University of Southern Queensland

Faculty of Health, Engineering and Sciences

3D Modelling for surveying projects using Unmanned Arial Vehicles (UAVs) and Laser Scanning

A dissertation submitted by

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in fulfilment of the requirements of

ENG4111 and 4112 Research Project

towards the degree of

Bachelor of Spatial Science (Honours) (Surveying)

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

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Abstract

3D models that have been created from photogrammetry have some evident limitations. To create better, more complete 3D models, it is necessary to understand and reduce these limitations. The project aims to look at the effect of camera orientation and its effect on the overall accuracy of the project. Furthermore, it is proposed to reduce the inevitable gaps in the model by the use of terrestrial photogrammetry. The primary comparison of the model will be between the data captured from photogrammetry techniques and that of traditional style of surveying methods such as total station and terrestrial scanning.

The research was conducted in late 2015 and was processed using the latest software versions as of mid-2016.

The research is supported by UAS Pacific, the aim is to ultimately provide the industry with a better understanding of the data and aims to improve the overall quality of 3D modelling with the use of new exciting technologies and techniques that are available to the public today.

Chapter 1 - Introduction

1.1 Project Background

Unmanned Arial Systems, also known as drones or UAV's (unmanned aerial vehicles) are becoming main stream tool for surveyors, particularly in 3D modelling and point cloud generation for calculating volumes and creating realistic models by photogrammetry or scanning. Often the word drone is related to the military, this is because much of the activities relating to drones has been in the military, however this is changing. It is important to recognise that this project is solely based on civilian drones, however some of the applications may apply to the military. In regard to civilian UAV's a variety of research has been carried out in the past with off the shelf platforms comparing comparatively low resolution data to existing methods of surveying. These platforms have their place in large topographic surveys, mines and the likes. However, when it comes to many engineering projects a much more detailed model is required hence the basis of this project. As a surveyor, accuracy, precision and the overall reliability of the data is paramount. Another key element is the product delivered to the client must be complete, even small amounts of missing data may require a large amount of work, hence incurred cost. Using a high resolution DSLR paired with a high quality lens aboard a UAV flying at altitudes of less than 120m yields a low GSD (Ground Sample Distance) with limited distortions. This ultimately allows the creation of more detailed and spatially correct models, even so the data may have gaps due to obstacles. This has raised the question, can UAS be used for higher accuracy projects such as road and rail, which rely on high accuracy and precision data. As far as camera orientation is concerned there is only limited research of both portrait and landscape photogrammetry meaning that there is an opportunity to better understand the effect of orientation on the precision accuracy and completeness of a photogrammetric model. Secondly the use of terrestrial (land based) photogrammetry to enhance a model has only limited research, this part of the project will help better understand the feasibility of combining both methods to ultimately create a more desirable model.

1.2 Statement of Problem

The idea of photogrammetry has been around since the 1400's when Leonardo Devinci developed the idea of perspective and geometry, it wasn't until 1990 when computers saw digital soft copy photogrammetry, (widely used today) come of age. As far as UAV's are concerned they were first seen in 1916 were mainly used by the military. By 1980 sensors were being integrated into these platforms, technology remained expensive, it wasn't until the 2000's civilian drones became more popular. Only in very recent times with the development of lithium based batteries and brushless motors have we seen a myriad of small, highly capable civilian drones in many shapes and forms for a variety of applications. (Colomina 2014)

1.3 Project Justification

It is important that we better understand both the effects of different camera orientations as well as their limitations and possible uses for different situations. However, this also enables us to gain a better understanding of high resolution photogrammetry which will allow surveyors the ability to better choose the right tool for the right job. It's important to understand that as far as surveying is concerned, UAV photogrammetry is another tool in a myriad of tools at the disposal of a conventional surveyor. Without significant benefit the tool may not be purchased due to its cost and additional expertise required. Furthermore, this project has the potential to allow surveyors to have the understanding and ability to undertake additional terrestrial photogrammetry to better meet client needs, ultimately making their product more competitive than others.

1.4 Project Aim

The aim of the project is to investigate the effect of camera orientation on photogrammetry results, as well as the ability to enhance a model with the use of terrestrial based images combined with UAV imagery.

1.5 Project Objectives

To determine the effect of portrait and landscape camera orientations on the overall accuracy of the resulting 3D model in term effecting the design of UAS, as well as accuracy the investigation of operational efficiencies such as flight times and processing times will be analysed.

To investigate the use of terrestrial photogrammetry alongside low altitude airborne photogrammetry in aim of producing a much more complete 3D model with a lesser effort/ input then that of traditional surveying methods.

The creation of 3D models in terms of their accuracy is highly dependent on the type of features being surveyed. This project is looking at the effect of accuracy in two main areas, firstly that of an engineering application. That being surveying the likes of a train station or that of a similar nature. It must include hard surfaces, buildings and the likes. The second area of focus is subdivision/earthworks based, where volume calculation is the main goal. The site should include a natural surface for the comparison as well as necessary trees and obstacles to provide a source of testing for terrestrial photogrammetry.

Furthermore, it is expected that the results will heavily depend on the process and techniques used to not only capture the data, but to process and analyse it. This is where past experience and knowledge combined with expertise from both industry and academic staff will be utilised to their full extent.

1.6 Structure of Dissertation

The structure of the dissertation is of high importance. Having information in an easy to follow order has been priority. The Dissertation has been arranged in chapters with 4 main sections. Chapter 1, Introduction, Chapter 2, Literature review, Chapter 3 Method, Chapter 4 Results, Chapter 5 Discussion, Chapter 6 Conclusion. Each of these has a myriad of sub headings which help guide the reader.

Chapter 2 - Literature Review

2.1 Photogrammetry

2.1.1 Overview

> *Photogrammetry is a technique of representing and measuring 3D objects using data stored on 2D photographs, which are the base for rectification. At least two projections are necessary to obtain information about three space coordinates, that is, from two photographs of the same object its true size can be determined and 3D model constructed.*

(Stojaković 2008)

Today photogrammetry is more accessible than ever. With advanced software the digital images are combined using methods and basic principles created over 100 years ago. This enables the creation of a 3D model allowing virtual worlds to be created.

2.2 Applications

A myriad of applications are possible however the 5 applications below are common in the industry, it is likely as technology advances that these applications may change as the ever increasing accuracy as well as cost effectiveness.

- 3D Reconstruction: UAV's are a valuable data source, unlike satellites can be used/deployed when required. They provide higher resolution images however may not be effective for extremely large areas.
- Environmental surveying: Low cost consecutive flights allow areas to be mapped on a regular basis. This enables the identification of the effects on time as the same mission can be flown repetitively to identify negative and positive outcomes. Also can be used for post disaster response.
- Traffic Monitoring: May be difficult for approval in Australia due to the strict regulations by CASA however tasks such as surveillance, incidents as well as accident response can be undertaken.
- Forestry & Agriculture: Allows producers to make well informed decisions during the growing process. It also can be used to identify possible damage (due to natural disasters) furthermore is may allow for the identification of species plus volume calculation.

- Archaeology & cultural heritage: Vital documentation of sites can be obtained which allows for the preservation of archaeological sites in a virtual world allowing for identification of damage and or erosion due to natural weathering.

2.3 Triangulation

The basis of many surveying practices are highly applicable to photogrammetry. Today aerial triangulation process is almost independent of human interaction.(Schenk 1996)

In photogrammetry triangulation takes place between images. Triangles with a more uniform shape are stronger, hence produce much better results. In order for triangles to be uniform the plane of the photograph should be similar to the plane of the object /item of which is being captured. Hence the reduced ability for aerial photogrammetry to accurately capture the walls of buildings, which planes are generally at right angles to the sensor.

2.4 Surface Construction & Feature Extraction

The methodology behind how images and meta data form a 3D model. Once data set has been captured and orientated the following steps are undertaken.

- Surface Measurement
- Feature Extraction

With the use of known camera location and $200 camera calibration details, a scene can be digitally reconstructed using automated dense image capturing techniques or interactive methods for manmade features. The automated processes are not perfect, however they allow a DSM to be produced which should accurately represent the surface of the land or mass of where the data has been collected. Much of the data must be simplified and interpolated to be practical for survey use, it may also be textured for a photo realistic visualisation. It’s important to use point density’s accurate for best identifying features of 3d models, meaning that the algorithm and settings must be tuned to reduce the number of points required of flat areas while maintaining enough points to show sharp and crisp edges on ridged objects.(F. Remondino a 2011)

2.5 Sensors

Almost any digital camera can be used for capture of data, however without the right camera and lens combination for the given task the results will vary greatly. The camera and lenses combination is of high importance when it comes to obtaining high quality results. Today many of the cameras feature a CCD or COMOS sensor, however both have their inherent strengths and weaknesses.(DALSA 2016)

2.6 Processing Software

Today much of the software is more user friendly than ever. This is mainly due to the increase in computer performance allowing a much better interface to be displayed as well as much more logical and intuitive menus.

A myriad of software is available however there are limitations due to cost. The software pack proposed for the use for the project are as follows.

2.6.1 Survey Data Processing

Liscad 11.1 SSE is a fully featured software pack which allows for the processing of a variety of data formats. The software enables users to perform a number of calculations and checks as well as input and output various data types. Listec also offers student licensing making it a cost effective solution.

2.6.2 Pix4D

Popular imaging software which allows processing and editing of images it enables a variety of inputs and a comparison of Pix-4D to 3DM analysist was made. The following conclusions can be drawn.

Processing times: 3DM took 4 hours compared to that of Pix-4D which only took 2 hours, that’s a time saving of approximately 50%.

Friendliness: Pix-4D is much more simple and intuitive then 3DM.

Comparison of processing software data to that of conventional methods.

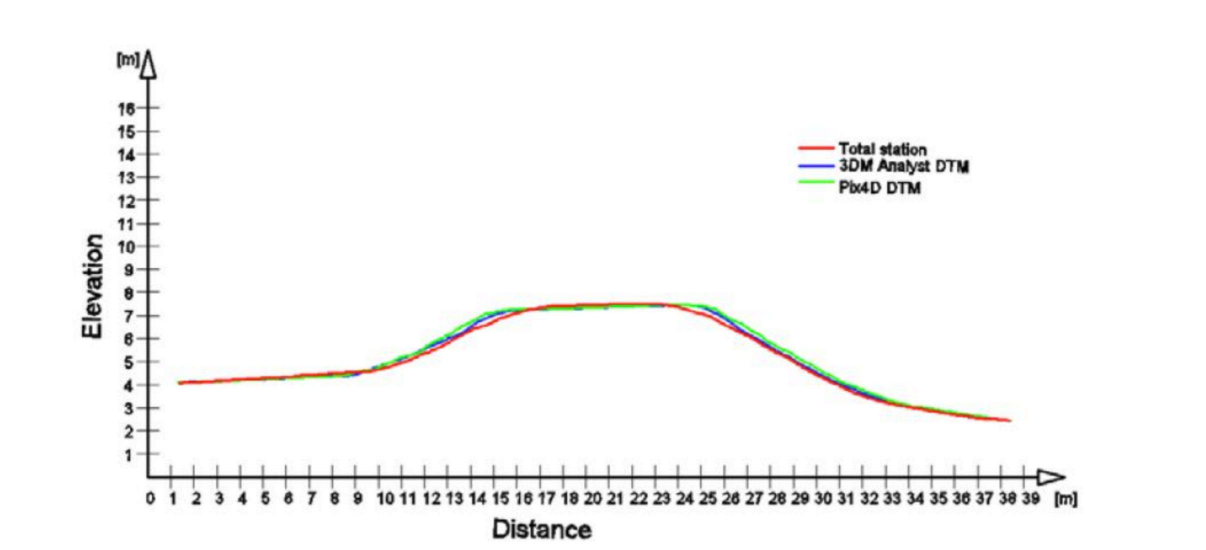


Figure 2.1 - Processing Software Accuracy

Figure 2.1 above demonstrated the similarity of both Pix4D and 3DM software outputs(Marin Govorčin & Đapo 2014).

In conclusion Pix4D is the most efficient software for processing aerial photogrammetry thanks to its highly developed user interface as well as efficient processing algorithms.

Pix4D has a variety of features, which include a variety of camera lens, corrections ground point editing functions as well as many automatic systems from point cloud densification to automatic brightness and colour correction. It has the capability of importing and exporting over 20 data types making it a versatile tool in the surveying industry.

2.7 Limitations of Photogrammetry

One of the major limitations of photogrammetry, it is limited to line of site. In terms what the lens can see is the data that will be picked up. Hence why gaps in the data are commonly formed. Secondly photogrammetry is limited to daytime as the requirement for photographs with the optimal brightness is required. Also shadows and irregular shapes can make photogrammetric readings difficult or impossible as it is a passive sensor, this in comparison to lidar which is an active sensor. It both sends and then receives a signal.

2.8 Base to Height Ratio

Base to height ratio greatly effects the overall quality and accuracy of a project. A study in 2000 using non digital methods found that a base to height ratio that is optimal for the creation of a DEM is between 0.5-0.9. The question today is with current methods, is this range still optimal and how does surveying in landscape v's portrait effect this ratio in term effecting the overall result of the project.

2.9 UAV Accuracy- Past Results Analysis

A summary of three prior accuracy research papers are summarised below they have sole focus of accuracy and do not relate both portrait and landscape.

2.9.1 Aerial Survey – Veio Italy

Table 2.1 - Survey Statistics

Year of Survey	2010
Drone Type	Multirotor - Quadcopter
Flying Height	35M
Camera	Pentax Optio (12MP)
Lens	8mm
Theoretical Precision	xy= ±0.6 cm z= ±2.3 cm.
Actual Precision	X= ± 4 cm, y= ±3 cm and z=± 7 cm in
XY: Z Ratio	0.5
Number of targets	5
Pixel Size (on ground)	1cm

The summary above identifies that an accuracy of 4cm and 7cm is achievable. Furthermore, the ratio of 0.5 mean the vertical accuracy is only half as good as what the horizontal accuracy is which will be further discussed in the project

2.9.2 Topographic Survey - NSW Australia

Table 2.2 - Survey Statistics

Year of Survey	2015
Drone Type	Fixed Wing- Sense Fly Ebee
Flight Height	
Camera	Canon S110 (12MP)
Lens	?
Theoretical Precision	XY= ±0.6 cm z= ±2.3 cm.
Actual Precision	X, Y= ± 1.9 cm, cm and z=± 5.2 cm in
XY: Z Ratio	0.35
Number of targets	6
Pixel Size (on ground)	3cm

This project achieved a better overall accuracy of 1.9 and 5.2cm respectively as would be expected from newer and more refined system, Note the poor XY/Z ratio. This may be a result of a poor BASE/Height Ratio.

Dem Accuracy- Turkey

Table 2.3 - Survey Statistics

Year of Survey	2015
Drone Type	Multirotor - OCTO XL
Flight Height	60m
Camera	Canon EOS M
Lens	EF-M 22 mm
Theoretical Precision	-
Actual Precision	z=± 6.62 cm
XY: Z Ratio	?
Number of targets	27
Pixel Size (on ground)	5cm

This project utilised the highest camera specifications of all the 3 tests, however it was flown at 60 metres (almost double the height) of the first study, however managed to achieve a better vertical accuracy. This is likely due to the camera and lenses combination.

2.9.3 Summary

Looking at the average Z accuracy for all projects they are all similar with an average of 6.3cm in vertical accuracy. This figure will be important part of comparing and contrasting data and results obtained in this project.

2.10 Portrait V's Landscape Accuracy

A study by Adam (TECHNOLOGY 2015) identified a variety of possible advantages from changing different camera orientations. Below in figures 2.2 and 2.3 identify the different camera orientations that are possible i.e. both portrait and landscape, while many manufactures believe that landscape is the better orientation there is much more to it.

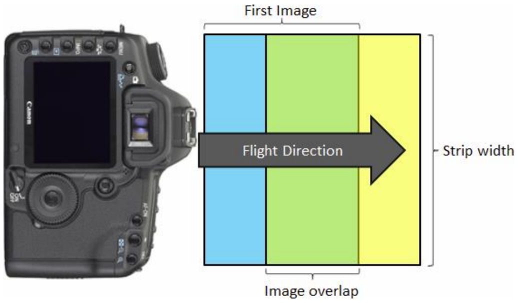


Figure 2.2 - Landscape

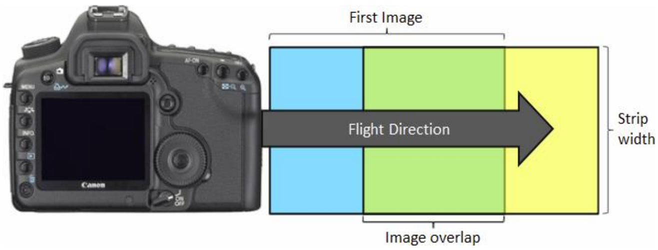
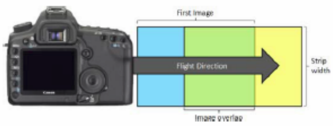


Figure 2.3 - Landscape

Below are two examples from ADAM technology which demonstrates from the same flight height (180m) the theoretical planimetric and height accuracy, as well as outlining some of the features that result from each orientation.

Table 2.4 - Portrait & Landscape Comparison

		
Images	7 strips, 21 Images/strip = 147 images	11 strips, 14 images/strip = 154 images
Planimetric Accuracy	1.6 cm	1.6 cm
Height Accuracy	4.0 cm	2.7 cm
Images when adjusted to same height accuracy (i.e. fly @ 180 m)		7 strips, 9 images/strip = 63 images
Key Features	Requires fewer strips *at a given flying height*	Achieves better height accuracy at a given flying height; *requires **fewer images** and **same no. of strips** at a **given height accuracy***

As can be seen above, the planimetric accuracy remains the same for both orientations however there is a notable change in the accuracy of the height with a theoretical vertical accuracy increase of 32.5%. Vertical accuracy on many projects the limiting factor, therefore it is highly important for further testing to be undertaken in order to identify the real world results from the different orientations. Not only does the height accuracy increase but there is also a reduced number of images required for a given flying height.

It important to remember that this information is from a company and not an independent source. Also there is no direct comparison or mention of the actual results gained, these statistics are based on calculations alone.

Some of the possible issues with portrait photogrammetry that have been discussed include;

- Most platforms are not designed for portrait orientation therefore without a special platform it may not be possible.
- Overlap and sidelap must be carefully taken into consideration to ensure that software is capable of processing the images.

2.11 Time and Cost Analysis

The ultimate goal of these modern survey techniques is to increase the efficiency of data capture and processing, proving cost effecting solution, however most of the study focus is on accuracy and not the relating product and or time and cost. A study by Hayton Smeaton surveying applications of photogrammetric UAVs - a comparison with conventional survey techniques attempted to put a dollar value to the cost of each type of survey undertaken. The conclusions of his findings are summarised below. Smeaton divided the total cost of the survey into five sections to right in (table 2.5).

Table 2.5 - Cost Comparison

Task	TPS	UAV
Planning	120	320
Field	1480	375
Process	180	320
Drafting	720	640
Volumes	60	120
Total	**2920**	**1775**

Note : TPS is Traditions Survey Party

A reduction in cost of over 39% with most of the savings in the data capture, this would suggest the use of the UAV for this particular application. However, from a business point of view would a greater profit be made from the traditional survey style, due to the increased cost or are you likely to become non-competitive in the market particularly as the price of drones fall while capability is enhanced.

This project did not include specific details regarding processing times as well as flight time of UAV.

2.12 Terrestrial Photogrammetry

Uses the same principal of regular photogrammetry however utilises images from the ground. See (figure 2.4) below.

Figure 2.4 - Triangulation (Stojakovie)

2.13 Oblique UAV Photogrammetry.

Is when a UAV takes an image at other the right angles to the ground. The idea of this is similar to that of combining UAV photogrammetry and Terrestrial Photogrammetry however instead of taking the images from the ground at the same height a UAV can be used to fly around a particular object varying in height and location. The particular UAV can be set to take images a pre-defined changes in location or height allowing a more desirable coverage of a given object.

2.14 Unmanned Arial Vehicles

Most surveying based systems descend from RC aircraft. The myriad of small and reliable sensors and electronic components has enabled small yet highly capable UAV’s that are used today. These are becoming more cost effective than ever before.

2.15 Types & Industry standards

It is important to understand the 3 main types of UAV’s all of which require a different type training through the CASA licensing system within Australia, for more on licensing see section 2.3.2, The Platform types are as follows.

2.15.1.1 Fixed Wing

This is the conventional plane style or delta wing type like the Ebee below.

2.15.1.2 Multirotor

The most common type of UAV on the market today. The DJI phantom series is leading the way as far as sub 2kg drones is concerned for personal use. Also compared to more traditional fixed wing drones, multirotor UAV's have the ability to take off and land is small spaces making them a far better solution for urban areas which are generally limited in space.

2.15.1.3 Helicopter (rotary wing)

Usually used for larger applications such as aerial spraying or high speed video recording. System are usually very expensive.

Four systems currently used in the industry. (next page)

Table - 2.6 The Unmanned Arial vehicles types and specifications

Platform	Ebee 	Trimble UX5HP 	Trimble ZX5 	UAS Pacific CBV-HL 
Platform Type	Fixed Wing	Fixed Wing	Multirotor	Multirotor
Sensor Type and Specifications	Photogrammetric WX (18.2 MP)	Photogrammetric Sony a7R 36MP	Photogrammetric Olympus 16mp	Photogrammetric Sony Nex-5 15MP
Sensor Orientation	Landscape	Landscape	Landscape	Portrait & Landscape
Flight Time	40 minutes	40 minutes	20 minutes	15 minutes
GSD	3cm	1cm	1cm	1cm

(Sensefly 2015)What accuracy and precision have other projects been able to achieve?

Industry standard Ebee RTK undertook a review to identify accuracy achieved by the product. The following results were concluded from the assessment: The accuracy was within 1-3 times the GSD, hence the EBEE can achieve 3cm horizontal accuracy and 5cm vertical accuracy.

A paper by(M. Yakar 2013) conducted an experiment using 18MP cannon camera enabled with accuracy on the 32 checkpoints ranging between 0.81cm and 8.55cm with an average of 6.62cm.

It is evident from the research that many companies are reluctant to put actual accuracy specifications on the systems and tend to only display this GSD of which the device is capable. The real issue with this is that the accuracy based on the EBee GSD can vary significantly from 1-3 times the GSD. Meaning that displaying the GSD isn't a great representation of accuracy. Not specifying accuracy helps remove the responsibility from the company as the GSD doesn't directly affect the accuracy instead only gives a guide to the overall accuracy.

2.16 Licencing

Within Australia to fly a drone over 2kg a licence is required for the correct type of platform of which you are operating. However, this does not allow you to operate the aircraft. Persons must fly under an OC (operators Certificate) again from CASA (Civil Aviation Safety Authority) for more information and details please visit the CASA Website.

2.17 Scanning (for comparison)

Scanning not dissimilar to photogrammetry however uses an active sensor. With the correct procedure allows for the rapid capture of highly accurate spatial data for a variety of applications from engineering to mining. Today many scanners allow for targetless from different station setups however a paper by (Cox 2015) demonstrated issues with targetless recognition and strongly recommended the use of targets as the use of targetless recognition introduces unavoidable errors and misalignments to occur during the processing phase.

Chapter 3 - Method

3.1 Introduction

This chapter identifies the proposed procedures to undertake the project in a timely and orderly fashion. Procedures to reduce errors and reduce cost have been implemented however due to the nature of the project the method is likely to vary, as unavoidable obstacles are likely to occur.

3.2 Design Considerations

3.2.1 Sensor & Settings

The sensor used for the project is a Sony Nex 5 with a wide angle lens. The camera features a 14mp with a 3:2 ratio Sensor.

Much effort and time has been placed into obtaining the optimal sensor settings, note these settings are highly variable based on local conditions.

Table 3.1 - Camera Setting

Proposed Settings	
F-Stop	5.6
Exposure Time	1/160 sec
ISO	400
Exposure Program	aperture priority
Contrast	Normal
Saturation	Normal
Sharpness	Normal
White Balance	Auto

3.2.2 Camera Stabilisation (Gimbal)

A gimbal is a pivot which aims to eliminate movement in either 2 or 3 axis(generally)see figure 3.1 to the right, of a modern 3 axis gimbal with a camera. Even with stabilisation the task of obtaining a high quality image for aerial photogrammetry is quite involved. The stabilisation of the camera allows the vehicle which is carrying the sensor to move and conduct a pre-programmed flight path without roll and pitch movement (and yaw) for a 3rd axis. In many off the shelf platforms the camera is fixed introducing the pitch and roll into the equation also adding to AIM (apparent image motion). In this case the yaw axis still remains fixed. Which with a Multi Rotor type setup is not an issue as with a correct compass calibration and alignment the platform will track straight.

Figure 3.1 - Gimbal & Camera

3.2.3 Apparent Image Motion (AIM)

When taking an image, an exposure allows for the light and data to pass through the lens and onto the sensor. This exposure time can be highly variable depending on camera settings however a camera in motion i.e. movement from both forward motion and vibration.

3.2.4 Platform

3.2.4.1 UAV Photogrammetry

In house design and built by UAS pacific, primary function as a photography and photogrammetry aircraft. The system is generally flown by two persons. A pilot in command and a ground station operator. The platform itself is known as a Y6, this configuration is known for the inherent stability, particularly in windy conditions. With a flight time of approximately 15 minutes and a flight ceiling of 400 feet (only due to CASA restrictions) it can cover up to 1km square which is highly dependent on desired outcomes.

3.3 Location

The project focuses on accuracy particularly looking at more engineering type application where a very high accuracy is required so to obtain the best possible best possible comparison, the location must have the following attributes.

- Areas of flat uniform land for easy comparison of surfaces.
- Solid structures i.e. Buildings
- Areas in the shadow of structures not seen by the photogrammetric eye in order for terrestrial photogrammetry testing.
- An area that is safe and has no restrictions in terms of the CASA regulations.

3.3.1 Control Network

Designed to optimise photogrammetry quality. To a certain point, the more control points on a given task the higher the overall accuracy. Control must be equally spaced throughout project. All points should be situated in a location with optimal view of the sky in hope of points being identifiable in more images, in term increasing accuracy. The control point accuracy will directly affect overall accuracy of the project.

3.3.2 Coordinate System

Due to the nature of the project it must only be physically correct within itself, this means there is no requirement for a specific coordinate system to be used, instead a local coordinate system is to be used. All photogrammetric data will be scaled and distorted based on the data captured by the total station.

3.4 Field Testing Procedure

3.4.1 Overview

A significant amount of planning is required in order for each component of the field testing procedure, to reduce time in the field as which ultimately limits costs. The data capture can be split into multiple parts. See figure 3.2 Below which is a typical workflow forum mission planning to completion of DTM.(Francesco Nex 2012)

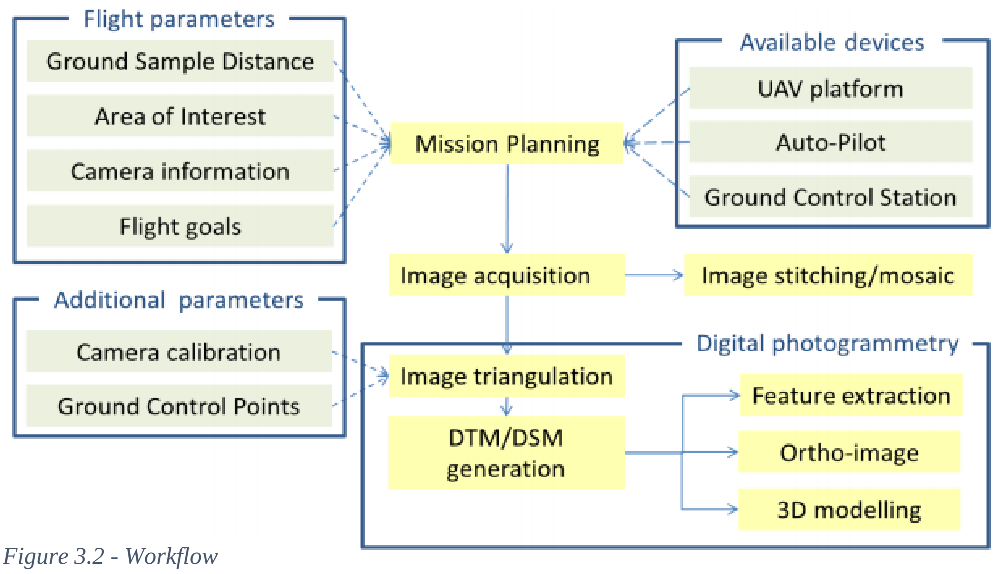


Figure 3.2 - Workflow

3.5

3.5.1 Traditional Surveying

Trimble S6 total station is to be used for control network as well as the capture of traditional topographic and engineering detail type data. The Trimble S6 is well known in the surveying industry and features high accuracy EDM and angle measurement. The project coordinate system is Cartesian Plane; this is due the small size of the project.

3.5.1.1 Coordinate System

For simplicity the Cartesian planer coordinate system is used this means no scale factor or conversions are required between data types. Also there is no need to have the project on MGA coordinate system as this would incur a significant cost to the project.

3.5.1.2 Control Network

A control network underlies the entire project. Firstly, it enables the photogrammetry part of the project to be correctly georeferenced and the appropriate distortions be made in order to achieve an accurate result. Secondly the control network allows for the integration of the various types of data which is to be used for comparison to the photogrammetric data. This means that the scanning data as well as the manually collected total station data can be compared. Below is the process and quality assurance undertaken during surveying the control network.

1. Identify suitable locations for the control network, this includes keeping control points as evenly spaced as possible. Also care must be taken to ensure best line of sight from the air to the ground in areas may be difficult due to vegetation.
2. Once points are identified. Using total a station take all precautions to setup instrument and targets correctly. The network should be as ridged as possible radiations within a control network must be avoided, each station should also have an independent observation which may include shots from different locations.
3. Once back in the office data should be checked and processed.

3.5.1.3 Topographic data capture

Known in the industry as a detail survey. In this case only small number of critical points such as edge of road, roofs and spot heights are to be captured for data comparison.

3.5.1.4 Checks

Standard surveying procedures include a variety of checks that reduce potential errors made in the field. They include checking of backsight as well as confirming pole height and offsets.

3.6 UAV Photogrammetry

3.6.1 Targets

A variety of targets are used in the industry however the most common are crosses and circular type targets. Some of the circular type targets allow for further calibration within specific software.

3.6.2 Front & Side Overlap

In order to obtain comparable results and after discussion with industry specialist, it was decided to fly at a height of 50m with overlaps for both portrait and landscape at: Overlap (80%) and side lap 60%. With the fixed values a true comparison between both data sets can be made. The DJI flight planning software enables for these values to be keyed in. As well as forwards speed (at 2m/s) Given the specified location the software calculates the appropriate number of photographs as well as the locations of which they should be taken.

3.6.3 Flight Operation & Flight Path

With the on-board DJI software and ground station an area of interest for capture is selected. The software only allows for square flight paths to be made. Furthermore, the software allows you to define the side and forward overlap as well as flight height. Other specifications such as sensor as well as lens specifications are also required to complete a mission. After defining flight details the automatically generated flight path is uploaded to the UAV. The mission can begin. Note: Prior to take off the UAV operator must have completed the myriad of checks and appropriate paper work in order for a safe and legal flight.

3.7 Simulations

3.7.1 Flight Time & Portrait v's Landscape Efficiency Simulation

In order to better understand the feasibility of portrait photography. A simulations were run to determine the time differences expected from that of both portrait and landscape as well as comparing the number of images required to capture the given area required for survey. Simulations are the only economical method of comparing multiple flight paths. Simulations also reduce the risk of flying the mission.

The ground station enables a view all calculated flight details the following are of interest.

- Flight Time
- Number of Images
- Flight Distance (total)
- Shooting Distance between photographs.

3.7.1.1 Control

- Simulation reduces the control required as it eliminates the effect a person may have on the outcome. i.e. Some pilots may take longer to fly a mission than other pilots.
- The simulations allow all other factors to remain fixed and the most accurate flight time to be produced.

3.8 Process

1. Determine an appropriate size of survey and note its extents to apply to both situations. Flight area of 200m*500m was selected for the simulation which is one Hectare.
2. Based on industry knowledge apply approximate values for UAV and camera specifications within simulations.
3. Identify the number of simulations to be made for a suitable analysis to be made. Each flight height must have two camera orientations therefore 8 simulations are to be made.
4. Identify the best comparison methods such as time V's accuracy or number of images for a given area V's for a given accuracy.
5. Analyse results and form conclusion.

3.8.1 Processing Efficiency Simulation

The principal behind this is to identify on a per point basis if there is a benefit from processing software on a point to time basis when processing portrait and landscape photogrammetry. Meta data is recorded when processing is undertaking the following information is to be collected.

- Total photographs processed
- Number of points created
- Total processing time (for initial & rigorous)

The following steps are used and the following control measures were applied.

3.8.1.1 Control

- Computer specifications identical as well as temperature and weather.
- No external interactions from user whilst processing in under way.

3.8.1.2 Process

1. Upload imaged and set processing going for both portrait and landscape respectively.
2. Using the meta data as specified above.
3. Take times from flight plan used when undertaking mission.
4. Analyse using a comparison of time taken per given number of points for both the flight time and processing time.

3.9 Terrestrial Photogrammetry

The whole basis of using this technique is that it must be simple and efficient. It is evident that terrestrial photogrammetry can be complete however the question is what result can be obtained requiring a limited amount of resources and prior knowledge. So at a distance of 5-10 metres from the chosen building taking an image every 3-4 metres with the camera pointing directly at the target. In hope of using this additional data alongside other UAV data collected to enhance the finished result. As far as control is concerned the idea is to use already rectified and processed data from the air as control to tie the terrestrial photographs. Also it is worth noting that the coordinates and orientation of the image is not recorded in this process which may affect the outcome.

3.10 Scanning

Scanning is to be used as a base for comparison, scanning with targets can provide sub centimetre accuracy and will be a great comparison to photogrammetric data. The scanner available for use is fairly widely used for engineering applications within Australia, the unit is compact and is intuitive to use. As scanning is timely a small portion of this site with the best features for comparison will be selected.

3.11 Targets

To reduce errors, targets provided with the instrument are to be used. Each station is proposed to have a minimum of 3 targets visible from station to station. The scanner is to be set on a mid-accuracy which reduces time without compromising the quality required for a comparison.

3.12 Data Storage

To eliminate the chance of data loss, once data is captured it will be removed from mobile device and stored on both PC and portable hard drive. Data must be easily accessible for processing.

3.13 Processing, Comparison & Analysis

3.13.1 Data Processing

Due to the nature of the project, there is a high reliance on the use of computers and software. A variety of software is to be used for the project and has been discussed further in section 2.2.

It is proposed that the data processing will be completed as follows.

3.13.2 Preliminarily Processing

Complete initial processing of photogrammetry data to check for gaps and holes in data for both surveying scanning and photogrammetric data. Complete further data collection if required.

3.13.3 Traditional Surveying and Control Network Processing

Process and check control network, output in a form compatible for photogrammetry processing. Check field work for holes. Have it prepared in Autodesk ready for data integration.

3.13.4 Photogrammetric Processing (Pix4D)

Ultimately utilise data from section 3.12.2 and apply distortions and corrections to data. On completion export to AutoCAD for direct comparison. However, the process is much lengthier and can be complete using these steps below.

1. Filter Image- Manually check each image for possible blur or incorrect exposures, removed. See figures below which compares two images, one sharp (figure 3.3) and clear the other of the same area out of focus (figure 3.4).

Figure 3.4 - Image Blur

Figure 3.3 - Clear Image

2. Load images into Pix4D, if available Meta data for each image would have been used however the platform used requires a high volume of editing to use image Meta data and would be inefficient.
3. Load GCP's from excel control file created when processing control.

4. Using basic editor window, identify each control point in a minimum of 3 images (5 images is proposed for this project).
5. Run processing and view results, identify any control points which can be optimised this is best achieved by checking the pixel error.
6. Use optimisation tool to check and optimise weakest control points.

3.13.5 Process Scanning Data

Process and check scanning data. Export to AutoCAD for comparison to both survey and photogrammetric data.

3.13.6 Process Terrestrial Photogrammetry

Investigation will be conducted to discover whether or not terrestrial photogrammetry data should be processed separately or if it should be introduced during 3.11.4. There are two different ways to approach this process, firstly process both data sets individually (Aerial & Terrestrial) and combine them, secondly combine them as a group and allow the processing to combine them the process is outlined below.

Individual process:

1. Process data set individually and check results.
2. Combine with aerial data.
3. Combine aerial and terrestrial data together.
4. Check accuracy & quality.
5. Compare & contrast.

Process all data in one step in Pix-4d

1. Check accuracy & quality.
2. Compare and contrast.

The following software is to be used to suffice the above

3.14 Photogrammetry Processing

The software used for processing photogrammetry data is Pix4D. It is common in the Survey/ UAV industry thanks to its simple yet powerful functions.

3.14.1 Scanner Processing

The scanner software is to be supplied by USQ is Faro scene. It allows the point cloud data processed colourised from here it allows for exporting to an external software package.

Furthermore, to combine and align the data a program called mapteck i-sight studio was used.
The laser scan data was captured using a Faro Focus 3D Laser Scanner. The data was captured using a high resolution setting that resulted in each scan potentially capturing approximately 176 million points.

Spherical targets were placed in the field of view for each scan. Several of these targets were common in adjacent scans and allowed the scans to be registered, relate to each other. This registration process was completed in the Faro Scene processing software. Each scan was then exported in a file format compatible with the Maptek I-Site Studio program.

These exported scan files were then imported into the Maptek I-Site Studio program. The scan data was then positioned and orientated to data captured during a total station pick-up of the survey area. This total station pick-up was in the same relative datum as the targets used in the UAV survey. A shed ridge line was used for this purpose, while the roof line in the house was used to confirm the positioning of the scans. Once this process was completed, the scan data was then re-exported through both the Maptek I-Site Studio and Faro Scene programs in a file format that was compatible with the Liscad SEE program for further analysis against the total station pick-up and the UAV dataset.

3.14.2 Survey, Photogrammetric and Scan Data Comparison Process

The core component of the project is the comparison on the data sets, identifying a process which enables and un-bias analysis of the data is of utmost importance. Looking at comparisons in the past in Smeaton and Sensefly, the comparison of only a small number of points <100 is made the points may be randomly selected however it may not include the entire picture missing areas which have a significant difference in terms of the overall results. For a more thorough comparison MapteK Isight studio allows for a comparison from surface to surface meaning that the entire areas chosen can be analysed comparing hundreds of thousands of points in total allowing for a realistic comparison. A direct comparison of scanning data to photogrammetric data was made to identify the strengths and weaknesses of photogrammetric data. Both UAV data sets will also be compared to further understand the limitations and accuracy of the data. Furthermore, the traditional surveying data is primarily used as a check as well as to align and confirm the scanning data which is to be used for the majority of the comparisons. To best analyse the data different types of surfaces have been compared they include

- Hard surfaces- (driveway) hard surface (roof).
- Natural surfaces (mown grass) (high texture).
- Generally, the hard surfaces are monotone type colours and have a limited amount of texture.

Process:

Taking the data from section 3.11.4(photogrammetric data) and 3.11.5 (scanning data) the following steps where undertaken to complete the comparison.

1) Import - all data into Maptek meaning that the scanning data, photogrammetric data as well as the surveying data can be viewed simultaneously. Confirm scanning data accuracy to that of the survey, shift where necessary.
2) Preparing the surfaces- A polygon was created to filter the data this mean that any data outside the extents of the polygon will not be used in the comparison. The filter was used to filter surfaces for comparison.
3) Tin surface and check for spiked & abnormalities which are common in scanning and photogrammetric data.
4) Use De-Spike tools and other tool to remove noise from scanning or photogrammetric data as required.
5) Using colour by distance from surface, select the scanning data as a base (as this is assumed to be most correct) then select the first portrait or landscape surface as a comparison.
6) A scale is calculated automatically and a colour grade however this can be modified as necessary.

7) Before outputting select output text file, this will be used for the data analysis stage as it includes the vertical difference in height between nearest points, hence will allow for an in-depth analysis of an entire surface.
8) Apply the settings and view results- print screen output as required.

3.15 Data analysis

Data analysis requires the use of excel and other visual as well as looking at data obtained when processing initial photogrammetric data. The mathematical data analysis technique discussed below was used to analyse the data.

Mean distance from the comparison surface to the model. This can be used for initial analysis. Where individual points can be selected can compared to each other.

Process:

1. Load text file into Excel.
2. Using statistical tool bar highlight data for analysis and output statistical overview.
3. Undertake the analysis on all data sets.
4. Create appropriate charts & graphs.

Chapter 4 - Results

4.1 Introduction

In order to form a better understanding of the project this chapter has been divided into two main sections which consist of the results and the subsequent discussion section. This chapter highlights the errors found in the models as well as the outcome of combining terrestrial based photogrammetry with aerial photogrammetry.

4.2 Simulation

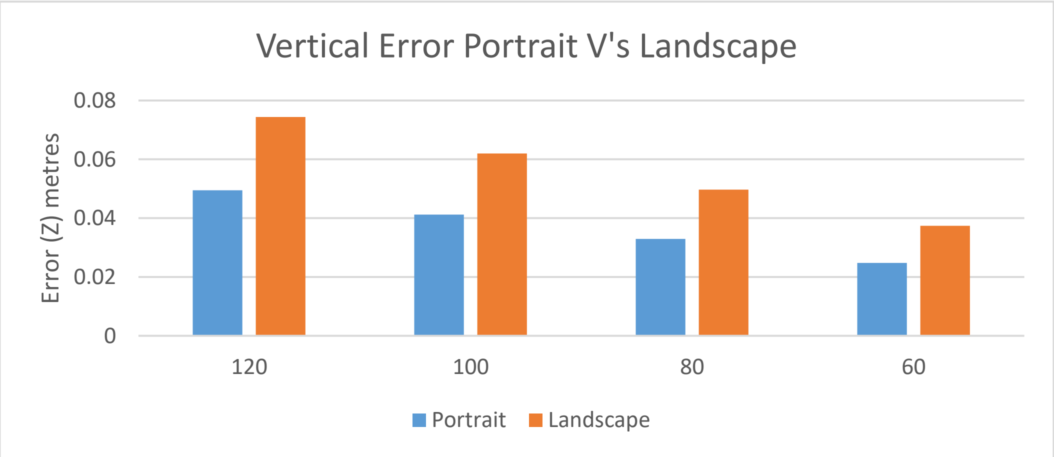
The simulation allows an alternate view of the potential outcomes of different outcomes. It allows the comparison of photogrammetry and different flying heights in both portrait and landscape with minimal cost.

4.3 Accuracy Analysis

Aim of this is to determine the effect of different heights on portrait v’s landscape photogrammetry.

Firstly, the analysis identified that the planimetric accuracy remains unchanged however there is a difference in the vertical accuracy (z axis) demonstrated below.

Table 4.1 Vertical Error, Portrait V’s Landscape



(Figure 4.1) Above shows a direct comparison between that of portrait and landscape accuracy at a given height. Note all other variables remain fixed. An average improvement of accuracy of 33.5% is achieved when flying a mission in portrait v's landscape based on the above calculations. These results will be compared to actual accuracy obtained from the field testing.

4.4 Flight Time Analysis

The main question posed, is the flight time between portrait and landscape photography significant. Also looking at the efficiency on a per point basis. The comparison determines the number of points obtained for each second of flight. Therefore, determining the amount of data captured for a given amount of time.

Using data obtained from processing the following can be concluded.

Total number of points collected for landscape and portrait are 26453581 and 43119418 respectively. Taking the amount of time for each flight and dividing it by the number of seconds in each flight gives us a number of points per minute calculation. The results are 41870 V's 45340 points a second resulting in an increase of 7.6% efficiency on a point to time basis. Note this does not relate to the calculated increase in accuracy of each point in the Z axis which based on the calculation exceeds 30%. This poses the question is why is there an increase in efficiency which will be covered later in the discussion section.

4.5 Processing Time analysis

4.5.1 Processing Without Control

For initial checks and testing of data. Similar to that of section 4.4 were a number of points per second is calculated, except this time looking at the processing time instead of the flight time. Again the number of points obtained were the same as section 4.4 however the processing times are significantly larger than that of the flight time of landscape and portrait being 142 and 272 minutes respectively this gives us a per second result of 186292.8 and 158527.3 meaning that the software process the data 14% slower for portrait then that of landscape. Again this has no relation to the actual point accuracy obtained for each point however it identifies the point density.

4.5.2 Processing with Control

For a finished product, this relates the 3D model to the survey data. Following from section 4.5.1 the number of point as well as the related time have been recorded. Processing time with control is much faster, this is probably due to many of the images already being aligned in the ground control point adding feature.

4.6 Results - Airborne Photogrammetry Quality Report Analysis.

This section covers primary project goal identifying actual accuracy's and quality of both portrait and landscape models.

4.6.1 Coverage Percentage

The more complete a model 3D model is in surveying in general the better the result. This sections compares the actual point density and the coverage area obtained from each flight of the flights undertaken.

4.6.2 Flat Surfaces

Identified as areas such as driveway and short grass.

4.6.3 Textured Surfaces

Identified as long grass, trees and roof which have an irregular formation.

4.6.4 Point Accuracy Survey Data Comparison

Compares the effect of portrait and landscape photogrammetry to that of traditional surveying data. This comparison used the data captured from the initial survey to compare to the photogrammetric data.

4.6.5 Point Accuracy Scanning Data Comparison

Compares the effect of portrait and landscape photogrammetry to scanning data. A total of 6 stations were used in order to capture enough data for an appropriate comparison. The scans were uploaded into faro before being combined in Maptek eyesight studio then later aligned to the survey data. During the pickup phase the control for the UAV was not in place hence a number of hard services were used to align the scanning data to the survey data. This will allow for an overall comparison between the UAV and scanning data.

4.7 Accuracy Analysis from Quality Reports

Where results can be quantified the green indicates the favourable statistic between portrait and landscape.

Table 4.2 - Quality Report Summary

Parameter	Landscape	Portrait
Average ground sampling distance (GSD)	1.30	1.29
Images Captured	59	70
Images Useable (filtered)	51	63
Number of calibrated images	51	62
Area Covered by flight (hectare)	0.85ha	0.99ha
Number of images per hectare	59 images/ha	63 Image/ ha
Matches per calibrated image	8576	8795
Geo referencing error	0.01	0.009
Density per M^3	13256	14608

4.7.1 Average Ground Sampling Distance (GSD)

As expected stayed basically the same for each project as the flight height for each flight way approximately the same meaning that the GSD would remain unchanged.

4.7.2 Images Captured

Images captured is the total number of images each flight obtained without removing any images which are blurred or incorrect.

4.7.3 Images Useable

Total number of images from the flight that are going to be used for processing, meaning that the user has manually filtered the images.

4.7.4 Calibrated Images

I.e. the number of images used for the creation of the point cloud. Working out the number of images per Ha gives the following results of 59 images per ha v’s 63 images per ha. Meaning that the percentage of images for portrait is only slightly greater. Even though the flight area to be captured was fixed the area that was captured useable was greater in the portrait orientation.

4.7.5 Area Covered by Flight (Hectares)

The total area of which was captured in flight based on processing. In this case the portrait had an area 16% greater than that of landscape which is a substantial difference.

4.7.6 Number of Images Per Hectare

Calculated using the number of images used for processing and the resulting area from the model. Portrait captures a slightly higher number of images then that of landscape meaning an increase of 6% in the number of images required per ha verses that of landscape.

4.7.7 Number of Points Per Hectare

Takes the number of points total in the model and divide by the resultant area to give a resulting number of points per hectare. This particular model 21853790 and 30008042 for portrait and landscape respectively. This difference in substantial with a 27 percent increase of points from landscape to portrait. Note this does not take into account the number accuracy of each point gained meaning that an even larger benefit may be obtained if the point both the number and accuracy of points increase for portrait orientation.

4.7.8 Matched Points

The number of matched point in each image will affect the quality of the calibrated images, those areas with higher number of matching points are likely to have higher strength and quality. In the processing above there is 3% increase in the number of matches form landscape to that of portrait meaning that the portrait should have slightly greater strength in terms of quality.

4.7.9 Geo-referencing Error

Is the error due to the perceived difference in location in height from different images? The z axis on the landscape images has influenced the overall accuracy of the project with an error or 9mm and 10mm for both portrait and landscape. In term meaning that there is little to no difference in the fit to the control.

4.7.10 Image Overlap

Areas of green are likely to be of higher strength and quality. The number of overlapping images for each flight is critical to the overall outcome, the footprint from the landscape is more broad this is due to the greater distance between flight paths compared to that of portrait. Meaning a higher percentage of the model may not be useable compared to the of the portrait model again placing favour to the portrait model. Note on projects that are much wider and require more flight paths the effect of this will be significantly reduced.

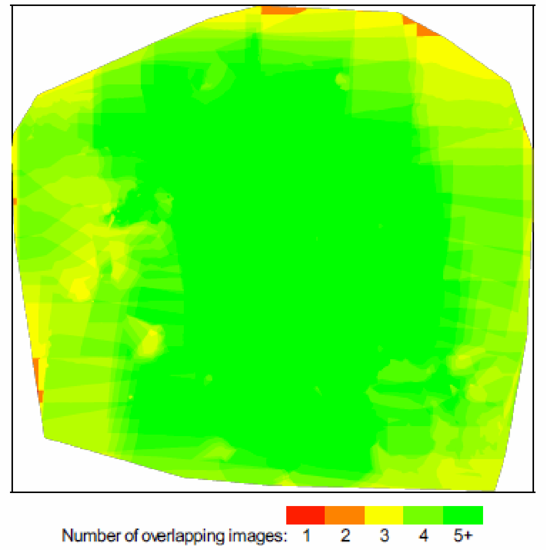


Figure 4.1 - Landscape Photo Coverage

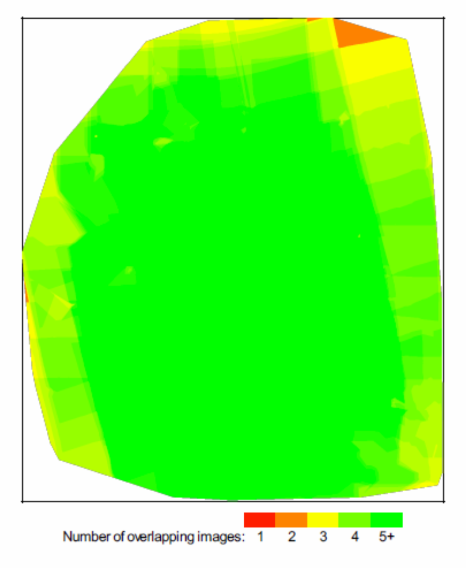


Figure 4.2 - Portrait Photo Coverage

4.7.11 Control Network

4.7.11.1 Network Overview

Below in (figure 4.3) the layout of the control network is displayed, in this situation the network had to be varied due to the nature of the site which has dense tree coverage in

Figure 4.3 - Control Network

areas.

When processing photogrammetry data the relevant software produces residuals that tell us the potential accuracy based on the control the results are summarised below in figures 4.4 and

Landscape			
GCP	X	Y	Z
1	0.007	0.004	0.021
2	0.007	0.002	0.021
3	0.010	0.004	0.027
4	0.005	0.004	0.002
5	0.008	0.008	0.003
6	0.004	0.006	0.001
Mean	0.007	0.005	0.013
Standard Error	0.001	0.001	0.005
Standard Deviaiton	0.002	0.002	0.012
CI 95%	0.002	0.002	0.012
Mean Error XYZ	0.008		

Figure 4.5 - Landscape Control Summary

Portrait			
GCP	X(m)	Y(m)	Z(m)
1	0.002	0.007	0.002
2	0.001	0.009	0.009
3	0.006	0.009	0.001
4	0.003	0.004	0.006
5	0.007	0.004	0.016
6	0.005	0.001	0.031
Mean	0.004	0.006	0.011
Standard Error	0.001	0.001	0.005
Standard Deviaiton	0.002	0.003	0.011
CI 95%	0.002	0.003	0.012
Mean Error XYZ	0.0069		

Figure 4.4 - Portrait Control Summary

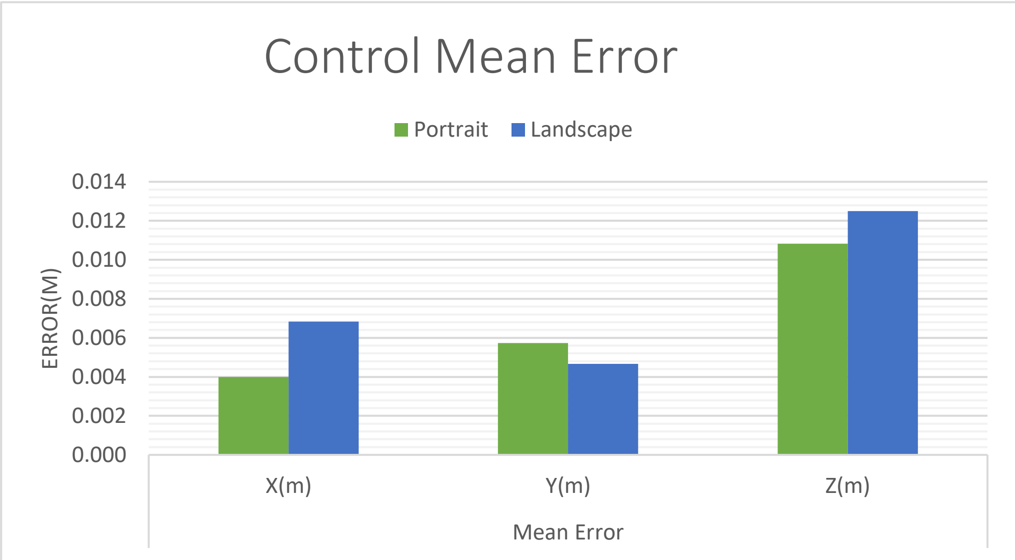


Figure 4.6 - Control Error

Firstly, from the literature (vertical) z accuracy is said to be approximately between 1-3 times the horizontal accuracy. The calculated base t height ratio is for portrait and landscape is 1.71 and 1.44 respectively. A the slightly higher XY to Z accuracy ratio for portrait, also saw slightly better results for both the X, and Z axis. From figure 2.1 the maximum for both of the results is 31mm (for the z axis) furthermore there is no obvious trend in relation to the accuracy of the control points this suggest there are no significant errors in the control as no outliers were determined in either of the processes.

4.1 Surface Comparison

The following analysis covers different surface types and their related results. The site is split then numbered. As can been seen in Figure 4.7 and table 4.3.

Each graph has 3 different comparisons being portrait compared with the scanning data, landscape compared with the scanning data and portrait compared with landscape photogrammetry. Each comparison area identifies the mean, median, mode and standard deviation.

Table 4.3 - Comparison Areas Summary

Area	Surface Type/Texture	Area M^2 (Approximatly)	Points (approximately)
1	Asphalt	60	60,0000
2	Corrugated Iron	60	60,0000
3	Grass	110	110000
4	Grass & Asphalt	80	80,0000
5	Corrugated Iron	60	60,0000

Figure 4.7 - Area Overview

4.2 Area 1 & 4 Driveway as well as Driveway and Grass

Area 1 features an asphalt driveway approximately 3m wide with a monotone black surface, area 4 features a combination of driveway and asphalt and the relevant transition between the surface types. Both these areas are analysed together as they are in a similar location with a similar result.

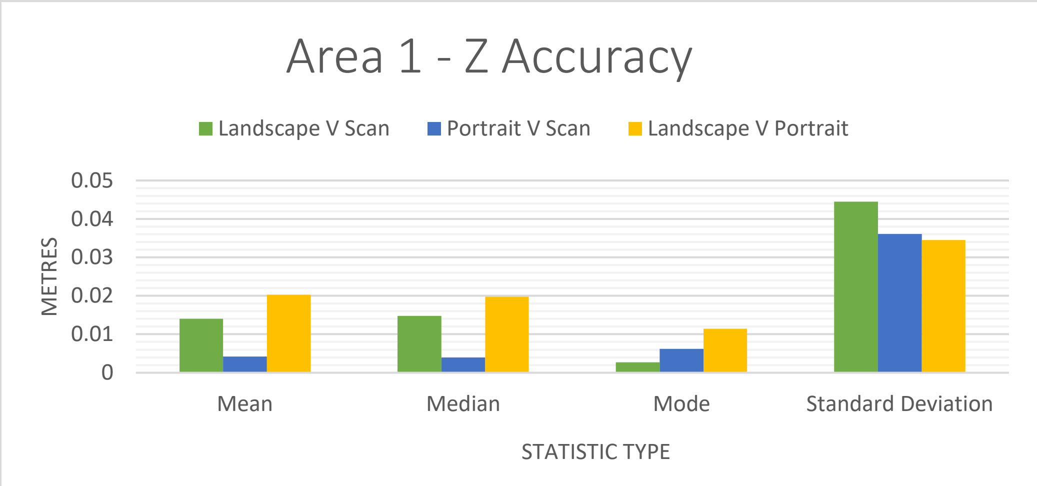


Figure 4.8 - Area 1 Statistics

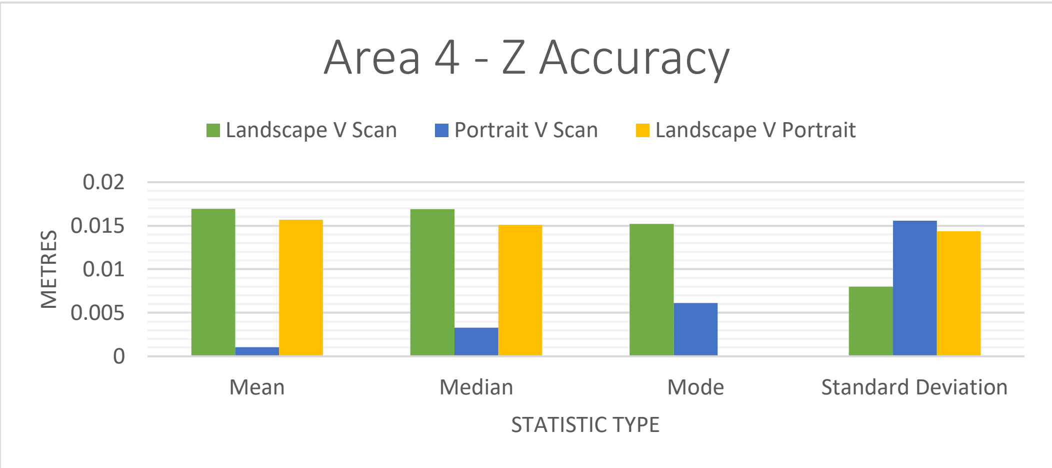


Figure 4.9 - Area 2 Statistics

The areas above feature a good landscape accuracy mean of less than 10mm each, however area 1 has a very high Standard deviation in comparison to that of the mean. Area 4 had a slightly better standard deviation. More will be covered in the discussion in chapter 5 as the validity of these results.

4.3 Areas 2 and 5

These sample areas are both on the roof. One sample is over an area with some visible errors, while the other area is free from any visible errors. The results reflect the poor accuracy for the area with the visible error. With an error of 30mm v's 12 on the surface with no error.

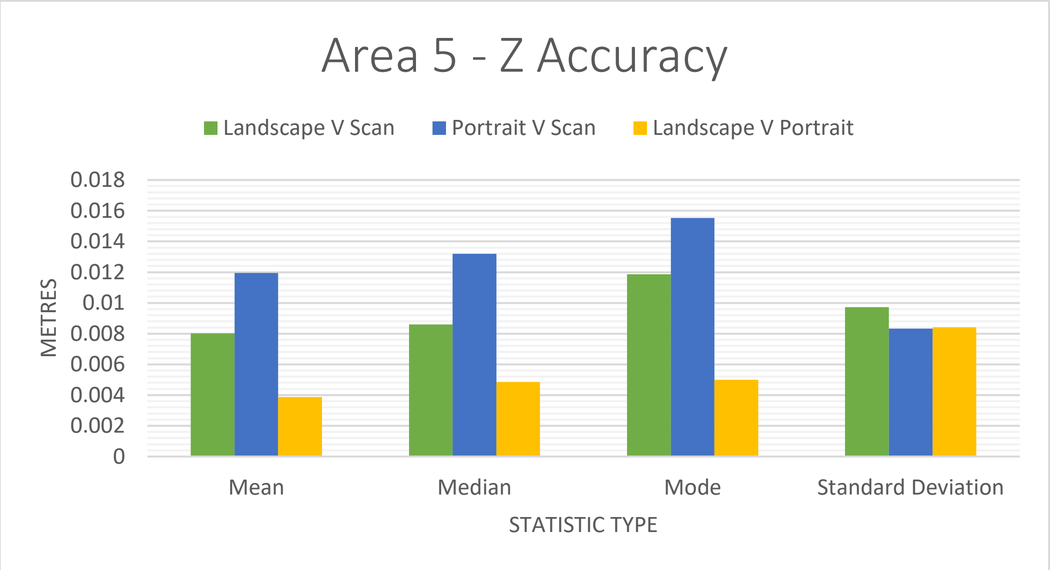


Figure 4.10 - Area 5 Statistics

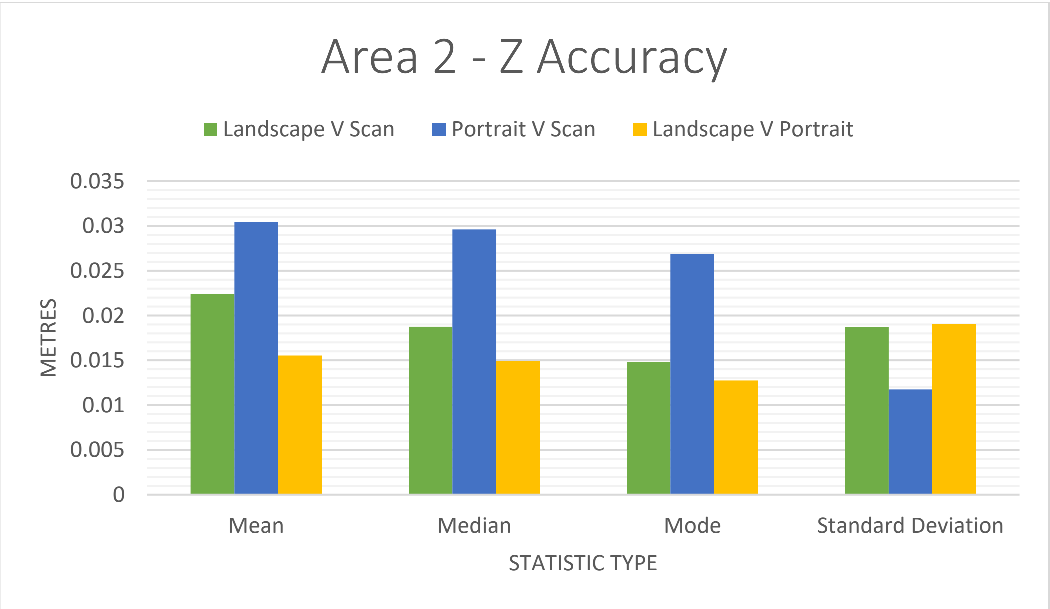


Figure 4.11 - Area 2 Statistics

4.4 Area 3 Short Grass

This area has a high texture. The ground itself sloping however makes a good comparison for natural surface type areas. In this area the standard devation is one of the lowest of all the areas even though it has one of the highest means.

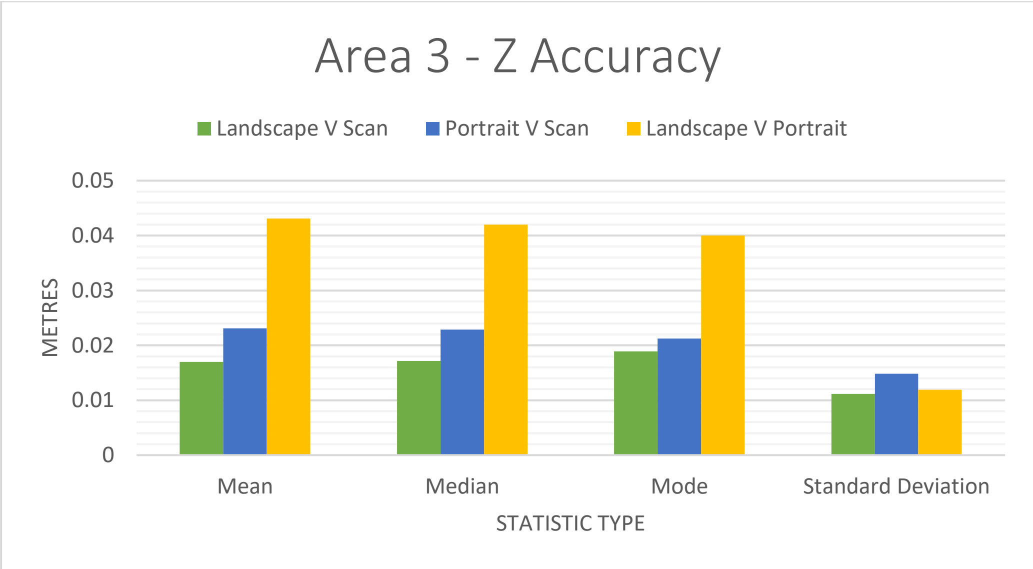


Figure 4.12 - Area 3 Statistics

4.5 Surfaces Summary

In summary the mean of all the results can be seen below. The mean over the entire surface was similar for both portrait and landscape.

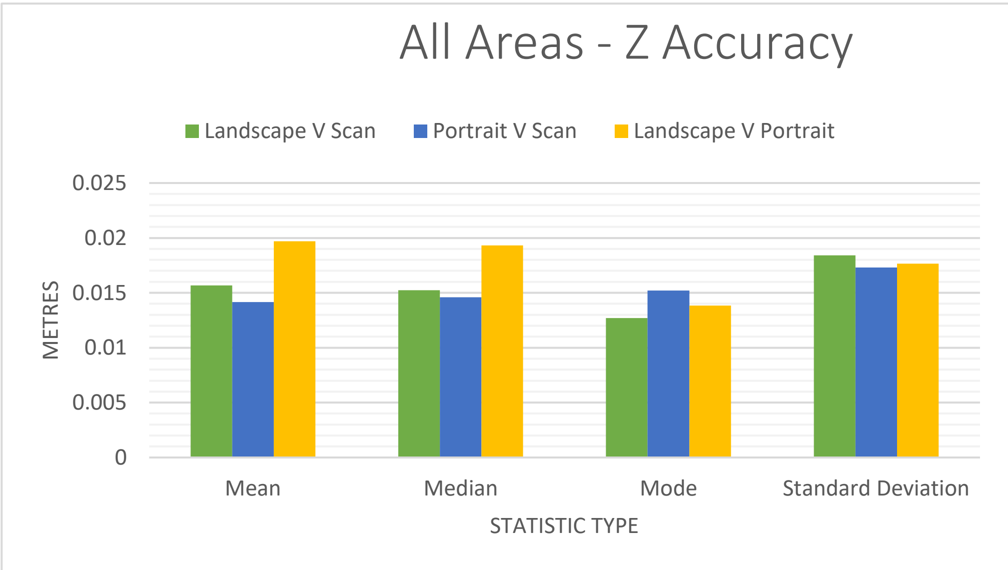


Figure 4.13 - Combined Area Statistics

4.6 Results Ground Based Photogrammetry

The attempt to try and easily combine terrestrial photogrammetry with aerial photogrammetry has not been successful in this particular case. There are several reasons I believe it was not a success. Firstly, trying to combine a large of number of images without any geolocation spread over a site was not going to work unless the software identified where each image was from. The biggest issues with this was that the images could not relate to other images as they were taken at right angles and did not include enough of the same data in order to match the aerial and terrestrial images.

The first attempt at combining the images as described in method one resulted with none of the terrestrial images being used for the model. This was a surprise as PIX4D is definitely capable however the capture method must not have been desirable in terms of overlap.

Using method two the images where processed individual as an entire group with only a very small portion of images being recognised. A final attempt was made to combine the images as induvial sets for each object. However, this still had only very limited success. The question in why didn't it work and how could we get it to work.

Potential Issues

- Image overlap
- Geo location
- Control

This raises the question is it likely that the requirements for planning, the use of control as well as the processing time a practical option for surveyors.

It also raises the question would units such as the V10 be a cost effective solution to reducing the number of gaps from airborne photogrammetric data.

Chapter 5 - Discussion

5.1 Introduction

This section covers further information regarding portrait and landscape photogrammetry. Looking at the number of landscape orientated platforms.

5.1.1 Area 1 & 4 –Discussion

Saw the lowest mean distance from surface to surface however, achieved a poor standard deviation exceeding 40mm the cause of this error is shadows which is covered in section 5.1.5. the area not effected by shadows have a significantly better standard deviation. When landscape the surface is compared to the portrait surface the errors mean is less than 5mm.

5.1.2 Areas 2 and 5 Discussion

Area two has visible errors in the model however both portrait and landscape both achieved accuracy of less than 30mm. The surface 5 which does not include the error is still noticeably worse accuracy then that of area 1 and 4. This raises the question why is the accuracy worse and how can we improve the accuracy on the building. In the case of this unless the GSD is small enough to capture the actual undulations in the corrugation a false flat surface is represented (which is the case here) whereas the scanner itself picks up actual points, meaning that the scanning surface may have an approximate flat surface with undulations. Hence causing a higher mean distance from surface to surface compared to the road. Also effecting the results is the change in height as well as not using any control on the building itself. The use of targets or locating some of the corners in the model and using this to process would greatly increase the accuracy. (Sauerbier).

5.1.3 Area 3 –Discussion

The grass in this area is much thinner than that of area 1, even though the grass is short it long enough to affect the results. Portrait was higher as suspected from photogrammetry. However, the landscape surface was lower than that of the scan. It’s worth note that the land is on a slight slope. However, I don’t think this would have significant effect on the project.

5.1.4 Surfaces Summary Discussion

Looking at all the results as a whole, the overall accuracy in terms of z is surprisingly good with both portrait and landscape being less than 16mm with portrait slightly better than that of landscape.

5.1.5 Shadows

As mentioned in the results, area 1 whilst overall had a great mean surface, however in relation to the range and standard deviation the results were poor meaning that many of the results were outside of 30mm some exceeding 100mm. A paper by M. Sauerbie in 2005 suggest the largest errors occur on steep surfaces with a low texture not a flat surface (like a road). After analysing the images and some research on the internet the most likely of the error is shadow. The accuracy standard deviation of the surface with the shadows (area 1) was approximately 40mm compared to area 4 which should have had a similar result was less than half of that of area 1 (15mm), meaning that the quality of the data is highly compromised when shadows are present. Trees are present on many country and a suburban roads meaning caution should be taken in order to prevent errors. See figures 5.1 & 5.7, firstly an overview of the shadows (Arial image) secondly a view of the model which has a visual error on the area where the shadow is. To reduce these errors effort should be made to pick flight times with minimal shadows and or overcast conditions which greatly reduce the shadows.

Figure 5.2 - Shadows

Figure 5.1 - Shadow Error

5.2 Model Completeness & Visual discussion

This discussion compares a variety of surfacees in different orientations to that of the photo’s it identifies strengths and weaknesses of different orientation in terms of the visual completeness of a model it compares portrait landscape and portrait as well as landscape combined to one another.

5.3 Case 1: Building N/S

Portrait & Landscape Combined (processed together).

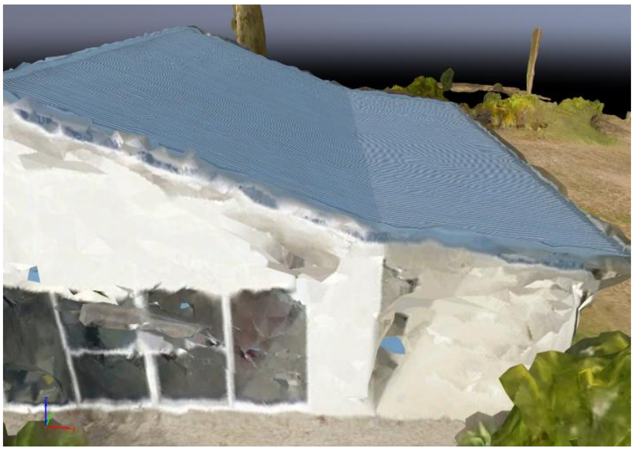


Figure 5.3 - Building Comparison N/S

In this case portrait orientation has a significantly better was construction compared to that of the other model. This trend is evident through most cases. In this case the landscape as well as the Landscape combined with the portrait have a similar result.

5.4 Case 2 : NE Building

Figure 5.4 - Building Comparison N/E

This case clearly shows the difference between portrait and landscape. The building itself has a far better appearance and structure then that of the landscape. The portrait and landscape model has an appearance quality between that of portrait and landscape. This case again demonstrates a better clarity and formation on the image/model for the portrait model (top left) however this is less significant in this particular model. Note that the portrait and landscape combined model appears to be in-between the quality of that of the portrait and landscape models.

5.5 Case 3- Building NE/SSW (diagonal to run lines)

Figure 5.5 - Building Comparison (diagonal)

Case 3 is a tin garage/shed note the deformation in the portrait model compared to that of the portrait model. It is unknown why in the particular case the landscape model is best however the building may lay in a better location in the images (by chance) on the landscape model. Note that this orientation does favour the landscape orientation. This combined landscape and portrait model is by far the worst in this case this is unlike cases 1 and 2.

5.6 Case 4 – Overgrown and Dense Foliage Area

Figure 5.6 - Comparison (dense & overgrown)

Case 4 differs from cases 1,2 and 3. It is in an area which is challenging for photogrammetry due to the location. The tanks are surrounded by shrubs and trees making any photogrammetry difficult. However, the tanks in the portrait model are far better developed then that of landscape where 2, 3 ,4. (from closest to farthest don’t even exist in term of the model. Portrait as well as the portrait and landscape combined both have modelled all the tanks however, portrait appears to be the most complete in this case.

5.7 Case 5 – Ground surface Coverage in Dense Trees

Many projects may have areas with dense tree coverage. Typically, photogrammetry performance is poor in these areas. Analysing the above images highlights the difference between portrait and landscape in terms of ground coverage. The area in black shows the area not complete by the survey. This case the area with the most ground coverage is portrait. Having a greater coverage under trees reduces the need for traditional survey work.

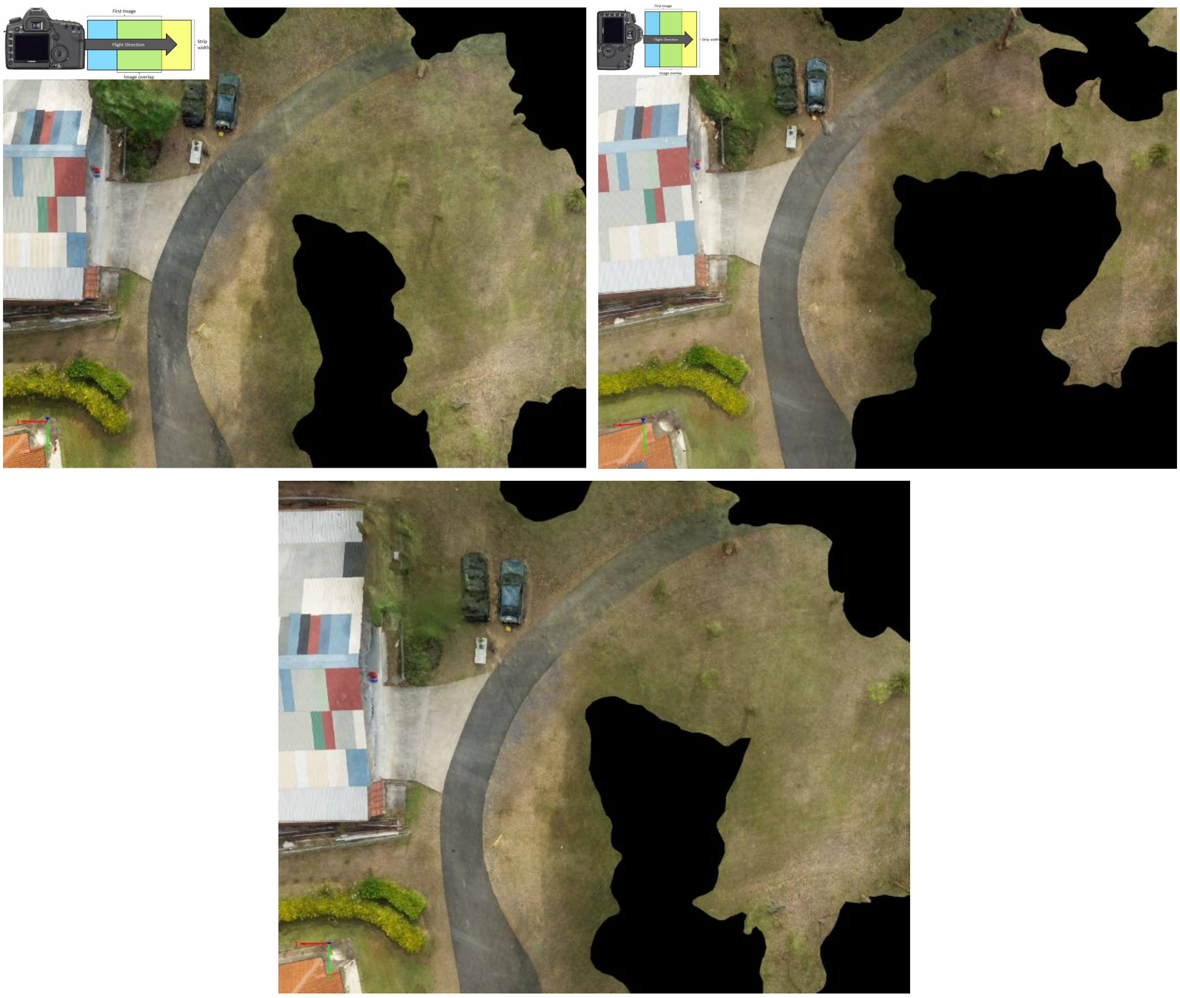


Figure 5.7 - Tree Coverage

5.8 Model Completeness & visual discussion conclusion

From analysing a series of cases comparing the 3 models in the 5 cases it can be concluded that portrait has definite advantage being better in 4 out of the 5 comparisons. Furthermore, the following statements have been derived.

- Portrait camera orientation produces better modelling (visually) of building and structures.
- Structures close two or near obstacles are generally better formed in portrait photogrammetry.
- Greater coverage of ground, in areas under trees is achieved by portrait photogrammetry.

5.8.1 Summary Table

Orientation	Portrait	Landscape	Portrait & Landscape
Case 1 -Building	Best	Poor	Better
Case 2 - Building	Best	Poor	Better
Case 3 - Building	Better	Best	Poor
Case 4 – Structure Difficult location	Best	Poor	Better
Case 5 – Ground coverage (under Trees)	Best	Poor	Better

Table 5.1 - Comparison Summary

5.8.2 Why does Portrait Capture Some Areas Otherwise Missed by Landscape?

Below figures 5.8 and 5.9 show the difference between the photo station layout for portrait (at top) and landscape down the bottom. Overall the spacing for the images is better for portrait hence allowing for a greater number of points as well as capturing data in more marginal areas.

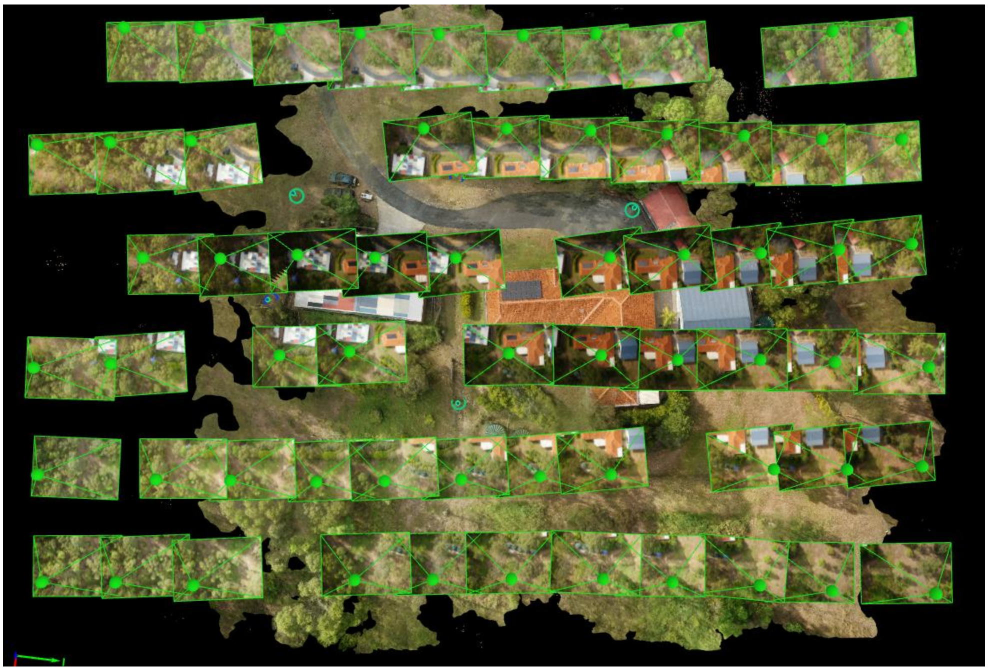


Figure 5.8 - Portrait Coverage

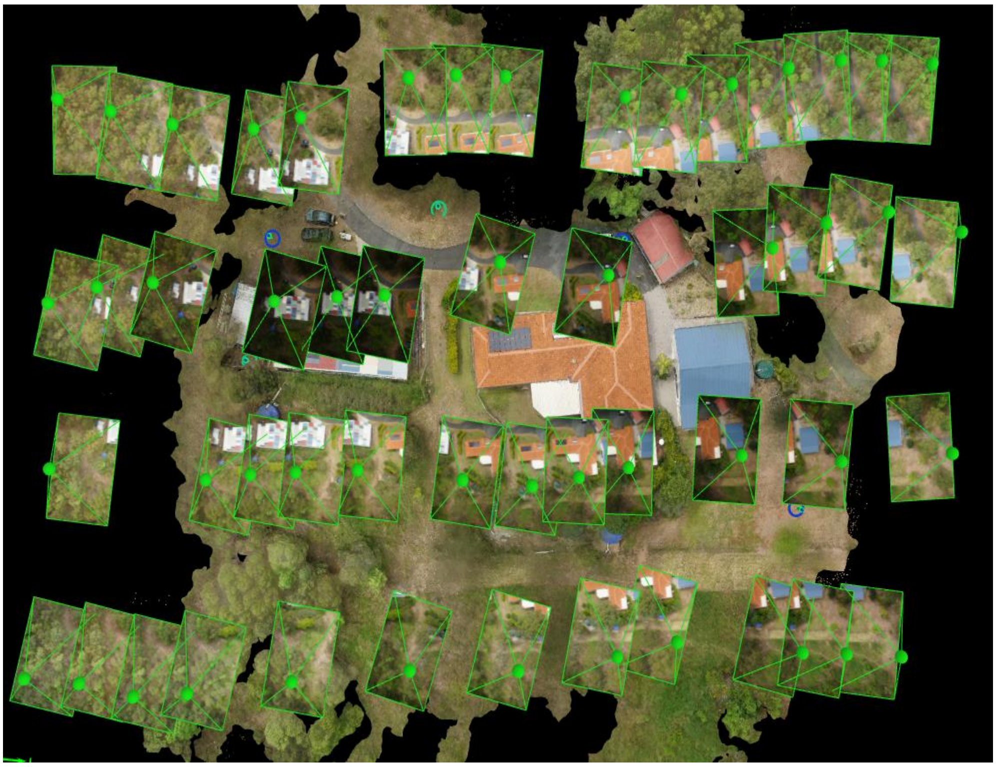


Figure 5.9 - Landscape Coverage

5.8.3 Camera Orientation Practicality

Why do some manufactures (particularly multirotor) not have the ability to change the camera orientation? First let's look at multirotor platforms.

5.8.3.1 Multirotor

Physical Limitations - Many of the low end systems (phantom) have a fixed camera direction meaning that the orientation cannot be changed (without advanced technical knowledge). Many larger systems also have only a two axis gimbal, meaning that the gimbal would physically have to be turned 90 degrees in order to achieve portrait orientation. The best option for this application (change between portrait and landscape) is the use of a 3 axis gimbal that can be programmed to face in both orientations with options for both built into the software. Then depending on the job an orientation can be selected.

Centre of Gravity - The cameras are hung from a gimbal (which must be balanced) assuming no changes in the balance and location of the gimbal the COG will not be changed.

Software - In terms of flight planning many of the main stream planners do not allow the change of parameters which would allow for changing camera orientation.

5.8.3.2 Fixed Wing

Physical Limitations - Many of the fixed wing platforms on the market are highly compact and therefore are not designed to allow for different camera orientations. Fixed wings generally have internally mounted cameras and do not have a gimbal, meaning that the camera is moved along with the airframe which in turbulent conditions may have a detrimental effect on the results.

Centre of Gravity - Due to the nature of the shelf platforms they often only have a small envelope of which the COG must be within. Particularly with flying wings. Therefore, platforms engineered for cameras in a certain orientation must remain in that orientation to make sure the COG remains within manufacturer specification.

Software - Most off the shelf systems software does not include flight planning for cameras in alternate orientations.

Chapter 6 - Conclusion

6.1.1 Findings

The height accuracy of portrait v's landscape photogrammetry was not found to be significant. Furthermore, an increase in number of images and runs (potentially) for the same area coverage does not make portrait photogrammetry economical. The accuracy difference may not have been significant however, structures in areas with dense trees had a noticeable advantage. In some cases, structures that were not formed with landscape were completely formed with portrait, furthermore portrait allows a larger area under the canopy to be mapped in comparison to that of landscape. Furthermore, this project highlights the effect of environmental conditions on the overall results of the project. In particular, the effect of shadows (which appears to be heightened on low texture surfaces) such as a road. It is recommended that flights where heights are critical that they are flown at times with the lowest shadow footprint (around midday) or even better in light overcast conditions which act as a filter and greatly reduce if not eliminate shadows.

6.1.2 Testing Limitations

Financial constraints

Due to the nature of the project and having to use UAV's, the amount of testing was limited to only one site and two different flights and flight parameters. This ultimately means that there is the potential for more comparisons of data sets with varying base to height ratios as well as side lap. Furthermore, only a single software package was used for the processing. Results may vary significantly with the use of other processing software.

Unknown errors

Only errors that were known about were analysed. The potential for other errors that have not been covered may have affected the outcome.

6.2 Further Research

The following areas have the potential for further works, they include.

- (Research 1) Terrestrial & Airborne photogrammetry combination
- (Research 2) Airborne oblique photogrammetry with normal airborne photogrammetry.
- (Research 3) Multi Sensor combination.

6.2.1 Research 1

This area has the potential to reduce the so called gaps in the data, taking what I have learnt from my project as well as other relevant projects completed this year (2016) the combination of data sets may allow for a greatly reduced amount of field work required by surveyors. Pix-4D is becoming increasingly advanced and allows the user to process project both individually and separately.

6.2.2 Research 2

Similar to that of Research 1 however uses a UAV to capture the oblique images. The idea again reducing the gaps in the data. This raises the question can normal aerial photogrammetry be processed, from here the areas in the capture that are missed which are still required. Could they automatically be included in a flight path which identifies possible safe flight paths (missing obstacles mapped) to then semi- automatically capture the data required to fill in the gaps.

6.2.3 Research 3

An area relatively untouched, it looks at the combination of sensor types. For instance, the use of photogrammetry alongside scanning. The idea being that the weaknesses in the different sensor types are eliminated. Take the area of focus in my project (country housing lot) where there are a variety of structure types as well as vegetation coverage. The aim being to capture not only the trees but the natural surface below. As well as more accurate information on the fixed surface. Then with use of a lidar type system to capture the areas in shadow from trees and in shadow. Then combine this with photogrammetry data. Some of the main factors which are likely to influence the cost is the significant cost of utilising these sensors, furthermore finding a platform (UAV) which is capable of carrying both the sensors. Other challenges may include the processing and combining of data. As smaller sensors are developed its more likely to become feasible!

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Appendix A

Project Specification

For: Bradley Redding

Title: 3D modelling for surveying projects using Unmanned Arial Vehicles (UAVs) and Laser scanning.

Major: Surveying

Supervisors: Zahra Gharineiat

Enrolment: ENG4111 – EXT S1, 2016

ENG4112 – ONC S2, 2016

Project Aim: Determine the effect of portrait & landscape photogrammetry on overall accuracy of the resulting model as well as investigate the use of terrestrial photogrammetry alongside airborne photogrammetry in order to create a more complete 3D model hence a better product.

Programme: Issue B, 4th march 2016

1. Identify/ research appropriate specifications for data capture.

2. Create a plan to capture data as well as identify instruments required.

3. Process data using appropriate software.

4. Analyse and compare models and identify if changes need to be made to the model in order to improve the overall results.

5. Capture more data as required to enhanced the model.

6. Make recommendations as to the use of portrait v's landscape photogrammetry. As well as the use of terrestrial photogrammetry and if it is an effective method of capture for industry.

If time permits:

7. Present findings and results to a conference and obtain feedback from the public.

Quality Report

Appendix B

Generated with Pro version 2.2.22

	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	project test #5 landscape 2.2
Processed	2016-08-17 06:12:56
Camera Model Name(s)	NEX-5N_E18-55mmF3.5-5.6OSS_19.0_4912x3264 (RGB)
Average Ground Sampling Distance (GSD)	1.3 cm / 0.51 in
Area Covered	0.014 km^2 / 1.3983 ha / 0.0054 sq. mi. / 3.4571 acres
Time for Initial Processing (without report)	08m:05s

Quality Check

Images	median of 51723 keypoints per image	
Dataset	51 out of 51 images calibrated (100%), all images enabled	
Camera Optimization	2.5% relative difference between initial and optimized internal camera parameters	
Matching	median of 7047.43 matches per calibrated image	
Georeferencing	yes, 6 GCPs (6 3D), mean RMS error = 0.009 m	

Preview

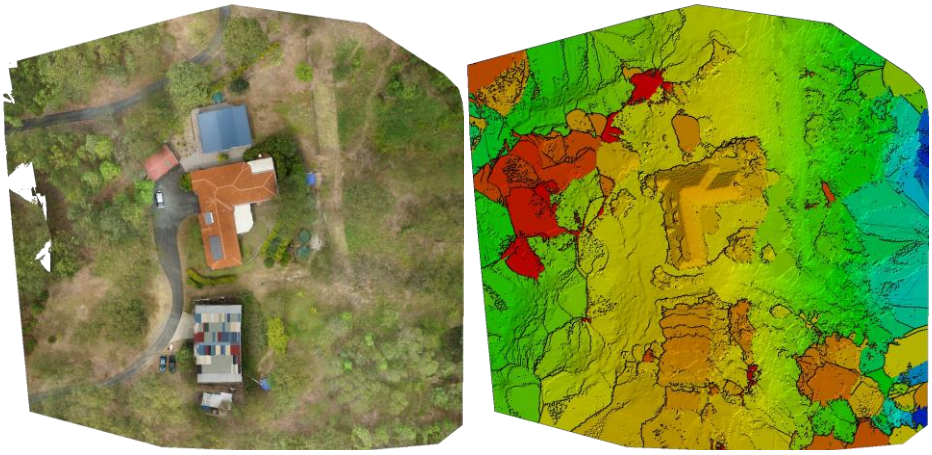


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

Calibration Details

Number of Calibrated Images	51 out of 51
Number of Geolocated Images	0 out of 51

Initial Image Positions

The preview is not generated for images without geolocation.

Computed Image/GCPs/Manual Tie Points Positions

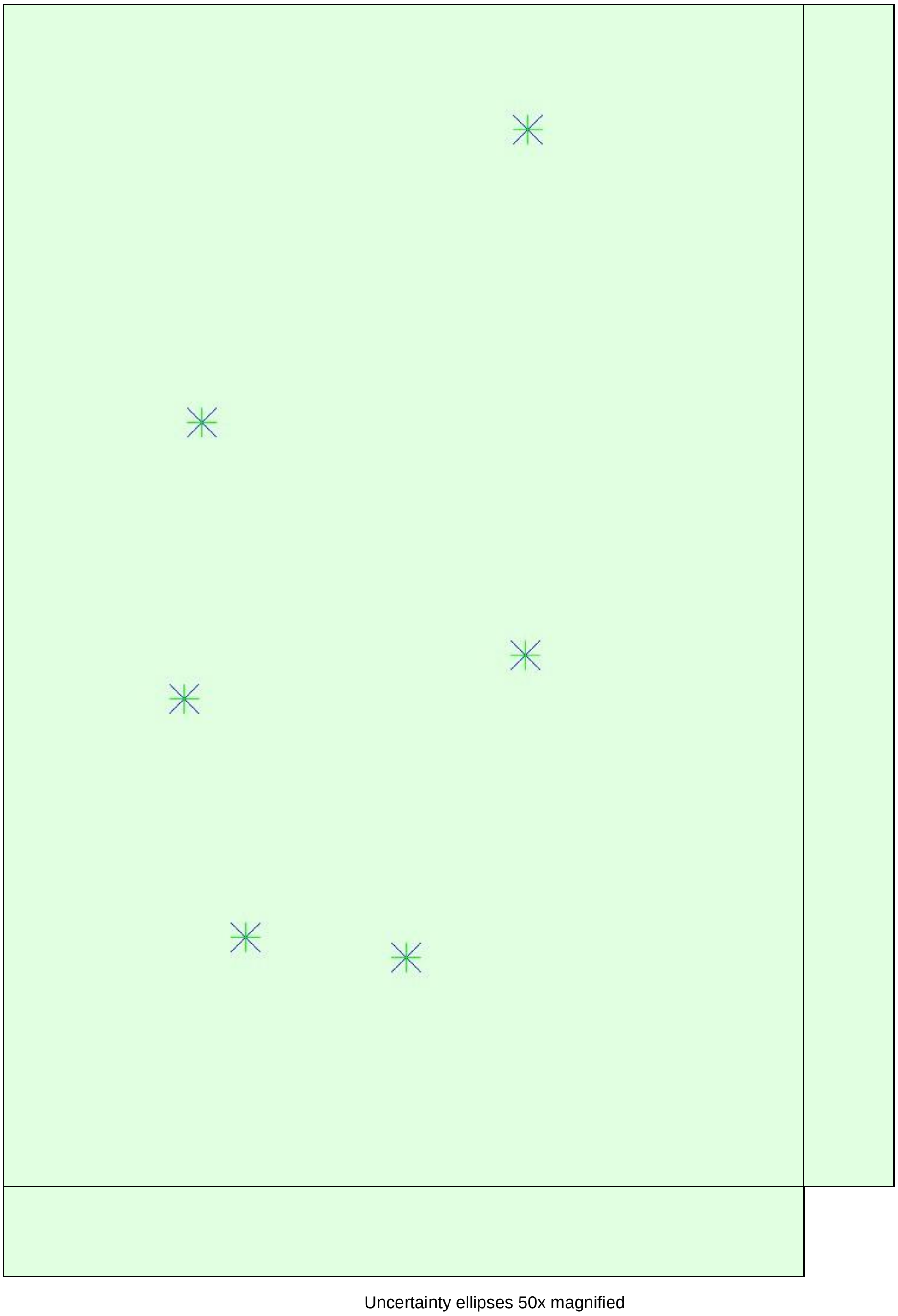


Figure 3: Offset between initial (blue dots) and computed (green dots) image positions as well as the offset between the GCPs initial positions (blue crosses) and their computed positions (green crosses) in the top-view (XY plane), front-view (XZ plane), and side-view (YZ plane). Dark green ellipses 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	0.039	0.041	0.129	0.045	0.043	0.011
Sigma	0.006	0.013	0.005	0.014	0.008	0.004

Overlap

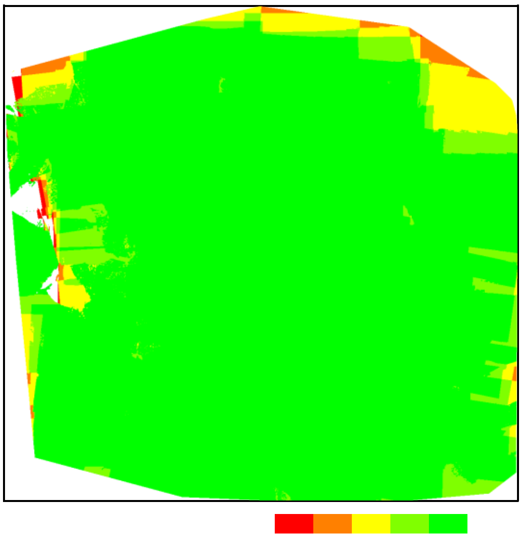


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.

Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	384125
Number of 3D Points for Bundle Block Adjustment	148373
Mean Reprojection Error [pixels]	0.159

Internal Camera Parameters NEX-5N_E18-55mmF3.5-5.6OSS_19.0_4912x3264 (RGB). Sensor Dimensions: 23.400 [mm] x 15.549 [mm]

EXIF ID: NEX-5N_E19mmF2.8_19.0_4912x3264

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	4047.575 [pixel] 19.282 [mm]	2456.002 [pixel] 11.700 [mm]	1632.001 [pixel] 7.775 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	3946.329 [pixel] 18.800 [mm]	2448.274 [pixel] 11.663 [mm]	1634.922 [pixel] 7.789 [mm]	-0.015	0.047	-0.048	-0.000	0.000
Uncertainties (Sigma)	9.748 [pixel] 0.046 [mm]	1.095 [pixel] 0.005 [mm]	1.232 [pixel] 0.006 [mm]	0.001	0.005	0.006	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

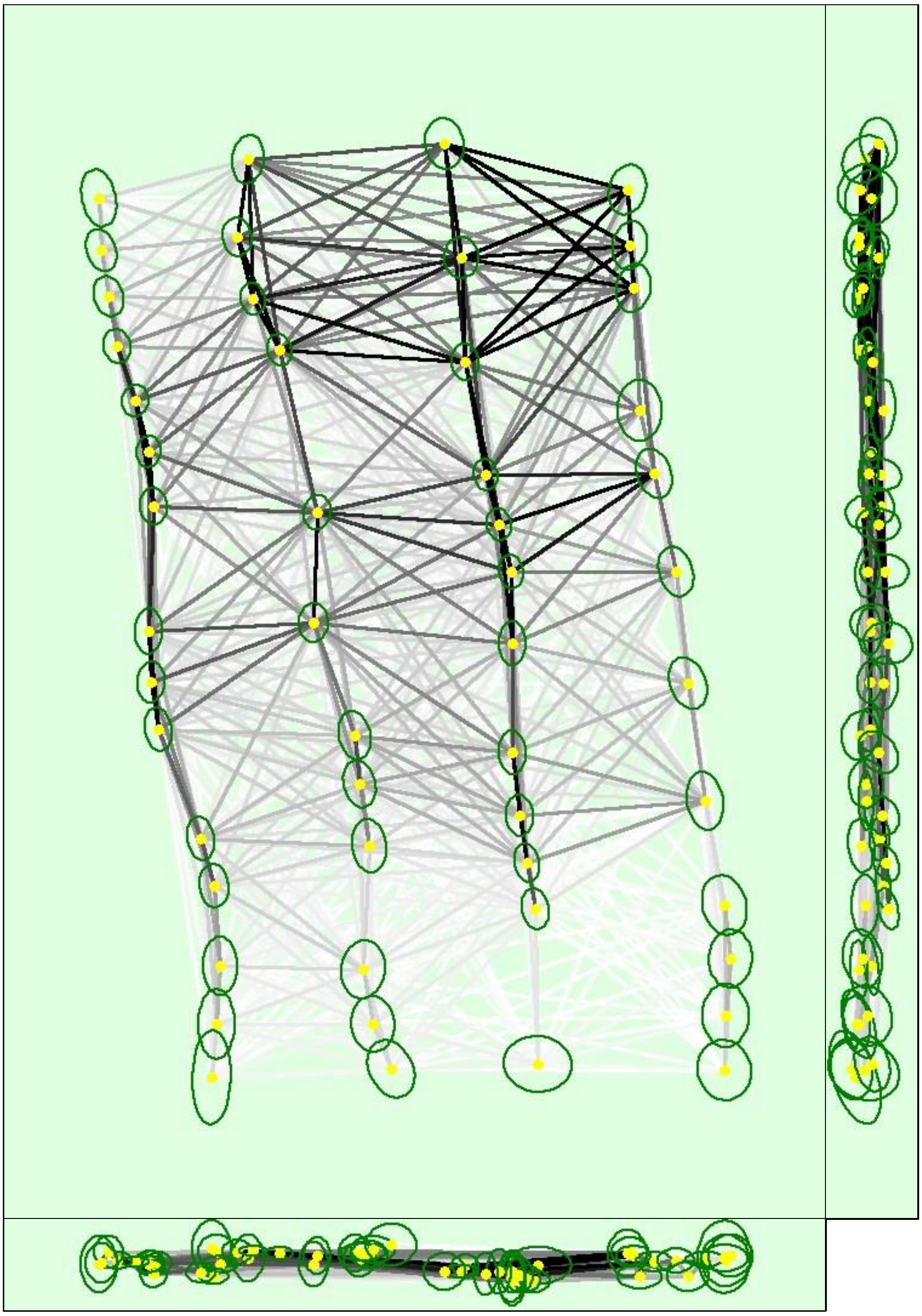
	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	51723	7047
Min	12952	1010
Max	79085	19018
Mean	50433	7532

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed

In 2 Images	105890
In 3 Images	23419
In 4 Images	8715
In 5 Images	4286
In 6 Images	2346
In 7 Images	1324
In 8 Images	901
In 9 Images	590
In 10 Images	452
In 11 Images	190
In 12 Images	138
In 13 Images	59
In 14 Images	47
In 15 Images	11
In 16 Images	5

2D Keypoint Matches



Uncertainty ellipses 100x magnified

Number of matches

25 222 444 666 888 1111 1333 1555 1777 2000

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.

	X [m]	Y [m]	Z [m]	Omega [degree]	Phi [degree]	Kappa [degree]
Mean	0.018	0.025	0.016	0.064	0.045	0.014
Sigma	0.005	0.006	0.007	0.028	0.018	0.003

Relative camera position and orientation uncertainties

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-3632QM CPU @ 2.20GHz RAM: 8GB GPU: Intel(R) HD Graphics 4000 (Driver: 10.18.10.4276)
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	Aerial Grid or Corridor
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 (Original image size, Slow)
Point Density	High (Slow)
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1 Maximum Number of Triangles per Leaf: 8
Advanced: Matching Window Size	7x7 pixels
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Advanced: Limit Camera Depth Automatically	no
Time for Point Cloud Densification	02h:43m:18s
Time for 3D Textured Mesh Generation	01h:30m:48s

Results

Number of Processed Clusters	4

Number of Generated Tiles	4
Number of 3D Densified Points	71018183
Average Density (per m^3)	9902.38

DSM, Orthomosaic and Index Details

Processing Options

DSM and Orthomosaic Resolution	1 x GSD (1.31 [cm/pixel])
DSM Filters	Noise Filtering: yes Surface Smoothing: yes, Type: Sharp
Grid DSM	Generated: yes, Spacing [cm]: 1
Time for DSM Generation	51m:44s

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	project test #16 portrait
Processed	2016-10-10 06:19:37
Camera Model Name(s)	NEX-5N_E18-55mmF3.5-5.6OSS_19.0_4912x3264 (RGB)
Average Ground Sampling Distance (GSD)	1.3 cm / 0.51 in
Area Covered	0.0125 km^2 / 1.2513 ha / 0.0048 sq. mi. / 3.0937 acres

Quality Check

Images	median of 54778 keypoints per image	
Dataset	62 out of 63 images calibrated (98%), all images enabled	
Camera Optimization	3.15% relative difference between initial and optimized internal camera parameters	
Matching	median of 7642.55 matches per calibrated image	
Georeferencing	yes, 6 GCPs (6 3D), mean RMS error = 0.009 m	

Preview

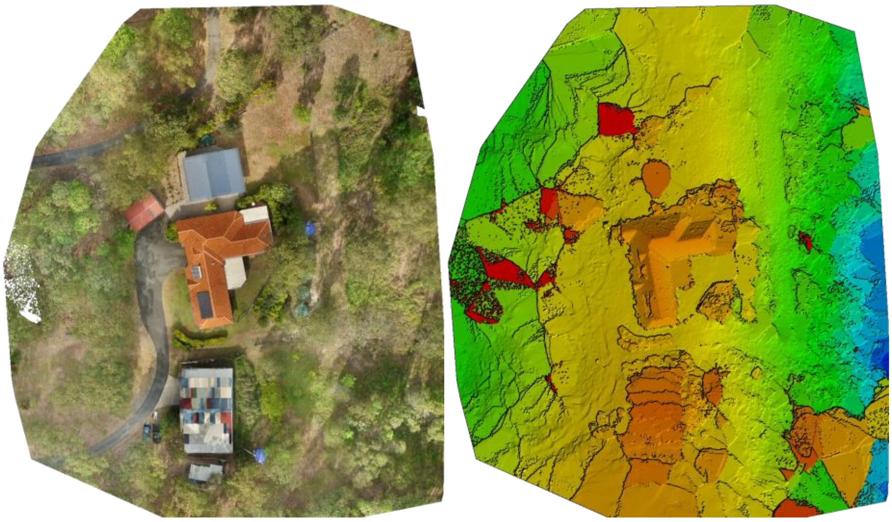


Figure 1: Orthomosaic and the corresponding sparse Digital Surface Model (DSM) before densification.

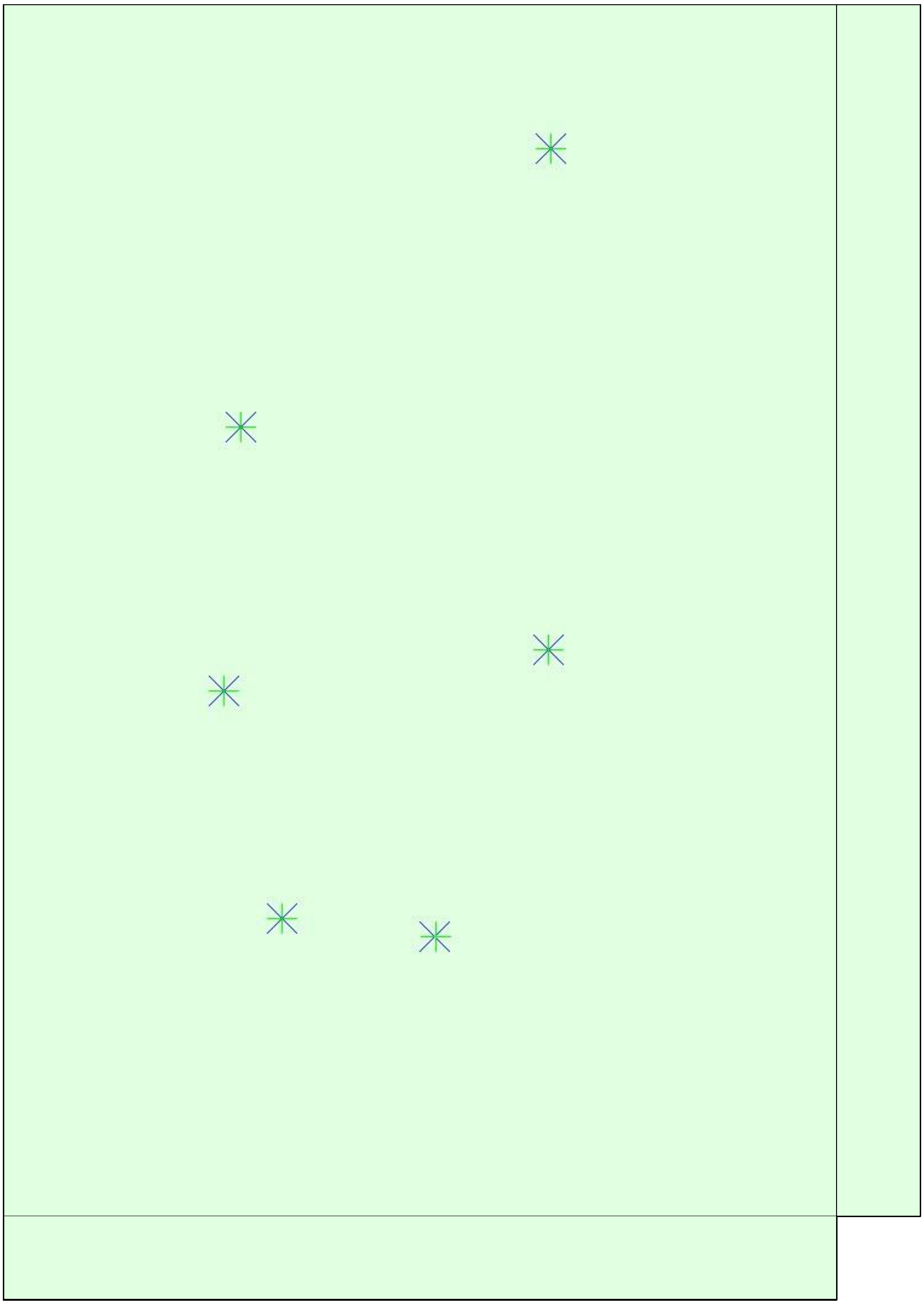
Calibration Details

Number of Calibrated Images	62 out of 63
Number of Geolocated Images	0 out of 63

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). Red dots indicate disabled or uncalibrated images. 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	0.030	0.030	0.129	0.034	0.031	0.009
Sigma	0.006	0.011	0.005	0.011	0.006	0.003

Overlap

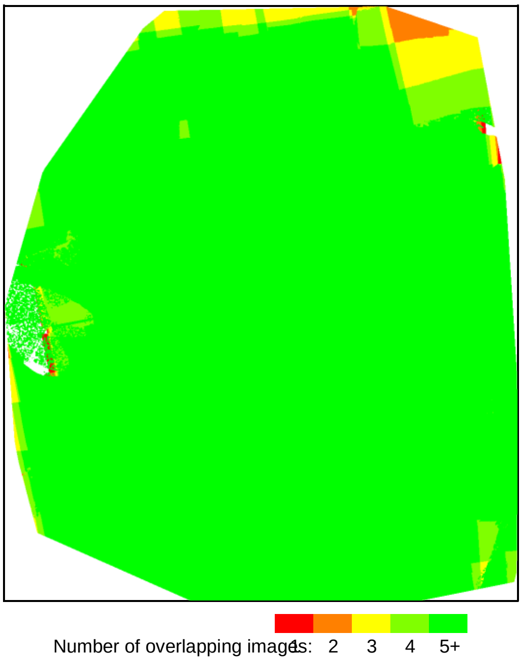


Figure 4: Number of overlapping images computed for each pixel of the orthomosaic.

Red and yellow areas indicate low overlap for which poor results may be generated. Green areas indicate an overlap of over 5 images for every pixel. Good quality results will be generated as long as the number of keypoint matches is also sufficient for these areas (see Figure 5 for keypoint matches).

Bundle Block Adjustment Details

Number of 2D Keypoint Observations for Bundle Block Adjustment	520091
Number of 3D Points for Bundle Block Adjustment	190586
Mean Reprojection Error [pixels]	0.163

Internal Camera Parameters NEX-5N_E18-55mmF3.5-5.6OSS_19.0_4912x3264 (RGB). Sensor Dimensions: 23.400 [mm] x 15.549 [mm]

EXIF ID: NEX-5N_E19mmF2.8_19.0_4912x3264

	Focal Length	Principal Point x	Principal Point y	R1	R2	R3	T1	T2
Initial Values	4047.575 [pixel] 19.282 [mm]	2456.002 [pixel] 11.700 [mm]	1632.001 [pixel] 7.775 [mm]	0.000	0.000	0.000	0.000	0.000
Optimized Values	3919.969 [pixel] 18.674 [mm]	2455.167 [pixel] 11.696 [mm]	1630.196 [pixel] 7.766 [mm]	-0.017	0.051	-0.054	-0.000	0.000
Uncertainties (Sigma)	9.905 [pixel] 0.047 [mm]	0.707 [pixel] 0.003 [mm]	0.668 [pixel] 0.003 [mm]	0.001	0.003	0.004	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.

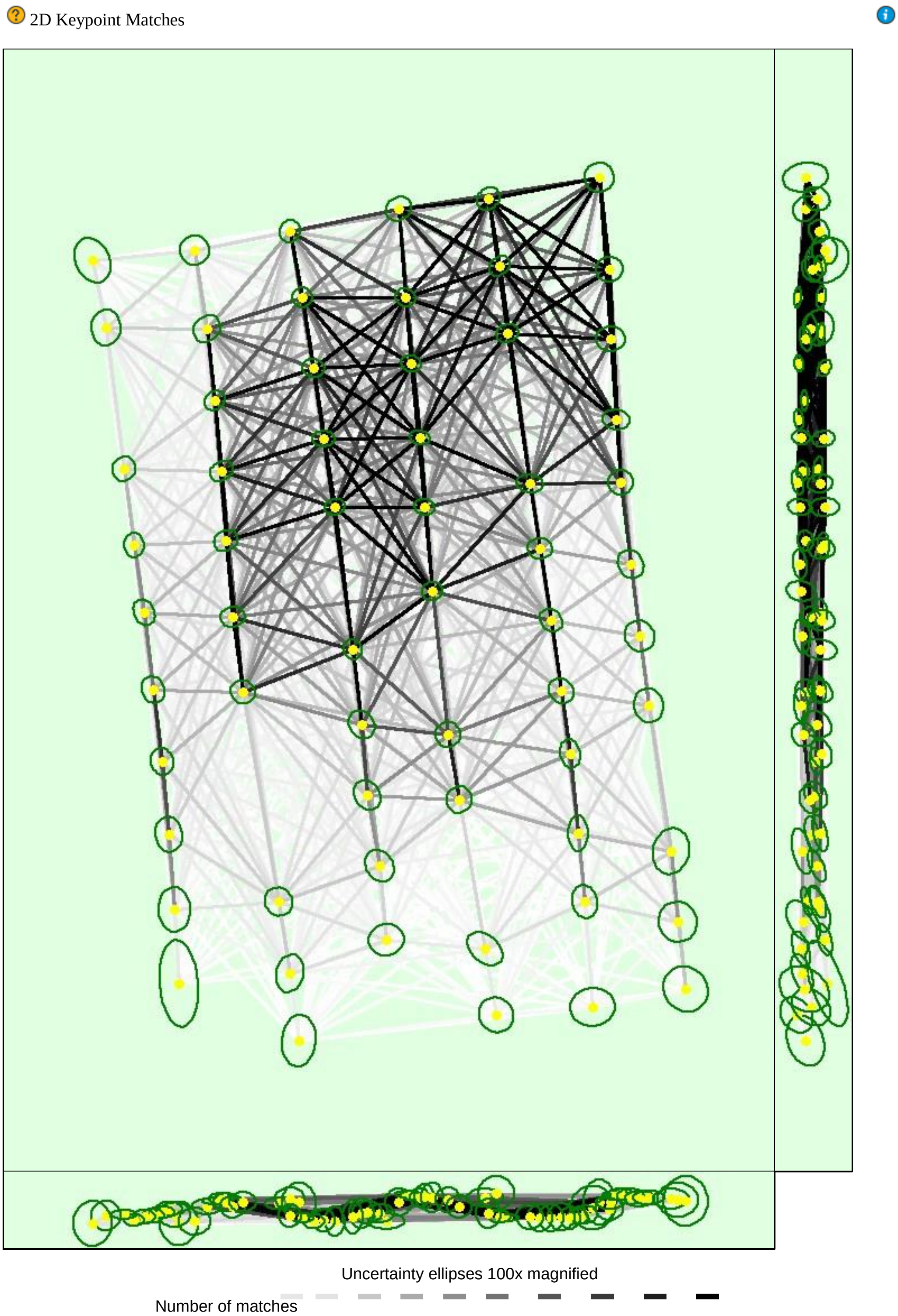
2D Keypoints Table

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	54778	7643
Min	22632	726
Max	73846	18897
Mean	52391	8389

3D Points from 2D Keypoint Matches

	Number of 3D Points Observed

In 2 Images	132592
In 3 Images	29336
In 4 Images	11769
In 5 Images	5988
In 6 Images	3548
In 7 Images	2111
In 8 Images	1536
In 9 Images	1063
In 10 Images	732
In 11 Images	578
In 12 Images	405
In 13 Images	324
In 14 Images	240
In 15 Images	157
In 16 Images	107
In 17 Images	55
In 18 Images	23
In 19 Images	9
In 20 Images	9
In 21 Images	3
In 23 Images	1



25 222 444 666 888 1111 1333 1555 1777 2000

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	0.017	0.018	0.013	0.049	0.037	0.009
Sigma	0.004	0.007	0.006	0.022	0.015	0.003

Initial Processing Details

System Information

Hardware	CPU: Intel(R) Core(TM) i7-3632QM CPU @ 2.20GHz RAM: 8GB GPU: Intel(R) HD Graphics 4000 (Driver: 10.18.10.4358)
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	Aerial Grid or Corridor
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 (Original image size, Slow)
Point Density	High (Slow)
Minimum Number of Matches	3
3D Textured Mesh Generation	yes
3D Textured Mesh Settings:	Resolution: Medium Resolution (default) Color Balancing: no
Advanced: 3D Textured Mesh Settings	Sample Density Divider: 1 Maximum Number of Triangles per Leaf: 8
Advanced: Matching Window Size	7x7 pixels
Advanced: Image Groups	group1
Advanced: Use Processing Area	yes
Advanced: Use Annotations	yes
Advanced: Limit Camera Depth Automatically	no