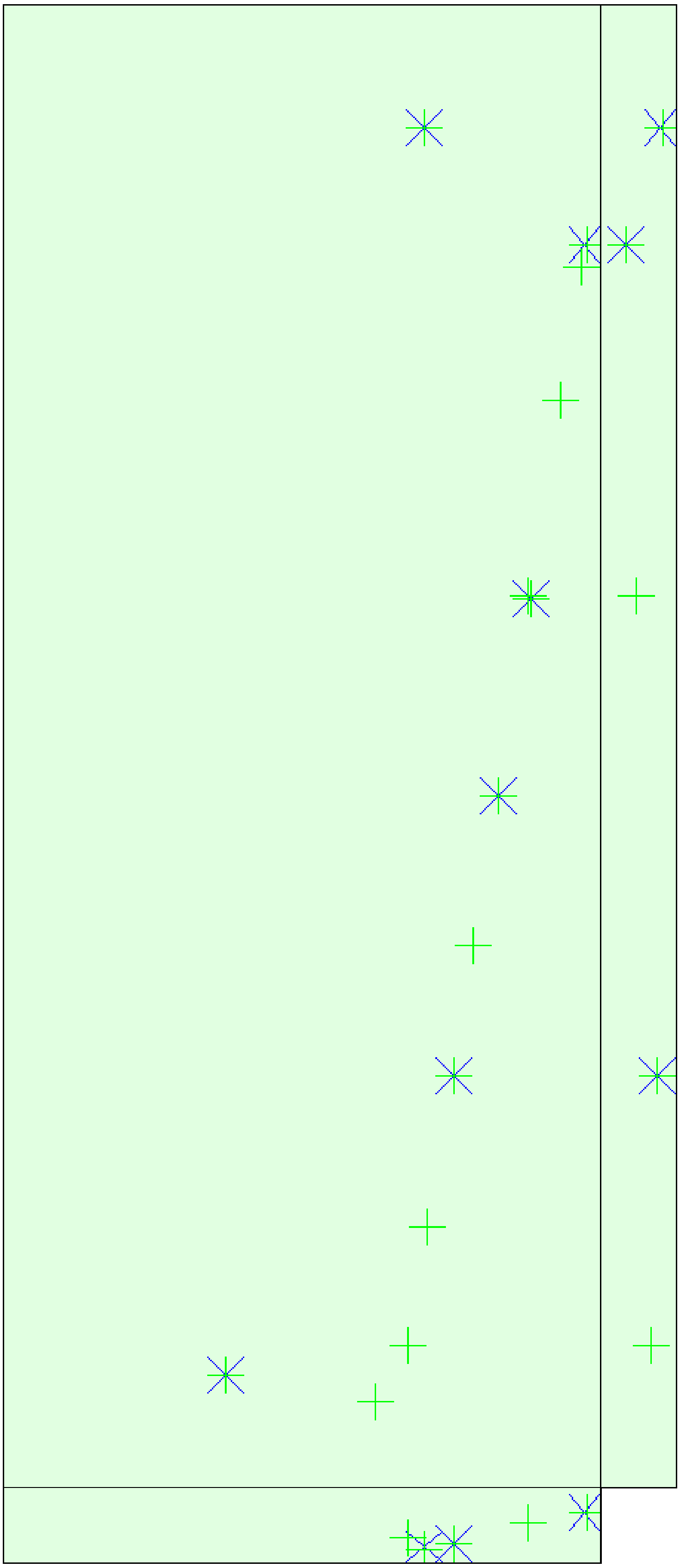
Calibration Details

Number of Calibrated Images	56 out of 56
Number of Geolocated Images	0 out of 56

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions



Uncertainty ellipses 100x magnified

Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses indicate the absolute position uncertainty of the bundle block adjustment result.

Absolute camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.002	0.002	0.002	0.025	0.010	0.021
Sigma	0.001	0.001	0.000	0.013	0.006	0.022

Bundle Block Adjustment Details

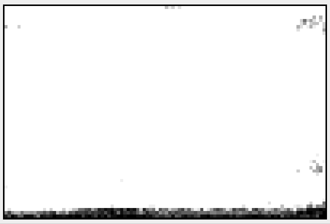
Number of 2D Keypoint Observations for Bundle Block Adjustment	1135445
Number of 3D Points for Bundle Block Adjustment	433678
Mean Reprojection Error [pixels]	0.195

Internal Camera Parameters

ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912 (RGB). Sensor Dimensions: 35.000 [mm] x 23.359 [mm]

EXIF ID: ILCE-7R_FE35mmF2.8ZA_35.0_7360x4912

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	7360.000 [pixel] 35.000 [mm]	3680.000 [pixel] 17.500 [mm]	2456.000 [pixel] 11.679 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	7405.931 [pixel] 35.218 [mm]	3691.814 [pixel] 17.556 [mm]	2439.004 [pixel] 11.599 [mm]	0.055	-0.242	0.031	-0.000	0.001
Uncertainties (Sigma)	0.889 [pixel] 0.004 [mm]	0.919 [pixel] 0.004 [mm]	0.921 [pixel] 0.004 [mm]	0.001	0.005	0.010	0.000	0.000



The number of Automatic Tie Points (ATPs) per pixel averaged over all images of the camera model is color coded between black and white. White indicates that, in average, more than 16 ATPs are extracted at this pixel location. Black indicates that, in average, 0 ATP has been extracted at this pixel location. Click on the image to the see the average direction and magnitude of the reprojection error for each pixel. Note that the vectors are scaled for better visualization.

2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	92033	21140
Min	65544	4018
Max	97659	29150
Mean	86436	20276

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed
In 2 Images	310049
In 3 Images	62020
In 4 Images	26808
In 5 Images	14679
In 6 Images	8117
In 7 Images	4884
In 8 Images	2971
In 9 Images	1791
In 10 Images	1067
In 11 Images	665
In 12 Images	378
In 13 Images	152
In 14 Images	72
In 15 Images	22
In 16 Images	3

2D Keypoint Matches

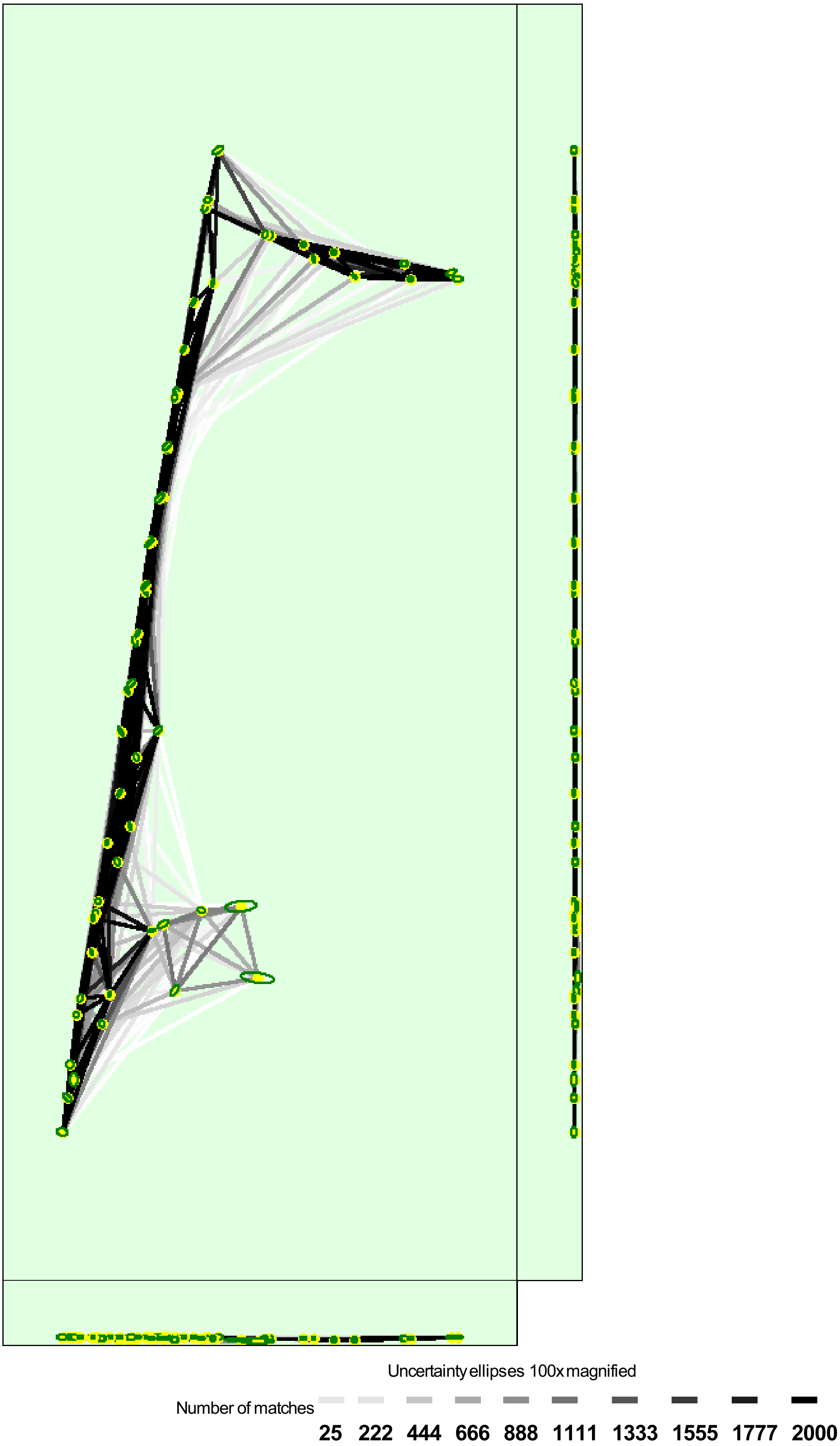


Figure 5: Computed image positions with links between matched images. The darkness of the links indicates the number of matched 2D keypoints between the images. Bright links indicate weak links and require manual tie points or more images. Dark green ellipses indicate the relative camera position uncertainty of the bundle block adjustment result.

Relative camera position and orientation uncertainties

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]

Mean	0.002	0.002	0.001	0.024	0.011	0.021
Sigma	0.001	0.001	0.000	0.013	0.008	0.023

Manual Tie Points

MTP Name	Projection Error [pixel]	Verified/Marked
mtp7	0.370	12 / 12
mtp8	0.834	9 / 9
mtp9	0.258	6 / 6
mtp11	0.341	8 / 8
mtp12	0.380	10 / 10
mtp13	0.522	10 / 10
mtp14	0.372	8 / 8
mtp15	0.441	11 / 11

Projection errors for manual tie points.The last column counts the number of images where the manual tie point has been automatically verified vs. manually marked.

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-3770 CPU @ 3.40GHz RAM: 32GB GPU: NVIDIA GeForce GTX 550 Ti (Driver: 10.18.13.5382)
Operating System	Windows 10 Home, 64-bit

Coordinate Systems

Ground Control Point (GCP) Coordinate System	Arbitrary (m)
Output Coordinate System	Arbitrary (m)

Processing Options

Detected Template	No Template Available
Keypoints Image Scale	Full, Image Scale: 1
Advanced: Matching Image Pairs	Free Flight or Terrestrial
Advanced: Matching Strategy	Use Geometrically Verified Matching: no
Advanced: Keypoint Extraction	Targeted Number of Keypoints: Automatic
Advanced: Calibration	Calibration Method: Standard Internal Parameters Optimization: All External Parameters Optimization: All Rematch: Auto, yes

Appendix L

Site B-The Office minimally constrained report,

3 fixed points from Trimble Realworks

Registration Report (Target-Based)
Report by station

User Name: lbroome

Date: Tue Jul 05 18:58:55 2016
Project Name: pmble-2

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

---

5 STATION(S) - Mean Distance: 0.0023 **Max Distance:** 0.0043
13 TARGET(S) - Mean Distance: 0.0032 **Max Distance:** 0.0048

Pymbl_Scan_000 - 7 **Scanned Objects - Mean Distance:** 0.0011

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	017	3	0.0005 m	-0.0002 m	-0.0000 m	0.0005 m	0.0002 m	11.4970 m
001	012	3	0.0004 m	-0.0002 m	-0.0003 m	0.0002 m	0.0001 m	11.8901 m
005	016	3	0.0011 m	-0.0001 m	-0.0001 m	0.0011 m	0.0002 m	10.8905 m
007	018	4	0.0014 m	0.0004 m	0.0003 m	-0.0013 m	0.0005 m	19.7875 m
Target5	--	--	--	--	--	--	0.0003 m	5.8399 m
Target6	--	--	--	--	--	--	0.0004 m	12.7020 m
Target7	024	2	0.0023 m	0.0001 m	-0.0023 m	0.0003 m	0.0004 m	12.1207 m

Pymbl_Scan_002 - 10 **Scanned Objects - Mean Distance:** 0.0043

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
007	018	4	0.0056 m	-0.0005 m	0.0013 m	-0.0055 m	0.0001 m	8.2188 m
001	012	3	0.0042 m	0.0002 m	0.0005 m	-0.0042 m	0.0001 m	9.7991 m
004	015	3	0.0009 m	0.0003 m	-0.0008 m	0.0002 m	0.0002 m	10.1559 m
006	017	3	0.0040 m	-0.0001 m	-0.0004 m	-0.0040 m	0.0001 m	9.1408 m
005	016	3	0.0041 m	-0.0001 m	-0.0002 m	-0.0041 m	0.0001 m	6.1597 m
003	014	3	0.0034 m	-0.0008 m	-0.0001 m	0.0033 m	0.0002 m	14.2087 m
009	020	3	0.0046 m	0.0000 m	-0.0001 m	0.0046 m	0.0002 m	15.0756 m
002	013	3	0.0042 m	0.0005 m	-0.0004 m	0.0042 m	0.0003 m	15.3472 m
008	019	3	0.0073 m	0.0006 m	-0.0002 m	0.0072 m	0.0002 m	20.8934 m
Target17	--	--	--	--	--	--	0.0004 m	8.8092 m

Pymbl_Scan_003 - 13 **Scanned Objects - Mean Distance:** 0.0032

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	012	3	0.0041 m	0.0000 m	-0.0002 m	0.0040 m	0.0004 m	25.8356 m
002	013	3	0.0025 m	-0.0002 m	0.0002 m	-0.0025 m	0.0001 m	7.9292 m
003	014	3	0.0049 m	0.0007 m	0.0001 m	-0.0048 m	0.0001 m	6.3883 m
004	015	3	0.0016 m	0.0005 m	0.0007 m	-0.0013 m	0.0001 m	11.9989 m
005	016	3	0.0030 m	0.0002 m	0.0003 m	0.0030 m	0.0005 m	20.9443 m
006	017	3	0.0035 m	0.0003 m	0.0004 m	0.0035 m	0.0006 m	21.5927 m
007	018	4	0.0013 m	-0.0006 m	-0.0007 m	0.0009 m	0.0005 m	19.3303 m
010	021	2	0.0034 m	-0.0008 m	0.0001 m	0.0033 m	0.0002 m	14.0177 m
008	019	3	0.0032 m	-0.0003 m	-0.0000 m	-0.0032 m	0.0001 m	7.6024 m
009	020	3	0.0045 m	0.0001 m	-0.0001 m	-0.0045 m	0.0002 m	2.2750 m
Target28	--	--	--	--	--	--	0.0003 m	6.1692 m
011	022	3	0.0025 m	0.0019 m	-0.0007 m	0.0016 m	0.0003 m	17.4414 m
Target46	023	2	0.0041 m	-0.0020 m	0.0030 m	-0.0019 m	0.0011 m	14.0217 m

Pymbl_Scan_004 - 11 **Scanned Objects - Mean Distance:** 0.0030

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	019	3	0.0040 m	-0.0003 m	0.0003 m	-0.0040 m	0.0001 m	10.2800 m
004	015	3	0.0014 m	-0.0008 m	0.0001 m	0.0011 m	0.0007 m	22.6895 m
003	014	3	0.0015 m	0.0001 m	-0.0001 m	0.0015 m	0.0007 m	19.0600 m
010	021	2	0.0034 m	0.0008 m	-0.0001 m	-0.0033 m	0.0002 m	3.2213 m
002	013	3	0.0018 m	-0.0004 m	0.0002 m	-0.0017 m	0.0007 m	16.3772 m
009	020	3	0.0003 m	-0.0001 m	0.0002 m	-0.0001 m	0.0004 m	15.4218 m
007	018	4	0.0060 m	0.0007 m	-0.0008 m	0.0059 m	0.0007 m	30.7065 m
011	022	3	0.0057 m	0.0018 m	0.0004 m	-0.0054 m	0.0002 m	3.8259 m
Target38	--	--	--	--	--	--	0.0019 m	9.9498 m
Target39	--	--	--	--	--	--	0.0002 m	3.7406 m
Target40	--	--	--	--	--	--	0.0022 m	16.6041 m

pymble-usq2 - 6 **Scanned Objects - Mean Distance:** 0.0000

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
6B	024	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
7B	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
8B	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1B	023	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
2B	--	--	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
3B	022	3	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--

Report by target

User Name: lbroome

Date: Tue Jul 05 18:58:55 2016
Project Name: pmble-2

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

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5 STATION(S) - Mean Distance: 0.0023 **Max Distance:** 0.0043
13 TARGET(S) - Mean Distance: 0.0032 **Max Distance:** 0.0048

012 - 3 **Scanned Objects - Mean Distance:** 0.0029 - **Mean Position** X=505.8909 Y=2000.2852 Z=18.8762

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	Pymbl_Scan_002	0.0042 m	0.0002 m	0.0005 m	-0.0042 m	0.0001 m	9.7991 m
001	Pymbl_Scan_003	0.0041 m	0.0000 m	-0.0002 m	0.0040 m	0.0004 m	25.8356 m
001	Pymbl_Scan_000	0.0004 m	-0.0002 m	-0.0003 m	0.0002 m	0.0001 m	11.8901 m

013 - 3 **Scanned Objects - Mean Distance:** 0.0028 - **Mean Position** X=508.1789 Y=2022.7119 Z=18.4554

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
002	Pymbl_Scan_002	0.0042 m	0.0005 m	-0.0004 m	0.0042 m	0.0003 m	15.3472 m
002	Pymbl_Scan_003	0.0025 m	-0.0002 m	0.0002 m	-0.0025 m	0.0001 m	7.9292 m
002	Pymbl_Scan_004	0.0018 m	-0.0004 m	0.0002 m	-0.0017 m	0.0007 m	16.3772 m

014 - 3 **Scanned Objects - Mean Distance:** 0.0032 **- Mean Position** X=495.9276 Y=2021.9784 Z=18.5139

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
003	Pymbl_Scan_002	0.0034 m	-0.0008 m	-0.0001 m	0.0033 m	0.0002 m	14.2087 m
003	Pymbl_Scan_003	0.0049 m	0.0007 m	0.0001 m	-0.0048 m	0.0001 m	6.3883 m
003	Pymbl_Scan_004	0.0015 m	0.0001 m	-0.0001 m	0.0015 m	0.0007 m	19.0600 m

015 - 3 **Scanned Objects - Mean Distance:** 0.0013 **- Mean Position** X=508.4294 Y=2016.3048 Z=18.7915

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
004	Pymbl_Scan_002	0.0009 m	0.0003 m	-0.0008 m	0.0002 m	0.0002 m	10.1559 m
004	Pymbl_Scan_003	0.0016 m	0.0005 m	0.0007 m	-0.0013 m	0.0001 m	11.9989 m
004	Pymbl_Scan_004	0.0014 m	-0.0008 m	0.0001 m	0.0011 m	0.0007 m	22.6895 m

016 - 3 **Scanned Objects - Mean Distance:** 0.0028 **- Mean Position** X=496.8977 Y=2005.1319 Z=18.4683

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
005	Pymbl_Scan_002	0.0041 m	-0.0001 m	-0.0002 m	-0.0041 m	0.0001 m	6.1597 m
005	Pymbl_Scan_003	0.0030 m	0.0002 m	0.0003 m	0.0030 m	0.0005 m	20.9443 m
005	Pymbl_Scan_000	0.0011 m	-0.0001 m	-0.0001 m	0.0011 m	0.0002 m	10.8905 m

017 - 3 **Scanned Objects - Mean Distance:** 0.0027 **- Mean Position** X=493.1291 Y=2005.5546 Z=18.5055

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	Pymbl_Scan_002	0.0040 m	-0.0001 m	-0.0004 m	-0.0040 m	0.0001 m	9.1408 m
006	Pymbl_Scan_003	0.0035 m	0.0003 m	0.0004 m	0.0035 m	0.0006 m	21.5927 m
006	Pymbl_Scan_000	0.0005 m	-0.0002 m	-0.0000 m	0.0005 m	0.0002 m	11.4970 m

018 - 4 **Scanned Objects - Mean Distance:** 0.0036 **- Mean Position** X=509.5608 Y=2008.3729 Z=18.5030

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
007	Pymbl_Scan_002	0.0056 m	-0.0005 m	0.0013 m	-0.0055 m	0.0001 m	8.2188 m
007	Pymbl_Scan_003	0.0013 m	-0.0006 m	-0.0007 m	0.0009 m	0.0005 m	19.3303 m
007	Pymbl_Scan_004	0.0060 m	0.0007 m	-0.0008 m	0.0059 m	0.0007 m	30.7065 m
007	Pymbl_Scan_000	0.0014 m	0.0004 m	0.0003 m	-0.0013 m	0.0005 m	19.7875 m

019 - 3 **Scanned Objects - Mean Distance:** 0.0048 **- Mean Position** X=507.6823 Y=2028.8862 Z=18.5715

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	Pymbl_Scan_002	0.0073 m	0.0006 m	-0.0002 m	0.0072 m	0.0002 m	20.8934 m
008	Pymbl_Scan_003	0.0032 m	-0.0003 m	-0.0000 m	-0.0032 m	0.0001 m	7.6024 m
008	Pymbl_Scan_004	0.0040 m	-0.0003 m	0.0003 m	-0.0040 m	0.0001 m	10.2800 m

020 - 3 **Scanned Objects - Mean Distance:** 0.0032 **- Mean Position** X=500.6751 Y=2023.9615 Z=18.4620

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
009	Pymbl_Scan_002	0.0046 m	0.0000 m	-0.0001 m	0.0046 m	0.0002 m	15.0756 m
009	Pymbl_Scan_003	0.0045 m	0.0001 m	-0.0001 m	-0.0045 m	0.0002 m	2.2750 m
009	Pymbl_Scan_004	0.0003 m	-0.0001 m	0.0002 m	-0.0001 m	0.0004 m	15.4218 m

021 - 2 **Scanned Objects - Mean Distance:** 0.0034 **- Mean Position** X=502.2205 Y=2039.5070 Z=18.5230

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
010	Pymbl_Scan_003	0.0034 m	-0.0008 m	0.0001 m	0.0033 m	0.0002 m	14.0177 m
010	Pymbl_Scan_004	0.0034 m	0.0008 m	-0.0001 m	-0.0033 m	0.0002 m	3.2213 m

022 - 3 **Scanned Objects - Mean Distance:** 0.0041 **- Mean Position** X=506.6520 Y=2042.1050 Z=20.3920

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
011	Pymbl_Scan_003	0.0025 m	0.0019 m	-0.0007 m	0.0016 m	0.0003 m	17.4414 m
011	Pymbl_Scan_004	0.0057 m	0.0018 m	0.0004 m	-0.0054 m	0.0002 m	3.8259 m
3B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--

023 - 2 **Scanned Objects - Mean Distance:** 0.0041 **- Mean Position** X=511.7059 Y=2019.5504 Z=26.6524

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target46	Pymbl_Scan_003	0.0041 m	-0.0020 m	0.0030 m	-0.0019 m	0.0011 m	14.0217 m

024 - 2 **Scanned Objects - Mean Distance:** 0.0023 **- Mean Position** X=497.1489 Y=1982.5069 Z=18.4220

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
6B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target7	Pymbl_Scan_000	0.0023 m	0.0001 m	-0.0023 m	0.0003 m	0.0004 m	12.1207 m

Appendix M

Site B-The Office fully constrained report from Trimble Realworks

Registration Report (Target-Based)
Report by station

User Name: lbroome

Date: Tue Jul 05 19:15:01 2016
Project Name: pmble-2

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

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5 STATION(S) - Mean Distance: 0.0023 **Max Distance:** 0.0040
16 TARGET(S) - Mean Distance: 0.0029 **Max Distance:** 0.0048

Pymbl_Scan_000 - 7 **Scanned Objects - Mean Distance:** 0.0014

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	017	3	0.0005 m	-0.0002 m	-0.0000 m	0.0005 m	0.0002 m	11.4970 m
001	012	3	0.0004 m	-0.0002 m	-0.0003 m	0.0002 m	0.0001 m	11.8901 m
005	016	3	0.0011 m	-0.0001 m	-0.0001 m	0.0011 m	0.0002 m	10.8905 m
007	018	4	0.0014 m	0.0004 m	0.0003 m	-0.0013 m	0.0005 m	19.7875 m
Target5	--	--	--	--	--	--	0.0003 m	5.8399 m
Target6	024	2	0.0023 m	-0.0005 m	-0.0017 m	-0.0015 m	0.0004 m	12.7020 m
Target7	023	2	0.0026 m	0.0009 m	-0.0023 m	0.0006 m	0.0004 m	12.1207 m

Pymbl_Scan_002 - 10 Scanned Objects - Mean Distance: 0.0040

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
007	018	4	0.0056 m	-0.0005 m	0.0013 m	-0.0055 m	0.0001 m	8.2188 m
001	012	3	0.0042 m	0.0002 m	0.0005 m	-0.0042 m	0.0001 m	9.7991 m
004	015	3	0.0009 m	0.0003 m	-0.0008 m	0.0002 m	0.0002 m	10.1559 m
006	017	3	0.0040 m	-0.0001 m	-0.0004 m	-0.0040 m	0.0001 m	9.1408 m
005	016	3	0.0041 m	-0.0001 m	-0.0002 m	-0.0041 m	0.0001 m	6.1597 m
003	014	3	0.0034 m	-0.0008 m	-0.0001 m	0.0033 m	0.0002 m	14.2087 m
009	020	3	0.0046 m	0.0000 m	-0.0001 m	0.0046 m	0.0002 m	15.0756 m
002	013	3	0.0042 m	0.0005 m	-0.0004 m	0.0042 m	0.0003 m	15.3472 m
008	019	3	0.0073 m	0.0006 m	-0.0002 m	0.0072 m	0.0002 m	20.8934 m
Target17	025	2	0.0014 m	-0.0011 m	-0.0002 m	0.0008 m	0.0004 m	8.8092 m

Pymbl_Scan_003 - 13 Scanned Objects - Mean Distance: 0.0032

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	012	3	0.0041 m	0.0000 m	-0.0002 m	0.0040 m	0.0004 m	25.8356 m
002	013	3	0.0025 m	-0.0002 m	0.0002 m	-0.0025 m	0.0001 m	7.9292 m
003	014	3	0.0049 m	0.0007 m	0.0001 m	-0.0048 m	0.0001 m	6.3883 m
004	015	3	0.0016 m	0.0005 m	0.0007 m	-0.0013 m	0.0001 m	11.9989 m
005	016	3	0.0030 m	0.0002 m	0.0003 m	0.0030 m	0.0005 m	20.9443 m
006	017	3	0.0035 m	0.0003 m	0.0004 m	0.0035 m	0.0006 m	21.5927 m
007	018	4	0.0013 m	-0.0006 m	-0.0007 m	0.0009 m	0.0005 m	19.3303 m
010	021	2	0.0034 m	-0.0008 m	0.0001 m	0.0033 m	0.0002 m	14.0177 m
008	019	3	0.0032 m	-0.0003 m	-0.0000 m	-0.0032 m	0.0001 m	7.6024 m
009	020	3	0.0045 m	0.0001 m	-0.0001 m	-0.0045 m	0.0002 m	2.2750 m
Target28	--	--	--	--	--	--	0.0003 m	6.1692 m
011	022	3	0.0027 m	0.0022 m	-0.0006 m	0.0014 m	0.0003 m	17.4414 m
Target46	026	2	0.0040 m	-0.0022 m	0.0033 m	-0.0010 m	0.0011 m	14.0217 m

Pymbl_Scan_004 - 11 **Scanned Objects - Mean Distance:** 0.0029

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	019	3	0.0040 m	-0.0003 m	0.0003 m	-0.0040 m	0.0001 m	10.2800 m
004	015	3	0.0014 m	-0.0008 m	0.0001 m	0.0011 m	0.0007 m	22.6895 m
003	014	3	0.0015 m	0.0001 m	-0.0001 m	0.0015 m	0.0007 m	19.0600 m
010	021	2	0.0034 m	0.0008 m	-0.0001 m	-0.0033 m	0.0002 m	3.2213 m
002	013	3	0.0018 m	-0.0004 m	0.0002 m	-0.0017 m	0.0007 m	16.3772 m
009	020	3	0.0003 m	-0.0001 m	0.0002 m	-0.0001 m	0.0004 m	15.4218 m
007	018	4	0.0060 m	0.0007 m	-0.0008 m	0.0059 m	0.0007 m	30.7065 m
011	022	3	0.0060 m	0.0021 m	0.0005 m	-0.0056 m	0.0002 m	3.8259 m
Target38	027	2	0.0018 m	0.0006 m	0.0016 m	-0.0004 m	0.0019 m	9.9498 m
Target39	--	--	--	--	--	--	0.0002 m	3.7406 m
Target40	--	--	--	--	--	--	0.0022 m	16.6041 m

pymble-usq2 - 6 **Scanned Objects - Mean Distance:** 0.0000

Object Name	Corresponding Target	Scan Per Target	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
6B	023	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
7B	024	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
8B	025	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
1B	026	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
2B	027	2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
3B	022	3	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--

Report by target

User Name: lbroome

Date: Tue Jul 05 19:15:01 2016
Project Name: pmble-2

Linear Measurement Units: Meters
Coordinates System: X, Y, Z

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5 STATION(S) - Mean Distance: 0.0023 **Max Distance:** 0.0040
16 TARGET(S) - Mean Distance: 0.0029 **Max Distance:** 0.0048

012 - 3 **Scanned Objects - Mean Distance:** 0.0029 - **Mean Position** X=505.8916 Y=2000.2852 Z=18.8769

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
001	Pymbl_Scan_002	0.0042 m	0.0002 m	0.0005 m	-0.0042 m	0.0001 m	9.7991 m
001	Pymbl_Scan_003	0.0041 m	0.0000 m	-0.0002 m	0.0040 m	0.0004 m	25.8356 m
001	Pymbl_Scan_000	0.0004 m	-0.0002 m	-0.0003 m	0.0002 m	0.0001 m	11.8901 m

013 - 3 **Scanned Objects - Mean Distance:** 0.0028 - **Mean Position** X=508.1795 Y=2022.7120 Z=18.4558

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
002	Pymbl_Scan_002	0.0042 m	0.0005 m	-0.0004 m	0.0042 m	0.0003 m	15.3472 m
002	Pymbl_Scan_003	0.0025 m	-0.0002 m	0.0002 m	-0.0025 m	0.0001 m	7.9292 m
002	Pymbl_Scan_004	0.0018 m	-0.0004 m	0.0002 m	-0.0017 m	0.0007 m	16.3772 m

014 – 3 **Scanned Objects - Mean Distance:** 0.0032 **- Mean Position** X=495.9283 Y=2021.9784 Z=18.5131

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
003	Pymbl_Scan_002	0.0034 m	-0.0008 m	-0.0001 m	0.0033 m	0.0002 m	14.2087 m
003	Pymbl_Scan_003	0.0049 m	0.0007 m	0.0001 m	-0.0048 m	0.0001 m	6.3883 m
003	Pymbl_Scan_004	0.0015 m	0.0001 m	-0.0001 m	0.0015 m	0.0007 m	19.0600 m

015 – 3 **Scanned Objects - Mean Distance:** 0.0013 **- Mean Position** X=508.4300 Y=2016.3048 Z=18.7921

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
004	Pymbl_Scan_002	0.0009 m	0.0003 m	-0.0008 m	0.0002 m	0.0002 m	10.1559 m
004	Pymbl_Scan_003	0.0016 m	0.0005 m	0.0007 m	-0.0013 m	0.0001 m	11.9989 m
004	Pymbl_Scan_004	0.0014 m	-0.0008 m	0.0001 m	0.0011 m	0.0007 m	22.6895 m

016 – 3 **Scanned Objects - Mean Distance:** 0.0028 **- Mean Position** X=496.8984 Y=2005.1319 Z=18.4681

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
005	Pymbl_Scan_002	0.0041 m	-0.0001 m	-0.0002 m	-0.0041 m	0.0001 m	6.1597 m
005	Pymbl_Scan_003	0.0030 m	0.0002 m	0.0003 m	0.0030 m	0.0005 m	20.9443 m
005	Pymbl_Scan_000	0.0011 m	-0.0001 m	-0.0001 m	0.0011 m	0.0002 m	10.8905 m

017 – 3 **Scanned Objects - Mean Distance:** 0.0027 **- Mean Position** X=493.1298 Y=2005.5546 Z=18.5049

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
006	Pymbl_Scan_002	0.0040 m	-0.0001 m	-0.0004 m	-0.0040 m	0.0001 m	9.1408 m
006	Pymbl_Scan_003	0.0035 m	0.0003 m	0.0004 m	0.0035 m	0.0006 m	21.5927 m
006	Pymbl_Scan_000	0.0005 m	-0.0002 m	-0.0000 m	0.0005 m	0.0002 m	11.4970 m

018 - 4 **Scanned Objects - Mean Distance:** 0.0036 **- Mean Position** X=509.5615 Y=2008.3729 Z=18.5040

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
007	Pymbl_Scan_002	0.0056 m	-0.0005 m	0.0013 m	-0.0055 m	0.0001 m	8.2188 m
007	Pymbl_Scan_003	0.0013 m	-0.0006 m	-0.0007 m	0.0009 m	0.0005 m	19.3303 m
007	Pymbl_Scan_004	0.0060 m	0.0007 m	-0.0008 m	0.0059 m	0.0007 m	30.7065 m
007	Pymbl_Scan_000	0.0014 m	0.0004 m	0.0003 m	-0.0013 m	0.0005 m	19.7875 m

019 - 3 **Scanned Objects - Mean Distance:** 0.0048 **- Mean Position** X=507.6829 Y=2028.8863 Z=18.5718

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
008	Pymbl_Scan_002	0.0073 m	0.0006 m	-0.0002 m	0.0072 m	0.0002 m	20.8934 m
008	Pymbl_Scan_003	0.0032 m	-0.0003 m	-0.0000 m	-0.0032 m	0.0001 m	7.6024 m
008	Pymbl_Scan_004	0.0040 m	-0.0003 m	0.0003 m	-0.0040 m	0.0001 m	10.2800 m

020 - 3 **Scanned Objects - Mean Distance:** 0.0032 **- Mean Position** X=500.6758 Y=2023.9615 Z=18.4617

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
009	Pymbl_Scan_002	0.0046 m	0.0000 m	-0.0001 m	0.0046 m	0.0002 m	15.0756 m
009	Pymbl_Scan_003	0.0045 m	0.0001 m	-0.0001 m	-0.0045 m	0.0002 m	2.2750 m
009	Pymbl_Scan_004	0.0003 m	-0.0001 m	0.0002 m	-0.0001 m	0.0004 m	15.4218 m

021 - 2 **Scanned Objects - Mean Distance:** 0.0034 **- Mean Position** X=502.2211 Y=2039.5070 Z=18.5224

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
010	Pymbl_Scan_003	0.0034 m	-0.0008 m	0.0001 m	0.0033 m	0.0002 m	14.0177 m
010	Pymbl_Scan_004	0.0034 m	0.0008 m	-0.0001 m	-0.0033 m	0.0002 m	3.2213 m

022 - 3 **Scanned Objects - Mean Distance:** 0.0043 **- Mean Position** X=506.6520 Y=2042.1050 Z=20.3920

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
011	Pymbl_Scan_003	0.0027 m	0.0022 m	-0.0006 m	0.0014 m	0.0003 m	17.4414 m
011	Pymbl_Scan_004	0.0060 m	0.0021 m	0.0005 m	-0.0056 m	0.0002 m	3.8259 m
3B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--

023 - 2 **Scanned Objects - Mean Distance:** 0.0026 **- Mean Position** X=497.1489 Y=1982.5069 Z=18.4220

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
6B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target7	Pymbl_Scan_000	0.0026 m	0.0009 m	-0.0023 m	0.0006 m	0.0004 m	12.1207 m

024 - 2 **Scanned Objects - Mean Distance:** 0.0023 **- Mean Position** X=508.0605 Y=1996.8281 Z=20.6520

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
7B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target6	Pymbl_Scan_000	0.0023 m	-0.0005 m	-0.0017 m	-0.0015 m	0.0004 m	12.7020 m

025 - 2 **Scanned Objects - Mean Distance:** 0.0014 **- Mean Position** X=510.2057 Y=2010.1850 Z=19.5238

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
8B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target17	Pymbl_Scan_002	0.0014 m	-0.0011 m	-0.0002 m	0.0008 m	0.0004 m	8.8092 m

026 - 2 **Scanned Objects - Mean Distance:** 0.0040 **- Mean Position** X=511.7059 Y=2019.5504 Z=26.6524

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
1B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target46	Pymbl_Scan_003	0.0040 m	-0.0022 m	0.0033 m	-0.0010 m	0.0011 m	14.0217 m

027 - 2 **Scanned Objects - Mean Distance:** 0.0018 **- Mean Position** X=514.4280 Y=2036.4844 Z=22.1277

Object Name	Corresponding Station	Residual Error	Delta X	Delta Y	Delta Z	Fitting Error	Distance to Scanner
2B	pymble-usq2	0.0000 m	0.0000 m	0.0000 m	0.0000 m	--	--
Target38	Pymbl_Scan_004	0.0018 m	0.0006 m	0.0016 m	-0.0004 m	0.0019 m	9.9498 m

Appendix N

Safety documentation

Degotardi Smith & Partners

OH&S PRE-JOB HAZARD ASSESSMENT

JOB NO: DATE: ___/____/___	WORK LOCATION: __Site A-Blk11__________________________ JOB DESCRIPTION_Comparison of photogrammetry and laser scanning	FIELD PARTY LEADER: Lachlan Broome

Site Specific SWMS ☐	Other (Give Details)

Pre- Work Discussions:	Mark with ✓		Comments
	Yes	No	
Has Safe Work Method Statement been discussed?	☑	☐	
Have plant, equipment, tools been checked?	☑	☐	
Has a site inspection been done?	☑	☐	
Are there inexperienced staff on site?	☐	☑	
Is the work site unusual/difficult?	☐	☑	
Is additional equipment/staff required to perform task?	☐	☑	
Are you working with other staff/contractors?	☑	☐	
Is access to the site safe?	☑	☐	
Does everyone agree on procedure of work?	☑	☐	
Can the task be done safely and professionally?	☑	☐	
Do you have an emergency procedure/phone?	☑	☐	
Is a first aid kit accessible?	☑	☐	

PERSONNEL:	PERSONNEL SIGN OFF:	PERSONNEL:	PERSONNEL SIGN OFF:
Lachlan Broome	L.B		
Andrew Broome	A.B.		

HAZARD IDENTIFICATION (identify hazards before leaving the office & again when you arrive on site)

Field	HAZARD	Field	HAZARD	Field	HAZARD
☐	Moving Machinery	☐	Hazardous Substances	☐	Confined Spaces
☐	Difficult Access	☐	Chemicals/Wastes	☐	Gases/explosion
☐	Dust	☐	Hot Surfaces	☐	Fire
☐	Electricity	☑	Insect Bites	☐	Manual Handling
☑	Heights	☑	Sunburn	☐	Noise/Vibration
☐	Water	☐	Lone Worker	☑	Uneven/slippery surfaces
☐	Overhead Hazards	☐	Pressure/Vacuum	☐	Multiple staff or contractors
☑	Construction/Demolition	☐	Traffic/Vehicles	☐	Other__________________

CONTROLS (apply generic controls & ensure any additional hazards are controlled before proceeding with work)

☐ Traffic Control Contractor	☑ Boots	☐ Lifting devices
☐ Manual Handling Risk Assessment	☑ Sun protection	☑ Harness
☐ Traffic Signage +TCP (Approved by RMS)	☑ Hats & protective clothing	☑ Communication devices
☐ Lock out/Tag out	☐ Supervision	
☐ Dust Masks	☐ Ear muffs	
☐ Gloves	☑ Goggles/sun glasses	

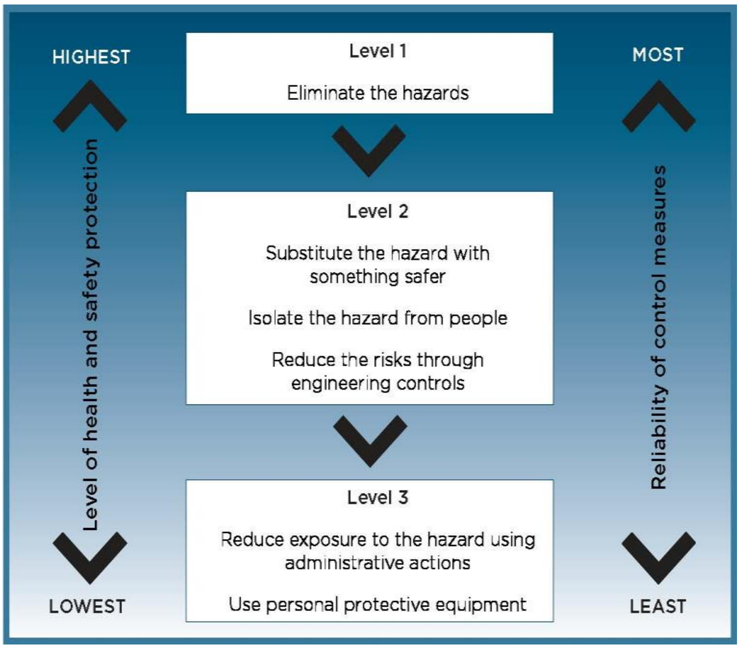
	Office	Field	
Risk Score After Controls (matrix overleaf): **Cease activity if risk 1 or 2**	3	3	Safe to Proceed Y

AFTER WORK COMPLETION	
Any new hazards identified :	
Office manager update Hazard Register	No:
Office manager update checks Job File for Records (SWMS; xxxx)	
AFTER WORK COMPLETION INCIDENT MANAGEMENT AND NEAR MISSES	
PARTNER NOTIFIED:	TIME:
DESCRIPTION of INCIDENT/NEAR MISS: ______ ______	
ACTIONS & OBSERVATIONS:______ ______	

RISK MATRIX

	Summary of Severity / Consequence		Likelihood			
			L1	L2	L3	L4
			Imminent or routinely	Very Likely	Likely	Unlikely or Rare
Catastrophic =	Death or permanent disability Long-term environmental damage	**C1**	1	1	2	3
Critical =	Lost-time injury Medium term environmental impact	**C2**	1	2	3	4
Minor =	Medical treatment or first aid Minor environmental harm being easily remediated	**C3**	2	3	4	5
Minimal =	No injury, illness or environmental harm	**C4**	3	4	5	6

High or Significant risk/impact (1-2)	> Cease activity, bring to management attention > Discontinue until hazard / impact can be eliminated or risk reduced by substitution > Implement remedial or corrective action ASAP
Substantial risk/impact (3)	> Bring to management attention > Consider substitution, off-set strategy or control of hazard / impact
Moderate risk/impact (4)	> Follow standard procedures > Where PPE if mandated > Consider submitting Environmental or OH&S Improvement Request
Low risk (5-6)	> None or limited action necessary



<table>
<tr>
<td>SWMS number:

DSP-SWMS-33627</td>
<td colspan="2">SWMS Name:
Construction Setout, Gordon carpark set out</td>
<td rowspan="2">SWMS Team:
Lachlan Broome</td>
</tr>
<tr>
<td rowspan="2">PPE required:
• First Aid Kit (Vehicle)
• Safety Boots (Lace Up)
• High Visibility Vests
• Hard Hat
• Sunscreen
• Long Sleeves and Trousers</td>
<td colspan="2" rowspan="2">Brief Job Description:

Construction set out of various structures at Gordon railway comuter carpark.</td>
</tr>
<tr>
<td rowspan="2">Approver (Position):

Lachlan Broome

Survey Technician</td>
</tr>
<tr>
<td>PPE as required:
• Safety Glasses/Goggles
• Gloves
• Safety harness</td>
<td rowspan="2">Plant/Equipment/Tools:
• Leica Total Station Reflectorless Theodolite
• Leica NA3003 digital level
• Non-metalic tripod legs
• Orange traffic cones
• Non-conducting levelling staff
• Non-conductive Ranging pole and reflector
• General survey equipment, tools and materials
• Sony A7r Camera
• Faro 3d X330 laser scanner</td>
<td rowspan="2">Permits/licences required:
NSW Drivers License</td>
</tr>
<tr>
<td>Applicable Standards, Codes of Practice and guidance:
• Surveying and Spatial Information Act 2002
• Surveying (Practice) Amendment Regulation 2006
• RTA Traffic Control at Worksites</td>
<td>Custodian (Position):
Senior surveyor</td>
</tr>
</table>

• Work Health and Safety Act 2011 • Work Health and Safety Regulation 2011 • AS1742.3-Traffic Control Devices for Work on Roads • Work Near Overhead Power Lines-Code of Practice 2006 • Risk Assessment Code of Practice 2001	**Equipment Maintenance** • Plant and equipment are serviced and tested in accordance with Degotardi Smith and Partners Quality Assurance. • Copies of the Equipment Maintenance Schedule is available in the office on request, however these documents will not be made available unless some specific safety issue arises.	**Training/Qualifications required:** • OHS General Induction Certificate • Relevant Surveying Qualification (Party Leader)

Number	Step	**Potential Hazard & Assessment** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Safety Controls	Risk ranking after controls	Responsibility
1	Job Planning, organise resources	Identification of Hazards	Various	• Collate site information prior to entering field • Contact relevant authorities for possible hazards • Brief senior surveyor on potential hazards including OH&S and environmental hazards.	Various	Job captain Surveyor
2	Drive vehicle to site	Fatigue Collision with other motorists Unfamiliar road conditions (4WD) Vehicle faults and defects Storage of equipment	1 1 1 3 3	• Pre-plan the trip and share the driving on longer trips. Have a break every 2 hours. • Must have current drivers licence • Visually inspect the vehicle prior to leaving the office • Be aware of unusual road conditions which can change during the day (eg. Weather, sun glare, etc.) • Equipment to be stored in the cargo area where possible. Survey equipment inside the vehicle must be secured with a strap or belt or stored on the floor if possible.	3 3 5 5 5	Surveyor Assistant
3	Loading/Unloading Vehicle and transfer to worksite.	Traffic Manual Handling Trips and falls	1 2 3	• Use the non-traffic or rear of the vehicle to load/unload equipment. Avoid having the vehicle parked in an area that causes risks. • Observe safe procedures for lifting and carrying. • Wear slip resistant safety boots at all times • Be aware of debris around the worksite • Position tools and equipment clear of all pedestrian walkways and vehicular access routes • Be aware of slippery surfaces, particularly after rain. • Avoid carrying loads on steep embankments • Share of minimise loads	3 5 5	Surveyor Assistant

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Web: www.degotardi.com.au Email: surveys@degotardi.com.au ABN 67 588 967 472

Number	Step	**Potential Hazard & Assessment** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Safety Controls	Risk ranking after controls	Responsibility
4	Establishing and removing traffic control if required	Manual Handling Traffic	2 1	• Refer to Step 3 above • Wear high visibility clothing/vest • Activate flashing lights on vehicles • Awareness of traffic speeds, volumes, pedestrians • Use approved Traffic Control Company if required • Refer to and place control devices in accordance with appropriate Traffic Control Plan • Mobile phones not to be used whilst placing traffic control devices	5 3	Surveyor Assistant
5	Survey Fieldwork including: • Setting up and removing theodolite and targets • Locating survey marks and services • Clearing • Surveying of infrastructure and natural features • Placing survey marks	Manual Handling Fall from heights	2	• Refer to Step 3 above • Use additional PPE if required • Use job rotation. • Fall arrest harness	5	Surveyor Assistant
6		Trips and Falls	3	• Refer to step 3 above	5	Surveyor Assistant
7		Snake bites, insect bites and stings	3	• Identify areas of high risk –long grass, dams, swampy areas, under rocks, logs • Where gloves where appropriate • Walk “heavily” • Use appropriate PPE – long sleeves and trousers, gaters • Use existing walking tracks	5	Surveyor Assistant

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Number	Step	**Potential Hazard & Assessment** (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Safety Controls	Risk ranking after controls	Responsibility
8		Heat Stress	3	• Ensure personnel can notice the signs of heat stress • Drink water at regular intervals • Commence work early in the day to take advantage of cooler periods • Where possible utlise the shade from trees or structures • Pace yourself • Monitor each others physical and mental responses	5	Surveyor Assistant
9		Exposure to UV Radiation	2	• "Slip, Slop, Slap". Use sunscreen and replace at the required intervals • Wear a wide brimmed hat. Use a hard hat brim when required. • Wear long sleeve shirts and long trousers • Utilise shade where possible • Wear sunglasses	5	Surveyor Assistant
10		Weather Conditions	2	• Use wet weather gear – rain jackets/trousers, gumboots • Use warm winter clothing • Be aware of approaching storms (lightning and strong winds) • Remain in vehicles or in buildings during extreme weather conditions.	5	Surveyor Assistant
11		Needle Sticks	3	• Be aware at all times • Do not place hands where they cannot be seen • Where safety boots at all times • If a needle is found, do not pick up or touch the needle • If needles prevent safe work, arrange for trained personnel to remove them	5	Surveyor Assistant

Number	Step	Potential Hazard & Assessment (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Safety Controls	Risk ranking after controls	Responsibility
12		Use of Mobile phones	3	• Discuss the use of mobile phones at the "tool box" meeting before commencing work • Leave the phones in the vehicles or turn them off if working on sites that require a greater need for awareness. • If you need to take a call, cease work, stand in a safe place clear of traffic, hazards and pedestrians prior to answering the phone	5	Surveyor Assistant
13		Hazardous substances - Spray paint, glues	2	• Refer to MSDS • Ensure all staff are trained in the use of MSDS • Wear gloves when using glues • Point spray paint away from body and other personnel and use downwind when possible • Replace lids and securely store in vehicles or equipment room when not in use.	4	Surveyor Assistant
14		Contact with contaminated groundwater, sediments, contaminated soils and asbestos	2	• Use the correct PPE including gloves, safety glasses, long shirt and trousers • Do not disturb asbestos under any circumstances • Don't raise dust during survey work • Don't excavate the soil or disturb the surface or groundwater	4	Surveyor Assistant
15		Exposure to public utilities	1	• Use non-conducting equipment • An invar levelling staff may be used if all electrical hazards are identified and the risk assessed to be low. Mininal clearance to electrical plant to be identified. • Check with 'Dial Before You Dig' and visually inspect the site prior to driving any survey marks more than 150mm into the ground • If service location is critical use an approved underground service locating company • Do not use staves when wet or in rain	4	Surveyor Assistant

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Number	Step	Potential Hazard & Assessment (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Safety Controls	Risk ranking after controls	Responsibility
16		Pedestrian and traffic hazard around theodolite	3	• Survey instrument to be set up greater than 1.5 metres from traffic lane • Place orange traffic cones around instrument or use barriers • Utilise lookouts if available • Position tools and equipment clear of pedestrian and vehicle routes • Plan surveys for work outside peak times in places of high pedestrian activity	5	Surveyor Assistant
17		Use of hand drill	4	• Use only battery operated hand drill • Read manufacturer's instructions and use accordingly • Ensure chuck is firmly secured • Hold drill firmly when drilling • Wear safety glasses	5	All
18		Strike from swinging hammer or brush hook	3	• Wear appropriate PPE – hardhat, safety boots, safety glasses • Remain clear of person using brush hook or hammer • Person to act as lookout for other pedestrians and plant in the area	4	All
19		General vehicle traffic	1	• Loading/unloading vehicle – refer to step 3 above • Establish and removal of traffic control – refer to step 4 above • Be alert and vigilant at all times. • Be aware of changing conditions that may effect drivers – eg. Fog, sun glare, weather conditions • Use two-way radios to warn other personnel of traffic in the vicinity • Plan an escape route.	3	All

Number	Step	Potential Hazard & Assessment (Safety/Environmental hazards identified, including physical environment, human errors, plant and equipment)	Risk ranking before controls	Safety Controls	Risk ranking after controls	Responsibility
20		Jumping over fences/electric fences	3	• If possible avoid jumping over or from fences. Use alternative methods such as going through access gates, going through, going around or use a ladder • Always assume an electric fence is active • Use an additional person to separate wires when going through a fence, especially barb wire fences • Pass all equipment over or through a fence	5	All
21		Placing nails in concrete	3	• Nail can act as a projectile if struck incorrectly. • Wear safety glasses	5	Assistant
22	Transfer equipment back to survey vehicle	See step 3 above				
23	Drive vehicle to office	See step 2 above	1	• There may be an increase in fatigue at the completion of the job which may require increased controls. Eg. Rotate driving more regularly	3	All

NOTE: Each work group or team member must sign off on the SWMS to acknowledge they have been briefed about or instructed in the SWMS

Team member name (Please print)	Team Member signature	Instructor/ Briefer name	Date	Team member name (Please print)	Team Member signature	Instructor/ Briefer name	Date
Lachlan Broome	LB	LB					
Andrew Broome	AB	AB					

RISK ASSESSMENT RECKONER	Probability of Hazard Occurring			
Severity	**Very Likely** Could happen at any time	**Likely** Could happen some time	**Unlikely** Could happen but rarely	**Very Unlikely** Could happen but probably never will
K or PD Kill or cause permanent disability or health	1	1	2	3
LTI or SI Long term illness or serious injury	1	2	3	4
MA Medical attention and several days off work	2	3	4	5
FA First Aid needed	3	4	5	6

Red	High
Yellow	Medium
Blue	Low

To score the risk, use the following steps:

1) Identify the possible outcome if the risk were to occur eg. K, LTI, etc.
2) Identify the probability of the risk occurring eg. Likely, Unlikely, etc.
3) Using a combination of the possible outcome and probability, determine the risk number using the matrix above.

OH&S PRE-JOB HAZARD ASSESSMENT

JOB NO: DATE: ___/____/___	WORK LOCATION: Site B-The Office JOB DESCRIPTION Comparison of photogrammetry and laser scanning	FIELD PARTY LEADER: Lachlan Broome

Site Specific SWMS	☐	Other (Give Details)	
Pre- Work Discussions:	Mark with ✓		Comments
	Yes	No	
Has Safe Work Method Statement been discussed?	☐	☑	A safe work method statement is not required for this task
Have plant, equipment, tools been checked?	☑	☐	
Has a site inspection been done?	☑	☐	
Are there inexperienced staff on site?	☐	☑	
Is the work site unusual/difficult?	☐	☑	
Is additional equipment/staff required to perform task?	☐	☑	
Are you working with other staff/contractors?	☐	☑	
Is access to the site safe?	☑	☐	
Does everyone agree on procedure of work?	☑	☐	
Can the task be done safely and professionally?	☑	☐	
Do you have an emergency procedure/phone?	☑	☐	
Is a first aid kit accessible?	☑	☐	

PERSONNEL:	PERSONNEL SIGN OFF:	PERSONNEL:	PERSONNEL SIGN OFF:
Lachlan Broome	L.B.		

HAZARD IDENTIFICATION (identify hazards before leaving the office & again when you arrive on site)

Field	HAZARD	Field	HAZARD	Field	HAZARD
☐	Moving Machinery	☐	Hazardous Substances	☐	Confined Spaces
☐	Difficult Access	☐	Chemicals/Wastes	☐	Gases/explosion
☐	Dust	☐	Hot Surfaces	☐	Fire
☐	Electricity	☑	Insect Bites	☐	Manual Handling
☑	Heights	☑	Sunburn	☐	Noise/Vibration
☐	Water	☐	Lone Worker	☑	Uneven/slippery surfaces
☐	Overhead Hazards	☐	Pressure/Vacuum	☐	Multiple staff or contractors
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CONTROLS (apply generic controls & ensure any additional hazards are controlled before proceeding with work)

☐ Traffic Control Contractor	☑ Boots	☐ Lifting devices
☐ Manual Handling Risk Assessment	☑ Sun protection	☐ Harness
☐ Traffic Signage +TCP (Approved by RMS)	☑ Hats & protective clothing	☑ Communication devices
☐ Lock out/Tag out	☐ Supervision	
☐ Dust Masks	☐ Ear muffs	
☐ Gloves	☑ Goggles/sun glasses	

	Office	Field	
Risk Score After Controls (matrix overleaf): **Cease activity if risk 1 or 2**	5	5	Safe to Proceed Y

AFTER WORK COMPLETION	
Any new hazards identified :	
Office manager update Hazard Register	No:
Office manager update checks Job File for Records (SWMS; xxxx)	
AFTER WORK COMPLETION INCIDENT MANAGEMENT AND NEAR MISSES	
PARTNER NOTIFIED:	TIME:
DESCRIPTION of INCIDENT/NEAR MISS: ___________	
ACTIONS & OBSERVATIONS:___________	

RISK MATRIX

	Summary of Severity / Consequence		Likelihood			
			L1	**L2**	**L3**	**L4**
			Imminent or routinely	Very Likely	Likely	Unlikely or Rare
Catastrophic =	Death or permanent disability Long-term environmental damage	**C1**	**1**	**1**	**2**	**3**
Critical =	Lost-time injury Medium term environmental impact	**C2**	**1**	**2**	**3**	**4**
Minor =	Medical treatment or first aid Minor environmental harm being easily remediated	**C3**	**2**	**3**	**4**	**5**
Minimal =	No injury, illness or environmental harm	**C4**	**3**	**4**	**5**	**6**

High or Significant risk/impact (1-2)	> Cease activity, bring to management attention > Discontinue until hazard / impact can be eliminated or risk reduced by substitution > Implement remedial or corrective action ASAP
Substantial risk/impact (3)	> Bring to management attention > Consider substitution, off-set strategy or control of hazard / impact
Moderate risk/impact (4)	> Follow standard procedures > Where PPE if mandated > Consider submitting Environmental or OH&S Improvement Request
Low risk (5-6)	> None or limited action necessary