University of Southern Queensland

Faculty of Health, Engineering and Sciences

UAVs IN PIPELINE DESIGN AND REHABILITATION OF CONSTRUCTION CORRIDORS

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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

Surveying techniques used in pipeline construction have evolved slowly. Terrestrial surveying has dominated the industry with surveyors generally using total stations or Real Time Kinematic (RTK) Global Navigation Satellite Systems (GNSS) systems. Newer technology such as Unmanned Aerial Vehicles (UAVs) has been developed and is creating interest in the pipeline construction and pipeline surveying industry.

This study compared terrestrial RTK GNSS surveying techniques against new UAV data collection techniques in terms of useability, field accuracy analysis and cost analysis when surveying the same 3.5km section of a 25m wide construction corridor. The study found no significant difference in the accuracies of the UAV surveys compared with those of the traditional RTK GNSS surveying techniques. However the operational costs using the UAV technology were about one third of the more traditional techniques. Moreover there were also significant benefits using UAV technology from workplace health and safety perspectives, from variations from initial planning perspectives, and for resolving post-pipeline disputes between landholders and pipe laying contractors.

This study suggests that high resolution aerial orthomosiac imagery, detailed digital surface models (DSM) and high density point clouds all generated from UAV data will become the benchmark for the design and rehabilitation stages of pipeline surveying and construction.

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I would also like to thank my family and partner for supporting me during my studies.

CHAPTER 1 - INTRODUCTION

For a long time industrial pipelines have been used to transfer fluids including oil, gas or water across land between two nominated destinations. Basic construction techniques have also remained relatively unchanged apart from technological advances in project planning, project design, machinery and environmental considerations. Contemporary surveyors and engineers plan an integral role in the design and rehabilitation of pipeline construction corridors for major pipeline projects across the world. In all cases they are bound by regulations from strict regulatory authorities. With greater emphasis being placed on design and rehabilitation of construction corridors, requirements for more detailed information (and data to generate this information) has become prevalent.

1.1 Statement of the Problem

Pipeline contractors generally demand accuracies of between 1mm and 100mm in pipeline surveys and this requires that survey contractors use older labour intensive practices. At the same time profit margins for the surveyors are diminishing and pipeline construction companies are always requesting additional information and of course at reduced expenditure. New technologies such as survey drones may help surveyors maintain both the survey accuracies and profitability whilst integrating innovative data collection techniques.

1.2 Aim and Objectives

This report aims to examine and investigate usability, efficiency and costs of using Unmanned Aerial Vehicles (UAVs) to collect data for use in pipeline design and for the rehabilitation of construction corridors. A comparison between traditional Real Time Kinematic (RTK) surveying methods and UAVs will be completed.

1.2.1 Project specific objectives

1. Provide a general discussion of pipeline corridors and construction sequences.
2. Research and select a UAV with accessories to perform the task of delivering quality data to achieve the best possible results.
3. Examine expected accuracies and overhead costs of selected UAV and RTK systems.
4. Discuss the benefits and limitations of each system for data collection.
5. Compare overall data useability, accuracy, efficiency and cost based on the outcomes of the deliverables.
6. Make recommendations on the system/technique of choice along with future possibilities.

1.3 Scope and Limitations of the Study

Although the project aims are to investigate UAV issues, this study will be restricted to using only one UAV, it being the Trimble UX5 HP UAV plus its associated software. Likewise it would be preferable to assess the UAV over a wide range of terrains and under a range of conditions. As noted in section 3.2 where the study area is described the UAV was trialled over mostly ploughed cropping area. However there are significant height differences across the study area as well as other natural features (trees and gullies) and man-made features (fences, roads, above ground pipe work and buildings. It is felt that these variations provide sufficient variation to test the UAV technology.

Timing of the project was very dependent of the UAV's availability where I am working on a pipeline project in New South Wales and Victoria. Surveying to obtain RTK data for comparison over the same area will be completed around the same time period.

CHAPTER 2 - LITERATURE REVIEW

2.1 Introduction

The process of pipeline surveying is quite standard. However new technology has continually impacted how these surveys are undertaken. The newest technology possibly suited for use in pipeline surveying is the unmanned aerial vehicle. To fully assess the usability of UAVs for pipeline surveying it is necessary to revisit the steps of the survey process and to examine whether or not the UAV would be applicable for that step. Also, even if the UAV was extremely suitable, it would not be feasible to use the technology if it was uneconomic.

The aim of this chapter is to:

- clearly define the pipeline survey process,
- examine the types of UAVs and their reported strengths and weaknesses,
- indicate the economics of UAVs in real life situations.

This will be achieved by searching through different online databases to determine what researchers and practitioners have reported. Also I have been employed as a pipeline surveyor for the last three years and will be drawing on my own experiences. Following in this chapter will be a detailed breakdown of the pipeline survey process. After this a review of the strengths and weaknesses of the different types of UAVs will be presented.

2.2 Surveys undertaken prior to and during pipeline construction

Pipeline surveying consists of sequential steps. Following is a brief description of these steps.

1. Route survey – This is a preliminary detail and feature survey of the proposed construction corridor or Right of Way (ROW). This process identifies features including man-made structures, geomorphology, vegetation and significant landmarks. During this process a survey control network is also established

within close proximity to the proposed alignment.

2. Staking of ROW – Survey crews stake the ROW extents every hundred metres or at intervisible points and bends.
3. Centreline (C/L) Staking – Survey crews mark the C/L with trench levels and other important features required for construction.
4. As-constructed survey – Once the pipe has been placed in the trench, survey crews will survey its final location prior to backfilling operations.
5. Rehabilitation survey – Final surface levels are measured over the centreline to ascertain the final depth of cover of the pipeline below natural surface.

Details of these steps 1 to 5 above are always negotiated between companies involved in the pipeline development before surveying and construction begins. An example is the *Site Setting Out and Survey Procedure* (Spiecapag Lucas 2016). Each step and the applicability of UAVs in capturing survey data for each of them will now be discussed.

2.2.1 Route Survey

Before the initial pipeline route survey commences, a preliminary design alignment will be provided to the survey contractor similar to that shown in Figure 2.2.1. The preliminary design alignment forms the direction and extents of the ROW that will be surveyed during the route survey. The initial pipeline route survey is generally completed by a two man survey crew consisting of a surveyor and survey assistant. This survey will locate (but is not limited to) existing natural features such as drainage patterns, man-made structures such as buildings, existing visible services/infrastructure (where possible) and surface levels so that a digital surface model (DSM) can be produced.

During the route survey, a control network will also be established through a network of static GPS observations. Measurements to new control points (usually a deep driven star picket every 5km) along the proposed alignment will be conducted along with measurements that will tie the network into existing known control points called permanent survey marks (PSM's).

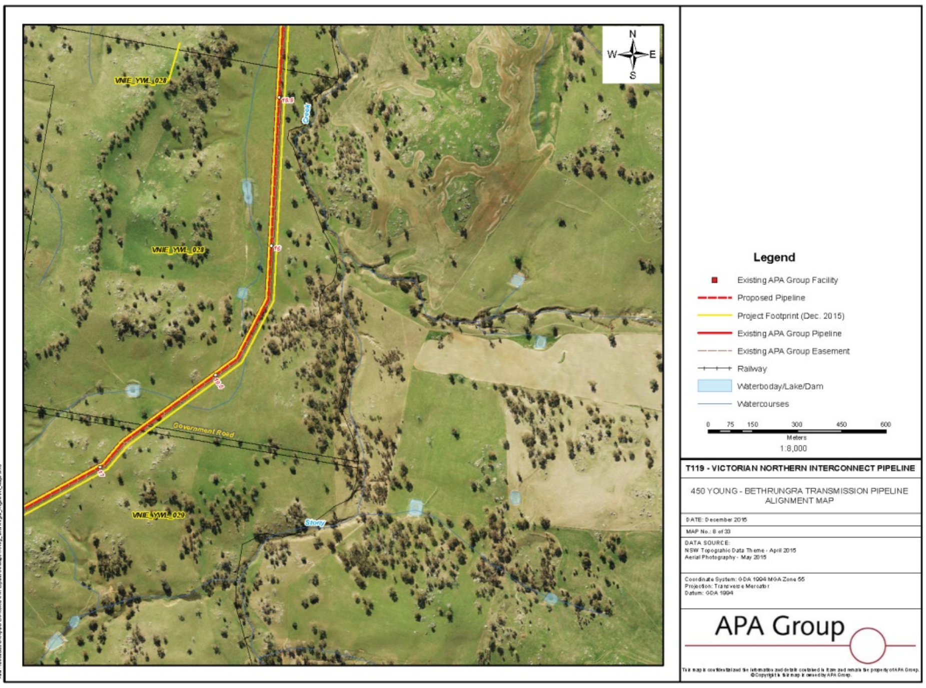

Figure 2.2.1: Example Alignment Route Map showing a proposed pipeline alignment (APA Group 2015, p. 8)

Acquiring survey data for route surveys can be a difficult task when using terrestrial surveying techniques. Ramirez and Hargraves (2016, p. 1) note that 'conventional methods of pipeline survey include an extensive network of ground crew personnel painstakingly covering hundreds of miles on foot to ensure accurate data is gathered'. Surveying large areas of vast and remote and sometimes even inaccessible terrain have also prompted Ramirez and Hargraves (2016, p. 1) to find 'a more efficient way of performing the same route survey and providing higher fidelity information deliveries must be accounted for'. Many possible pipeline routes are through freehold land and access can be limited due to a number of reasons. These may include problem land owners, very few or no roads and access tracks, steep slopes and rocky areas, dangerous fauna and limited existing survey control networks. Ramirez and Hargraves (2016) have also seen value in using UAVs for pipeline design with the ability of UAVs to collect survey data without physically accessing private property. Difficulties listed above can be overcome by the use of UAV data acquisition because there is no need to physically access many of these areas. UAVs can fly over, collect the necessary data, take off and land in designated locations and even survey areas with minimal ground control.

Route surveys generally assist defining the proposed pipeline alignment. However construction crews may request a design change due to unforeseen circumstance. Terrestrial surveying techniques in many cases are time consuming and unless specifically instructed the survey will only gather data within pre-defined areas. Should there be reason to re-align the pipeline route there is little chance of data being available. UAVs have the ability to collect large amounts of data over an increased area in a short period of time. By proxy, UAVs capture more data than necessary to allow for increased overlap should any of the images be deemed unusable. With additional data being collected, UAVs can prevent the need for future second site visits.

2.2.2 Staking of Right of Way

As noted above survey crews stake the ROW extents every hundred metres or intervisible points and bends. This work involves the crew working directly from approved alignment sheets. UAV technology is not relevant for this section.

2.2.3 Centreline Staking

Survey crews mark the C/L with trench levels and other important features required for construction. UAV technology is not relevant for this section.

2.2.4 As-constructed Survey

Once the pipe has been placed in the trench, survey crews will survey its final location prior to backfilling operations. UAV technology is not relevant for this section.

2.2.5 Rehabilitation Survey

The rehabilitation survey begins after the pipeline has been back filled. Large scale earthmoving machinery spreads the topsoil that was stripped on the ROW at the start of construction. Pipeline marker posts will be installed and temporary fencing is replaced with original permanent fencing. Pipeline marker posts, new gate locations and final rehabilitated surface levels are all surveyed at this point in time. Top of pipe levels are then subtracted from final surface levels to calculate the final depth of cover below rehabilitated surface level. Final surface levels are measured over the centreline to ascertain the final depth of cover of the pipeline below natural surface. Rehabilitated creek banks may also need to be surveyed to ensure drainage channels have not been affected by construction.

The post construction rehabilitation survey has traditionally been completed with a survey crew walking the pipeline route and taking levels every 20m or change of grade along centreline. As mentioned above the location of marker posts, fence lines, gates and any other features are all surveyed at this point in time. With all vegetation removed during clear and grade activities and with a clearly defined corridor visible from the air, UAVs can obtain complete unobstructed coverage of the ROW. Without any obstructions such as trees and vegetation to hinder data acquisition, UAVs will easily obtain accurate locations of the required features mentioned above.

Post construction imagery can also be obtained in dispute resolution cases. There have been cases whereby landowners have been unsatisfied with the rehabilitation process and complained about the drainage patterns not being reinstated correctly. Figure 2.2.2 and Figure 2.2.3 show aerial imagery obtained over a pipeline construction corridor pre-construction and post construction respectively. UAVs have the ability to survey any locations where disputes have been raised without the need for ground survey. Comparing preliminary flyovers with those post construction have significant value according to Ramirez and Hargraves (2016, p. 6). They suggest 'by supplying visual proof of right of way down to 3cm, a record of compliance to assist all parties is essential (regulators, pipeline companies and landowners)' (2016, p. 6). With UAVs having the ability to create a visual record of a ROW at a point in time, subsequent flyovers can be conducted to provide ongoing tracking of site features and conditions.

Figure 2.2.2: Aerial image of a pipeline construction corridor pre-construction (Nearmap 2013)

Figure 2.2.3: Aerial imagery of a pipeline construction corridor post construction (Nearmap 2016)

2.3 Types of UAVs and Equipment

2.3.1 UAV Data Collection Equipment:

There are several different UAV data collection platforms. They include mini-airships, fixed wing and rotary winged aircraft. UAVs come in many different shapes and sizes as listed in Table 2.3.1 (Eisenbeiss 2004, p. 2). Eisenbeiss (2004, p. 2) classifies UAVs into four categories, them being Micro, Mini, Close Range, Medium Range and High Altitude Long endurance. Micro and Mini UAVs will be discussed in this document.

Micro and Mini UAVs can be electric or fuel propelled. All have some form of remote control. Controls may be manual, pre-flight programmed, or a combination of both. Information in Table 2.3.2 (Nex & Remondino 2013, p. 3) provides some information about these different data collection platforms. Note that a recommendation of 1 is low rating and 5 for high.

Category name	Mass [kg]	Range [km]	Flight Altitude [m]	Endurance [hours]
Micro	< 5	< 10	250	1
Mini	<25/30/150	< 10	150/250/300	< 2
Close Range	25 –150	10 – 30	3000	2 – 4
Medium Range	50 –250	30 – 70	3000	3 – 6
High Alt. Long Endurance	> 250	> 70	> 3000	> 6

Table 2.3.1: Extract of UAV categories (Eisenbeiss 2004, p. 2)

	Kite/ balloon	Fixed wing		Rotary wings	
		Electric	ICE engine	Electric	ICE engine
Payload	3	3	4	2	4
Wind resistance	4	2	3	2	4
Minimum speed	4	2	2	4	4
Flying autonomy	–	3	5	2	4
Portability	3	2	2	3	3
Landing distance	4	3	2	4	4

Table 2.3.2: Evaluation of UAV Platforms (Nex & Remondino 2013, p. 3)

Sensefly (2016) states that multicopters are better used for 'closer range imagery and smaller applications where the fixed wing was not practical' (p. 1). General construction areas for pipelines are remote and have lots of room for take-off and landing, as is required by fixed wing UAVs. The multicopters are be better suited to situations like surveying specific sites such as an inner city development where nearby buildings are present.

On board the UAV, data is usually collected using a red, green and blue (RGB) mounted digital camera. RGB cameras acquire images in the visible spectrum with wavelengths between 0.4 to 0.7µm (USQ 2016). Most digital cameras sold today would be appropriate for the task providing the focal length of the camera lens is accurately known. However, it should be noted that photos taken of the subject area will govern the quality of the results and/or deliverables. Therefore it is recommended that photos are taken with a camera that has both good geometric and optical qualities.

The ROW is generally twenty-five to forty metres wide (see Route Survey in the previous section 2.2.1) so a large coverage area is not required. Collecting high quality data within this area is of high importance and therefore a camera with a longer focal length can be utilised. Ideally a 25mm focal length lens would be adopted for this type of survey, however only a 15mm lens was available at the time of survey. The digital camera to be used for data collection is a 36 megapixel (MP) mirrorless full frame with a 15mm focal length to generate the image resolution. Also because the route is not too wide and because the UAV is flying at an altitude of about 100 metres, a wide angle lens (shorter focal length) is not necessarily required. A 15mm focal length camera flying at an average altitude of 100 metres will cover a path 320m wide. Therefore minimum flyovers are required given sufficient overlap and wind direction.

2.3.3 Financial considerations for UAVs

Survey grade UAVs and associated equipment can be expensive especially when looking for an automated unit. The Trimble UX5 HP system contains a survey accurate Global Navigation Satellite System (GNSS) receiver to minimise the need for ground control points. However this also significantly increases initial outlay cost. Other UAV systems may not include a high accuracy receiver and therefore may provide a cheaper alternative. A cheaper UAV system may initially seem like a good option, but the cost and sometimes inability to install the required ground control points suggests a larger initial outlay would be worthwhile. The Trimble UX5 HP unit costs about $75,000 and comes with a launcher unit and control tablet. Ongoing costs include maintenance and hardware warranties.

Another cost associated with UAVs is initial licencing required by the Civil Aviation Safety Authority (CASA). To fly a remotely piloted aircraft commercially an UAV operator's certificate is mandatory. The cost of obtaining one of these certificates is currently around $4,000 plus additional commitments of keeping up with legislation.

2.3.4 Requirements for operating UAVs

Completing an initial route survey or rehabilitation survey with a UAV system requires only one person as opposed to two people when using terrestrial survey techniques. The pilot, who would in this case also be a qualified surveyor will complete all pre-flight setup and checks. This would include installing ground control points and setup of a GNSS base station.

2.3.5 UAV accuracy assessments

Previous studies have been conducted by (Barry & Coakley 2013, p. 1) to 'establish the accuracy of the geographic data derived from our UAV photogrammetry'. Barry and Coakley (2013, p. 1) placed 45 ground markers as check points and 10 ground control points to become fixed tie-in locations. Both ground markers and control points were placed within a two hectare site and then surveyed using RTK GPS techniques. They reported a horizontal accuracy of 41mm and vertical accuracy of 68mm at a 95% confidence interval over a 1cm ground sample distance at the 45 check point locations. They concluded that when using data derived from aerial imagery with a 1cm GSD, the results are within acceptable standards compared to RTK survey data. The prediction that UAV photogrammetry will take a few years to become mainstream is correct; however their idea of almost fully replacing current methods of engineering surveying is difficult to completely agree on. Whilst UAVs can complete the majority works over a large scale project, there will always be limitations around heavily vegetated areas for example. There is also a need for ongoing verification of photogrammetric data using terrestrial ground survey techniques. In terms of efficiency, collecting data using photogrammetric techniques can be completed in a much shorter timeframe,

The possibility of using UAVs to assist or even replace existing surveying techniques has become more and more debated by contemporary surveyors and professionals. Smeaton (2015) compared measurements and cost when surveying a civil construction project (subdivision) with generic total station versus the Sensefly Ebee UAV. The Sensefly Ebee UAV does not require ground control because of on board RTK capabilities. Six ground control points were used to help create the photogrammetric deliverables. Comparisons were made between 10 measurements in the horizontal and vertical dimension and 10 in just the vertical dimension. When comparing the data against total station measurements, Smeaton (2015) factored in several site considerations such as ground cover, vegetation, buildings and other man-made structures including concrete footpaths and kerbs. The outcome of the comparison suggested an accuracy of 19mm in horizontal and 52mm in vertical component. Smeaton (2015) also compared an overall costing of the project when completed with a total station and UAV. The overall cost decreased by approximately 40% when using the UAV measurement techniques. Despite the savings in cost it became apparent that while the overall contour data was much more complete and accurate, the lack of point data and line work defining different features was not.

Smeaton (2015, p . 65) concluded that there is no real benefit to surveyors when using UAVs to create detailed feature survey information such as a small-medium subdivision. However, they are very useful for the creation of topographic contour information over large areas. This suggests that the use of UAVs for the purpose of pipeline design and rehabilitation could be revolutionary. Pipeline design and rehabilitation does not require high end detailed information but rather more generalised information over larger distances and areas. Anything that may require detailed survey data would generally be completed during a site inspection or site feature survey.

Although using UAVs is not completely new to the pipeline industry, there have been innovative usage ideas already underway. A German company, Thyssengas who is an LNG pipeline operator and transporter has been using UAVs for monitoring existing infrastructure. These above and below ground pieces of infrastructure must be monitored legally at least every 28 days.

Rathlev et al. (2012, p. 1) discusses Thyssengas as a company performing aerial pipeline surveys for many years because land based surveys along the length of their pipelines would be far too labour intensive.

Before UAVs, helicopters manned with a pilot and a spotter were employed to do this task. This process is expensive due to costs involved in flying and inefficient due to double handling of reconnaissance information. The UAVs which operate more or less independently come with payloads suitable for optical recording.

Although the UAVs are not collecting information for design and rehabilitation purposes, they are still collecting vital information from the air. Rathlev et al. (2012, p. 1) notes that over 16,000 building applications are filed within the nearby area of the 4200 kilometres of pipeline. It is estimated that about one-third of the applications directly or indirectly affect the existing infrastructure. It is therefore important for companies like Thyssengas to be monitoring any activities that may be present around their pipelines. The article also notes the possibility of the UAV system being using for initial measurement for the planning stages or new constructions or even reconstructions. Uses such as this supports and justifies ongoing research into UAV uses in the pipeline industry.

2.4 UAVs and Cost Savings

Using UAVs to survey vast areas of pipeline routes creates opportunities for significant cost savings. As previously mentioned, terrestrial survey techniques involving walking hundreds of kilometres with a GPS receiver to collect data is extremely time consuming. Ramirez and Hargraves (2016, p. 6) conducted a cost analysis comparing identical data collections being a terrestrial survey crew and an integrated UAV survey crew. This involved surveying an 8 mile long pipeline corridor over a densely populated area. The traditional survey crew method comprised of three two person field crews and a supervisor to oversee the operation. The integrated aerial survey crew comprised of one survey crew with a UAV crew. The results from this are shown in Table 2.4.1. The result of this cost was quantified with an overall efficiency of 66%. Ramirez and Hargraves (2016, p. 6) discuss the correlation reduction in man field man hours but also the reduction in crew exposure to safety and environmental hazards such as fauna and sun exposure.

Position	Units	Days	Hrs/Day	Total Field Man Hours
Supervisor	1	22	10	**220**
2-Man Survey Crew	3	22	10	**1320**

Fig. 9. Time in Field: Traditional Survey Crew; Total hours: 1,540

Position	Units	Days	Hrs/Day	Total Field Man Hours
3-Man UAV Crew	1	2	10	**90**
2-Man Survey Crew	1	22	10	**440**

Fig. 10. Time in Field: Integrated Aerial Survey Crew, Total hours: 530

Table 2.4.1: Cost comparison of 8 miles of ROW (Ramirez & Hargraves 2016, p. 6)

2.5 Conclusion

The literature identified five separate survey steps in the pipeline process. Of these two were identified as being extremely suited for UAV technology. They were the Initial Route Survey and the Rehabilitation Survey. Using UAV technology for the Initial Route Survey gave pipeline designers a visual perspective of the proposed route and enabled them to make smaller pipeline directional changes without having to revisit the site for new data. Using UAV data from the Rehabilitation Survey has an added benefit to both pipeline constructors and land owners in so far as slopes, vegetation and man-made structures are clearly definable for the pre- and post- construction phases.

Concerning UAVs the literature suggests that:

- given the distances covered for pipeline surveys, it appears that the fixed wing UAV is the preferred UAV platform for those surveys,
- result accuracy is within acceptable standards compared to RTK survey data although there are limitations around heavily vegetated areas,
- there are operational cost savings to be achieved.

CHAPTER 3 - RESEARCH METHODS

3.1 Introduction

Information in the previous chapter noted the survey steps for which RTK versus UAV comparisons would be relevant, noted that UAV accuracy standards were acceptably, and that cost savings could be achieved.

The aim of this chapter is to:

- define the study area,
- clearly define how the data was captured,
- clearly define how the data was analysed

Both data collection and data processing methods will mimic commercial practice. The two sets of data will then be compared using regular statistical analytical methods.

3.2 The Study Area

The study area shown in red in Figure 3.2.1 is a 3.5km section along design centreline of the pipeline. Data will be collected across the width of the 25m wide construction corridor. Included in the corridor are features such as an exposed gas pipeline and associated fittings, roads and drainage channels. Part of the section will include a rehabilitated area.

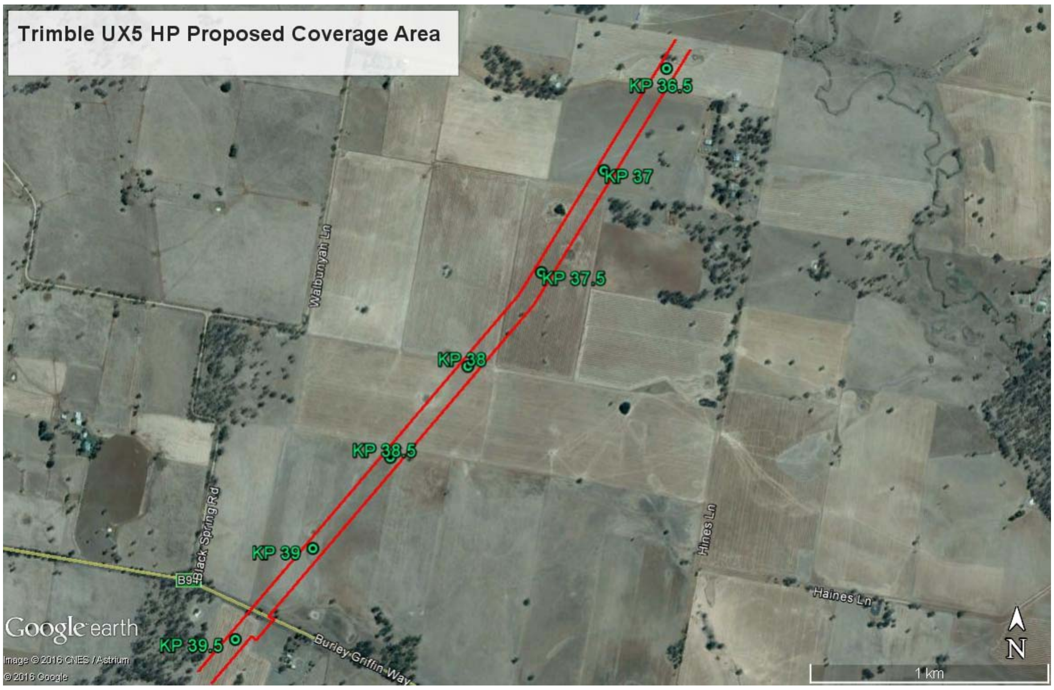

Figure 3.2.1: The study area shown in red (Google Earth 2016)

3.3 Data Capture and Acquisition

The study area will be surveyed twice. The first survey will use standard RTK procedures and the second using a Trimble UX5 HP UAV system.

3.3.1 RTK Survey

Used will be a Trimble R6-4 GNSS RTK system shown in Figure 3.3.1 and two person survey crew. An existing survey control network will be utilised when conducting the field work. Records will be kept of the time taken to complete the task. Once the data has been collected it will be processed in Civil 3D and a DSM will be created along across the ROW and around surveyed features mentioned above.

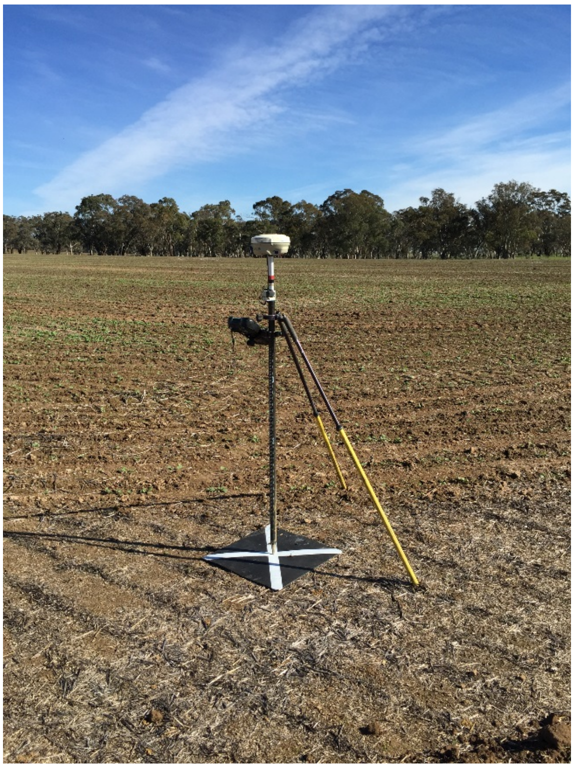

Figure 3.3.1: Trimble R6-4 GNSS RTK system

When surveying for initial route survey, depending on the size of the project, at least one survey crew consisting of a surveyor and survey assistant is required. The surveyor would generally walk the proposed alignment with an RTK system and locate features and take levels where required. To survey a 1km section of 25m wide construction corridor, the estimated time frame would be around an hour with a two person survey crew. Total hours for the rehabilitation survey with a two person survey crew would be reduced to 0.75 hours. The reduced timeframe is due to levels only being required on centreline rather than across the entire width of the construction corridor.

The data will be collected, downloaded and reduced in the Autodesk CIVIL3D software package.

3.3.2 UAV Survey

Used will be a Trimble UX5 HP UAV system as shown in Figure 3.3.2. Due to budgetary constraints the Trimble UX5 HP and the Trimble R6 GNSS was the only collection and processing equipment readily available. The Trimble UX5 HP UAV is a fixed wing craft and therefore will be an ideal selection for pipeline route selection and construction surveying activities. This is because it can fly in weather conditions that others cannot, for example, wind and light rain. It can also cover large areas, which is ideal for pipelines as they can be hundreds of kilometres long. Siebert and Teizer (2014, p. 3) notes fixed wing aircraft offers more efficiency and range that assists in surveying large areas and at lower costs. Fixed wing aircraft also have the capability to carry a greater payload. This means having options that can include the ability to carry more than one type of sensor.

The UX5 HP is Trimble's most sophisticated UAV system that is currently available. This fixed wing unit is powered by an electric motor, contains a high accuracy on-board Global Navigation Satellite System (GNSS) receiver and 36MP camera. This lightweight 2.9 kilogram automated system is catapulted when launched and has the ability to land without assistance on its belly.

Figure 3.3.2: Trimble UX5 HP UAV System (Trimble Navigation Limited 2015)

The Trimble UX5 HP datasheet (Trimble Navigation Limited 2015) claims a flying range of 52kms, cruising speed of 82kph, maximum tested altitude of 5000m and a ground resolution down to 1cm for processed orthomosaics. The Trimble UX5 HP UAV system has a built in GNSS receiver and will also utilise the same existing survey control network used for RTK observations. During the flight, a Trimble R6-4 GNSS receiver will log positions over a known point at 10Hz, and the Trimble UX5 system will record measurements at 20Hz to allow for post processing of logged GNSS data. Four ground control points (see Figure 3.3.3) will be strategically placed, however only one will be used to assist in data reduction and alignment of aerial imagery. The remaining three will be used as checking stations.

The collected data will be processed in Trimble Business Centre – Photogrammetry Module and a DSM will be created across the entire width of the 25m wide construction corridor. Flying the UAV will be a representative from Ultimate Positioning Group.

Figure 3.3.3: One of the four ground control points

Time taken to complete the task will be recorded. In particular, notes will be taken about the pre-flight set up and who did it, flight time, post processing data collection set-up and the data analysis.

3.4 Flying the UAV

In most cases it is possible to pre-program the flight path and other parameters into the field computer. These parameters include setting the shutter speed (1/32 of a second in this case), the elevon (pitch and height of aircraft) and the required forward and side lap of 80%. The software within the field computer then automatically calculates the number of flight lines. A total of 50 flight lines was required to survey a 3.5km long and 25m wide section of ROW.

On site a GNSS receiver was set up over a known point within 10km of the flight path. The R6-4 receiver then logged at 10Hz throughout the duration of the flight. The data logged by the R6-4 receiver was post processed in TBC along with the data logged by the on board GNSS receiver in the UX5.

Next in the setup of the Trimble UX5 unit was the launching system. The Trimble UX5 uses a catapult style launching system as seen in Figure 3.4.1, and always takes off and lands into the wind. Note the red tag on the UX5 unit. This red tag is only removed at the last minute before take-off once the pre-flight checks have been carried out. This includes physically checking condition and functionality of moving parts along with automatic ones completed by the on board software such as battery connection and camera trigger checks.

Figure 3.4.1: Trimble UX5 HP Unit and Catapult Launch System

Following completion of the above, the Trimble UX5 HP system was ready for flight. The total flight time including landing was 0.5 hours. After landing the Trimble UX5 HP unit the data could be downloaded immediately or left until the end of the day.

Downloaded raw flight data will be exported from the field computer using the Trimble Access Aerial Imaging software. The output contained the photos, flight data and GNSS log file in JPEG, JXL and T04 file types respectively. The three file types were imported into Trimble Business Centre (TBC) for the processing and creation of deliverables.

Trimble Business Centre software processes all data collected by the Trimble UX5 HP system. Contained within TBC is a specialised Photogrammetry Module. The software will complete all the initial processing of data collected by the Trimble UX5 HP system before exporting it in a format supported by Autodesk Civil 3D. The software 'allows users to process their aerial imagery accurately using traditionally collected ground survey data in a seamlessly integrated workflow. The deliverables include a dense point cloud, raster digital surface model (DSM) and an orthomosiac' (Trimble Navigation Limited 2013, p. 1). Trimble Navation Limited (2013) discusses image processing theories and provides examples of case studies with comparisons to terrestrial survey data obtained by total station and laser scanners. Based on this information it becomes evident TBC– Photogrammetry module will provide a sound platform to process the aerial imagery.

TBC generates a flight adjustment report which is attached as Appendix B. This report contains information about the following items.

- Job file metadata such as coordinate system and zone.
- Total number of images and photo scale.
- Number of flight strips.
- Flying height and terrain height.
- Tie-in point distribution.
- Camera calibration, distortion values and image residuals.
- Ground control, exterior orientation and adjustment results.
- GNSS post processing results.

The final step in data processing will be executed in Autodesk Civil 3D. This involves importing the RTK data, georeferenced aerial imagery and point cloud data. A DSM as shown in Figure 3.4.2 will be created from both RTK data and the point cloud generated by TBC. Autodesk Civil 3D can then extract XYZ coordinates generated by the UAV using the aerial imagery and surface elevations. Once coordinates have been established, the deltas will be calculated and a root mean squared error analysis completed.

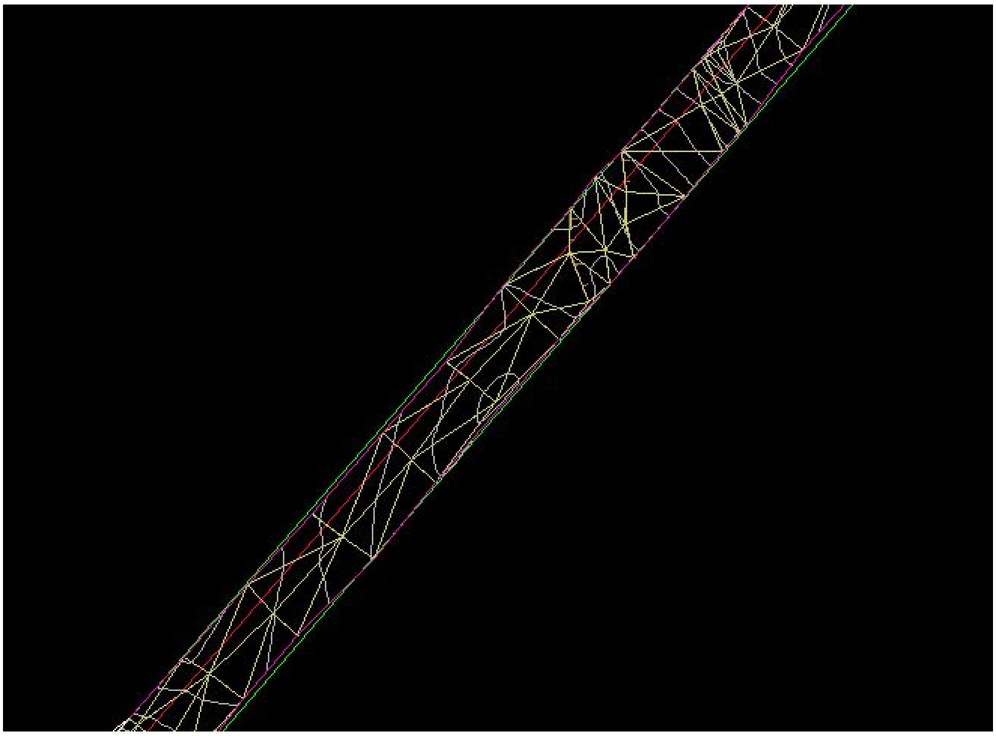

Figure 3.4.2: DSM created over the ROW in Autodesk Civil 3D

3.5 Post Processing Data Analysis

The root mean squared error (RMSE) is defined by the Warnell School of Forestry and Natural Resources (2016, para. 1) as 'the square root of the average of the set of squared differences between collected coordinates and coordinates from an independent source of higher accuracy ("control points") for identical locations'. In this case, the collected coordinates will be the UAV data and the independent source of higher accuracy will be RTK data. The RMSE will be calculated separately for the eastings (X value), northings (Y value) and elevation (Z value). A total of 21 points (Observation Set "A") will be analysed in the XYZ and 227 surface levels (Observation Set "B") will be analysed for elevation only. The elevation RMSE will be calculated for the complete set of 227 observations. Within these 227 observations a substantial number of points were in areas of long grass, around trees, fence posts and other features that could possibly create false representation of data and results. For this reason, a separate analysis of 81 observations

(Observation Set C) will be completed on another group of random points across the ROW. These 81 observations are located in an open paddock, away from any obstacles/features. This will reduce variables when calculating the RMSE. Results from the RMSE analysis will be displayed in tabulated form and discussed later in this report.

3.6 Conclusion

Clearly defining the research methods is important. This will allow other researchers to test the results in other areas and with different UAVs. It will also give surveyors greater confidence to make commercial decisions concerning adoption of UAV technology.

CHAPTER 4 - RESULTS

4.1 Introduction

As mentioned in the last chapter the data were collected using clearly defined and commercially relevant practices.

The aim of this chapter is to:

- Note the environmental conditions,
- Report on the RMSE analysis of 21 X, Y and Z observations,
- Report on the RMSE analysis of 227 elevation (Z) observations,
- report on the RMSE analysis of 81 elevation (Z) observations, and
- Report on the cost analyses of UAV and RTK surveys.

Based on prior research and analysis conducted by others, the results discussed in this section appear to be within expected tolerances. Weather conditions on the day of flying were excellent with full sunshine and very little wind (around 5-15km/hr).

RTK measurements were recorded over a 1km section of 25m wide ROW and used as control points (points of higher accuracy) for the basis of comparison against UAV data.

Observation Set A in Figure 4.2.1 containing the majority of 21 XYZ comparison points table will be displayed in this section. Observation Set B and C containing the 227 elevation points and 81 elevation points respectively are attached in Appendix C and D respectively.

4.2 OBSERVATION SET A: RMSE Analysis of 21 X, Y and Z Observations

Figure 4.2.1: Plan View of Observation Set A Comparison Points

This group of observations was strategically selected to provide an accurate representation of the UAV accuracy when compared to RTK data. Easily identifiable points with no obstructions nearby was the main reason behind the selection.

The RMSE for the X value equalled 0.025m which is shown in Table 4.2.1 and the Y value equalled 0.031m shown in Table 4.2.2. The combined horizontal RMSE value calculated 0.040m. The RMSE for elevation (Z) amounted to 0.048m as shown in Table 4.2.3. Both of these values compares reasonably closely with results obtained by both Smeaton and Barry & Coakley. Smeaton obtained a mean horizontal difference of 0.019m and vertical difference of 0.052m. Barry and Coakley reported mean horizontal differences of 0.023 horizontally and 0.035m vertically.

Point No.	Description	RTK	UAV	Difference
1	Top End of Pipe	602897.528	602897.526	0.002
2	Top Face of Pipe Flange	602890.996	602891.011	-0.015
3	Top Face of Pipe Flange	602890.383	602890.372	0.011
4	Top of Tee in Pipe	602890.063	602890.063	0.000
5	Corner Concrete	602892.629	602892.584	0.045
6	Ground Control SW Most point	602881.181	602881.182	-0.001
7	Ground Control Middle Paddock	603548.225	603548.200	0.025
8	Ground Control NE Most	603950.837	603950.829	0.008
9	End White Line SE	602931.888	602931.854	0.034
10	End White Line	602929.239	602929.197	0.042
11	End White Line	602920.654	602920.648	0.006
12	End White Line	602917.910	602917.854	0.056
13	End White Line	602909.908	602909.932	-0.024
14	End White Line	602907.086	602907.121	-0.035
15	End White Line	602898.940	602898.949	-0.009
16	End White Line NW	602896.163	602896.139	0.024
17	Top of Concrete Headwall	602923.332	602923.342	-0.009
18	Top of Concrete Headwall	602924.632	602924.627	0.005
19	Top of Concrete Headwall	602925.804	602925.777	0.027
20	Top of Concrete Headwall	602925.310	602925.305	0.005
21	Top of Concrete Headwall	602930.254	602930.230	0.024
				RMS X 0.025

Table 4.2.1: Calculated RMSE Value for X coordinate

Point No.	Description	RTK	UAV	Difference
1	Top End of Pipe	6180386.731	6180386.750	-0.019
2	Top Face of Pipe Flange	6180387.897	6180387.879	0.018
3	Top Face of Pipe Flange	6180388.441	6180388.431	0.010
4	Top of Tee in Pipe	6180388.730	6180388.706	0.024
5	Corner Concrete	6180392.379	6180392.380	-0.001
6	Ground Control SW Most point	6180358.200	6180358.205	-0.005
7	Ground Control Middle Paddock	6181111.589	6181111.576	0.013
8	Ground Control NE Most	6181590.624	6181590.620	0.004
9	End White Line SE	6180399.622	6180399.679	-0.057
10	End White Line	6180400.872	6180400.919	-0.047
11	End White Line	6180404.868	6180404.893	-0.025
12	End White Line	6180406.157	6180406.193	-0.036
13	End White Line	6180409.907	6180409.931	-0.024
14	End White Line	6180411.210	6180411.206	0.004
15	End White Line	6180415.031	6180415.044	-0.013
16	End White Line NW	6180416.331	6180416.371	-0.040
17	Top of Concrete Headwall	6180388.036	6180388.023	0.013
18	Top of Concrete Headwall	6180388.732	6180388.753	-0.021
19	Top of Concrete Headwall	6180391.485	6180391.473	0.012
20	Top of Concrete Headwall	6180392.381	6180392.341	0.040
21	Top of Concrete Headwall	6180389.475	6180389.398	0.077
				RMS Y 0.031

Table 4.2.2: Calculated RMSE Value for Y coordinate

Point No.	Description	RTK	UAV	Difference
1	Top End of Pipe	485.205	485.168	0.037
2	Top Face of Pipe Flange	486.773	486.734	0.039
3	Top Face of Pipe Flange	486.774	486.727	0.047
4	Top of Tee in Pipe	486.675	486.711	-0.036
5	Corner Concrete	487.863	487.895	-0.032
6	Ground Control SW Most point	488.287	488.328	-0.041
7	Ground Control Middle Paddock	503.054	503.060	-0.006
8	Ground Control NE Most	519.621	519.686	-0.065
9	End White Line SE	488.589	488.597	-0.008
10	End White Line	488.600	488.585	0.015
11	End White Line	488.630	488.612	0.018
12	End White Line	488.648	488.616	0.032
13	End White Line	488.658	488.725	-0.067
14	End White Line	488.670	488.662	0.008
15	End White Line	488.684	488.613	0.071
16	End White Line NW	488.676	488.715	-0.039
17	Top of Concrete Headwall	487.957	487.972	-0.015
18	Top of Concrete Headwall	488.193	488.110	0.083
19	Top of Concrete Headwall	488.239	488.263	-0.024
20	Top of Concrete Headwall	487.940	488.009	-0.069
21	Top of Concrete Headwall	488.183	488.279	-0.096
				RMS Z 0.048

Table 4.2.3: Calculated RMSE Value for Elevation (Z coordinate)

4.3 OBSERVATION SET B: RMSE Analysis of 227 Elevation (Z) Observations

This set of measurements contained a larger sample of observations over a more diverse array of surfaces, textures and changes in elevation. Surfaces such as dirt, long grass, fence lines/posts, ploughed land, bitumen, cast shadows, drains and changes grade of featured in the sample. This type of terrain generally resembles a pre-stripped ROW surface.

Surveyed RTK data points were compared against a DSM created from a point cloud with a density of 100 points per square metre generated from UAV data. The RMSE for elevation was computed to be 0.070m. As previously mentioned the points contained within this data were not on a flat, even or solid surface. The RTK data was collected by physically placing a survey pole at ground level and recording the measurement. UAV data has been calculated from remotely surveyed measurements. Long grass for example appears to have had a detrimental effect on UAV measurements. This could be due to the common points obtained from separate images being distorted and creating inconsistent results. This same effect appears to have happened around fence lines and bunting (a temporary construction fence made of plastic). Inconsistencies such as these has created errors and therefor increased the RMSE elevation value for the entire data set.

4.4 OBSERVATION SET C: RMSE Analysis of 81 Elevation (Z) Observations

This final set of data is assembled from points in an open paddock over a ploughed field with topographical features such as drainage lines and rolling hills. This type of terrain and conditions resembles a rehabilitated ROW surface. Here there were no obstructions and the results reflect that. The RMSE analysis output an elevation error value of 0.037m. This result reflects the best outcome for the UAV from all data sets analysed in this report.

4.5 Cost Analyses of UAV and RTK Surveys

Collecting data and commenting results is only one aspect when considering the possibility of utilising UAVs in the pipeline industry. If a construction contractor can find a technique to save on costs whilst still obtaining similar outcomes the method of survey becomes clear immediately. For this reason, a cost analysis comparing the overall expenses for completing a similar type of survey will be conducted. Total costs based on hourly comparisons for both UAV and RTK surveys are presented in Table 4.5.1 and Table 4.5.2. Overall costs for the 3.5km ROW surveys were $270 and $855 respectively.

UAV Cost Analysis for Time Taken to Survey 3.5km of ROW	
Setup RTK Base Station (hrs)	0.25
Install and Survey 1 Ground Control Station (hrs)	0.33
Setup UAV Flight Path (hrs)	0.25
Setup UAV Catapult Launcher (hrs)	0.25
Flight Time (hrs for 3.5km)	0.5
Landing and Pack Up of UAV	0.33
Pack up Base Station	0.25
Total Hours for One Person Survey Crew	2.16
Total Cost at $125/hr	$270.00

Table 4.5.1: Hourly time breakdown for UAV Survey

RTK Survey Cost Analysis for Time Taken to Survey 3.5km of ROW	
Setup RTK Base Station (hrs)	0.25
Setup RTK Rover and Check M'ment (hrs)	0.25
Survey Time (hrs for 3.5km)	4
Pack up Base Station (hrs)	0.25
Total Hours for Two Person Survey Crew	4.75
Total Cost at $180/hr	$855.00

Table 4.5.2: Hourly time breakdown for UAV Survey

4.6 Conclusion

All of the analyses were successfully undertaken and presented. This analysed data will now form the basis of the accuracy discussions contained in the next chapter.

CHAPTER 5 - DISCUSSION

5.1 Introduction

Data generated in the previous section will be used to compare the UAV and RTK methods of pipeline surveying. Also subjective comparisons of pipeline surveying using the UAV and RTK methods will be made.

The aim of this section is to:

- discuss numeric cost and accuracy comparisons between UAV and RTK methods,
- comment on the safety and dispute resolution advantages offered by UAV methodology,
- discuss some study limitations concerning processing software comparisons and other UAV comparisons.

5.2 Costs

Surveying pipeline routes before and after construction has long been a laborious task for surveyors. For example following the rehabilitation of a pipeline corridor, existing fences may have been reinstated without gates. This means access is more difficult and production can often be slow, which in turn makes the rehabilitation survey more expensive. Pipelines can stretch from tens to thousands of kilometres in length so incurring additional costs can often mount up to large sums of money. With the cost of surveying pipelines with drones being approximately one-third of the cost of RTK techniques the choice is simple from a monetary point of view.

A comparison of the costs of field time spent surveying the ROW for both the route and asconstructed surveys follows. It was determined that overall cost to survey the same 3.5km section of ROW was 68% less when using UAV technology and surveying techniques when compared to terrestrial RTK surveying techniques. As previously mentioned, a similar study conducted by Ramirez and Hargraves (2016, p. 1) drew extremely similar conclusions. Ramirez and Hargraves (2016, p. 6) calculated a 66% reduction in cost when using UAVs to also survey a section of ROW. Research outcomes like this suggests that using UAVs in pipeline construction is the way of the future for surveyors.

It should be noted that the costs mentioned previously are time associated variable costs. This means they do not include hire or purchase or maintenance costs of the UAV or RTK units. The economic viability of hiring or owning or leasing a UAV or RTK unit would depend very much on the surveying company's strategic direction.

In May 2016 the retail price of a Trimble UX5 HP unit was around $75,000. This included everything required to go straight into the field and begin work. An issue was obtaining PPK satellite data for processing flight data. Although there are other methods of acquiring satellite data such as the Continiously Operating Reference Station (CORS) network, there is still a need for a GNSS base station to be used in conjunction with the Trimble UX5, especially in remote locations where there is no CORS network available. The additional GNSS receiver would add an additional $20,000 to the initial cost. Another initial outlay of around $4,000 associated with UAV's is the training to become a registered pilot. This brings the total to around $100,000 which even larger established survey companies will want justified prior to purchase.

The current retail price for a Trimble RTK GNSS kit is around $55,000 and is also provided as a full kit ready to begin work. The upfront cost is about half of that of a working Trimble UX5 UAV system. It can be argued that clients have for years been satisfied with the data provided by RTK systems and change is not necessary. Whilst this currently may be the case, sooner or later one or more surveying companies will adopt UAV measurement techniques and set a benchmark moving forward. Companies using UAV's will have a competitive marketing advantage.

5.3 Accuracy

Surveyors often talk about or are questioned about accuracy. During the tender and audit stages of a project, expected accuracies must be disclosed about the surveying equipment used throughout. Based on the results from the UAV data, determined accuracies would be acceptable for use on pipeline projects for both pre-construction and post construction ROW survey. Whilst testing the Trimble UX5 HP UAV system the recorded figures were generally within tolerance; however some areas may require field verification using RTK techniques.

Pre-stripped ROW areas covered by long grass greater than 0.3 metres appeared to give errors of up to 0.2m in elevation. Quite often around creeks, table drain inverts beside roads and even paddocks not used for agriculture contain long grass. This presents a problem because incorrect elevations shown on pipeline alignment sheets could result in incorrect design depths being displayed. Without conducting a site visit and possible RTK field survey it would be very difficult to ascertain where these areas are and how significant errors may be. Another possibility for resolving or identifying problem areas could be using GIS software. Some software can identify or eliminate errors in areas such as these using sophisticated algorithms.

The DSM created from the point cloud data also produced errors close by to features such as stationary cars, trees and shrubs, buildings or fence posts with a significant diameter. Examples of DSM contours that do not provide an accurate representation of the natural surface can be seen in detail in Figure 5.3.1. This data can be manually edited to show a true representation of the natural surface shown in Figure 5.3.2 however must be done within software suites and can take significant time. Similar inaccuracies were found nearby to fence posts and buildings and would require additional works come processing time.

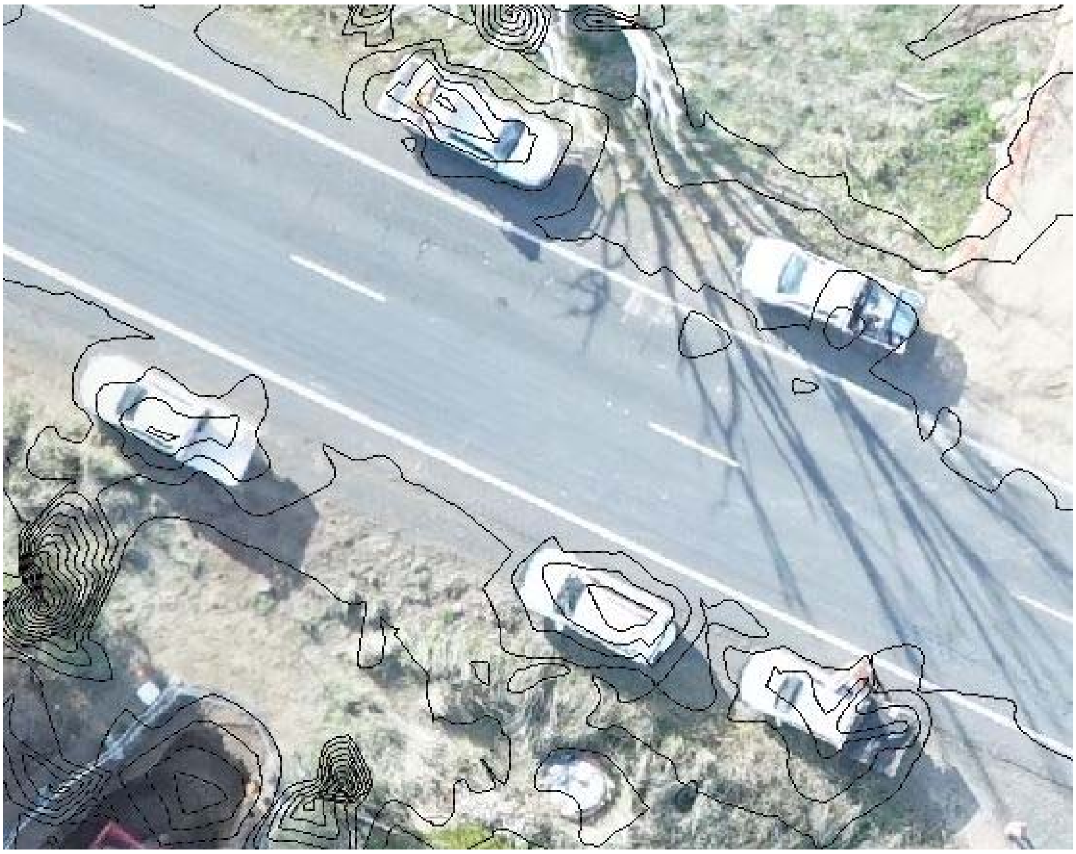

Figure 5.3.1: DSM contours that do not represent a true natural surface.

Figure 5.3.2: A true contour surface from the same location as above.

Following the reinstatement process along the ROW is the installation of pipeline warning markers. These posts are installed along the pipeline route to warn of the dangers of high pressure gas in the near vicinity. The posts are typically made from galvanised iron 50mm in diameter, are 2m high and have a sign that reads "Warning – High Pressure Gas Pipeline in the Vicinity. Post installation the locations of the signs must be surveyed and as-constructed reports generated. Acquiring asbuilt coordinates of the pipeline warning markers were intended on being generated from UAV data. It became evident that it was not possible given the resolution of the imagery because the posts could not be identified. A possible solution could involve surveying the rehabilitated ROW early in the morning and later in the afternoon so the posts could be identified through using basic interpretive elements such shadow and association with fence lines, roads, tracks etc. Crossing features such as these will help identify locations because of government legislative requirements to install pipeline warning marker at all of these locations.

5.4 Safety

Collecting survey data along proposed and rehabilitated pipeline routes will more often than not require working remotely. Large scale pipeline construction projects that are best suited to fixed wing UAVs avoid significant towns and cities. This means working in remote isolated areas and entering properties with the occasional difficult owner. Other risks include dehydration, flora and fauna, sun exposure, cars when working near roads, slips, trips and falls. Data collection using UAV's drastically reduces and sometimes even eliminates these risks. If a surveyor does not physically have to be present to survey a paddock or road carriageway than the risk of him/her slipping or being struck by a moving vehicle simply cannot happen. Safety is considered paramount in the contemporary oil and gas industry and replacing terrestrial ground survey techniques with solutions such as UAVs will no doubt receive a warm welcome.

5.5 Dispute Resolution

Nearly every pipeline project contains at least one unsatisfied land owner. In many cases issues surrounding the conflict are warranted and in others they are not. Issues such as drainage patterns, collateral damage before after construction, creek and waterway reinstatement can often hamper the outcome of what seemed a successful project. RTK surveys rarely provide information outside the extent of the ROW and therefore is not known or documented should there be a dispute post construction. UAVs have the ability to survey additional areas outside of the ROW without generating a significant additional cost. There are also possibilities of damage or changes to contours of the land due to other variables such as inclement weather and agriculture. If data is collected pre-construction and then post construction, evidence can be stored and later presented should a problem arise. Without any evidence it may be difficult to generate a valid reason for presumed ground or collateral damages. History suggests the pipeline constructor will end up paying damages when events such as these occur.

5.6 Comparisons of Processing Softwares

Details surrounding software types and processing have not been thoroughly investigated in this report. One of the reasons is because of the numerous different types available. Each software suite claims to be the best for one reason or another. Quite often it depends on user training, experience, required inputs/outputs or deliverables and sometimes even computer speed. Limited time and training were available for using the software required to process the collected information. This made it difficult to discuss and estimate processing time for the UAV data. Even if estimating the total time was possible, the deliverables are different. For example, a survey completed with an RTK system will only contain data at the physical points of survey and everything in between such as contours will be interpolated. With UAV data being so rich and sometimes excessive in nature, there are little to no gaps in the information. Due to this incredible amount of data, comparing the deliverables and processing time for a different outcome or result does not seem conclusive.

5.7 Comparisons Against Other UAV Systems

Ideally when comparing UAV data against RTK data an array of UAV systems would be tested. Due to time and budgetary constraints this was not completed in this dissertation. With multiple UAV systems available such as the rotary wing or balloons it would be interesting to compare results and cost between them. Previous research conducted by Sensefly (2016), concluded that multicopters were only better when fixed wing UAV systems could not be used. Many variables such as stability, size, camera type, focal length, weather conditions, speed and even processing software can affect the outcomes of the deliverables. To generate an accurate comparison it would be necessary to test under controlled conditions. If different UAV systems were tested in this manner, one would assume to achieve similar results.

With so many variables that cannot be eliminated in the real world environment, a decision was made to go with Trimble's UAV system. The Trimble UX5 HP unit was also selected due to availability, fixed wing structure, software compatibility, and because it was designed for long range flights which is ideal for the pipeline construction environment.

5.8 Conclusion

No significant difference were found between data collected by the UAV and RTK systems. However the UAV collection process offered significant advantages over the RTK system from a workplace health and safety perspective. The images captured during the pre- and post- flyovers offer significant opportunities for dispute resolution. It was suggested that companies using UAVS for pipeline work will have a definite cost advantage over non-UAV adopters.

CHAPTER 6 - CONCLUSIONS

This project was conducted with the intention of examining the useability, efficiency and cost of using UAVs versus RTK techniques to collect survey accurate data for the use in pipeline design and rehabilitation of construction corridors. The Trimble UX5 HP unit was selected for comparisons in useability, accuracy, efficiency and cost against the Trimble R6 GNSS RTK system.

A general discussion was provided around pipeline surveying requirements and construction sequences. This provided the basis and outlined the future need for a change of techniques when obtaining survey accurate data for pipeline projects. This set the basis for determining a methodology that would allow for real world comparisons analysis of existing RTK methods and future UAV data collection possibilities. Once data was obtained and analysis completed across several pipeline construction scenarios, outstanding cost reductions were presented and justified.

Quantifying results obtained by the Trimble UX5 HP UAV system, found it provided survey accurate data within +/-0.040m for horizontal accuracy and +/-0.048m in vertical accuracy over general pipeline corridor ROW features when compared to RTK surveyed data. Comparing UAV data collection for pre-stripped ROW produced results in the range of +/-0.070m in the vertical plane. Finally when comparing UAV data to a rehabilitated, post construction ROW delivered an accuracy of +/-0.037m also in the vertical plane. Results such as these demonstrated that UAVs have the ability to be used in the pipeline construction industry for both design and rehabilitation phases of construction.

Despite providing results within general pipeline tolerances, UAV data still had some limitations. Areas of dense vegetation such as creeks, drains or forests significantly reduced accuracy. This suggests that while UAVs have the ability to generate survey grade data there is still a need for terrestrial RTK survey techniques for verification and additional data collection in said areas.

The useability of UAV data was much greater than that of RTK data. UAV data was rich and left no gaps or unknowns. Not only was the data rich; it also provided detailed information about the immediate surrounds outside of the ROW extents and essentially captured a point in time with high resolution imagery that generates a better overview of the entire site.

The efficiency of data collection was much greater when using UAV surveying techniques rather than RTK. This provided a 68% reduction in cost when surveying a section of ROW with the UAV. Cost savings such as these can provide a surveying company with a leading edge over competitors in the pipeline industry.

Initial overhead UAV costs may present a barrier for any surveying company contemplating investment in UAV technology. It is important to consider the bigger picture and although there is a large outlay to begin with, it would not take long to recover these costs with increased efficiency and elimination of several safety risks that could amount to large compensation claims should an incident occur. Another potential cost saving measure could be associated with dispute resolution if there was a claim made against the pipeline contractor or surveying company. As previously mentioned, UAVs have the ability to capture huge amounts of spatial data and capture a point in time with aerial imagery. This spatial data can be used as evidence and prevent costly litigation practices should this occur.

6.1 Recommendations for Practical Applications

It is recommended that UAVs are suitable for use on pipeline projects for both the design and rehabilitation of construction corridors. However it is strongly recommended they be used in conjunction with terrestrial RTK survey methods. It became evident that UAV data and technology is not at the stage whereby it can be trusted as a stand along surveying technique and that some ground truthing and verification is required in suspect locations such as dense vegetation.

6.2 Recommendations for Future Research

UAVs are still relatively new technology and have many applications in contemporary surveying. There is still room for extensive research moving forward into the future. This thesis indicates a possibility for future research into:

- Incorporating additional payloads such as LiDAR (Light Imaging Detection and Radar) to reduce photogrammetric errors.

- Various software that through algorithms can reduce false surfaces created in DSMs with UAV data.
- Creation of 3D point clouds for pipeline design to enable a realistic viewing platform for various consultants.
- Pipeline asset monitoring and detection of dangerous gases in emergency situations.
- Increasing safety yet reducing workplace injuries and incidents.
- Cost analysis of processing times of UAV data versus RTK terrestrial data.
- Error expectancies for different vegetation types and density.

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Appendix A: Project Specification

ENG4111/4112 RESEARCH PROJECT

PROJECT SPECIFICATION

For: Anton Breinl

Title: UAVs in Pipeline Design and Rehabilitation of Construction Corridors

Major: Bachelor of Spatial Science (Honours)

Supervisors: Zahra Gharineiat

Enrolment: ENG4111 - EXT S1, 2016
ENG4112 - EXT S2, 2016

Project Aim: Investigate useability, efficiency and cost of UAVs in pipeline design and rehabilitation of construction corridors comparing traditional RTK surveying methods versus UAVs.

Programme: Issue A, 16th March 2016

1. Provide a general discussion of pipeline corridors and construction sequences.
2. Research and select a UAV with accessories to perform the task of delivering quality data to achieve the best possible results.
3. Examine expected accuracies and overhead costs of selected UAV and RTK systems.
4. Discuss the benefits and limitations of each system for data collection.
5. Review collected data from both systems and finalise into two separate deliverable products using nominated software packages.
6. Compare overall data useability, accuracy, efficiency and cost based on the outcomes of the deliverables.
7. Make recommendations on the system/technique of choice along with future possibilities.

Appendix B: Trimble Business Centre Flight Adjustment Report

Trimble UAS

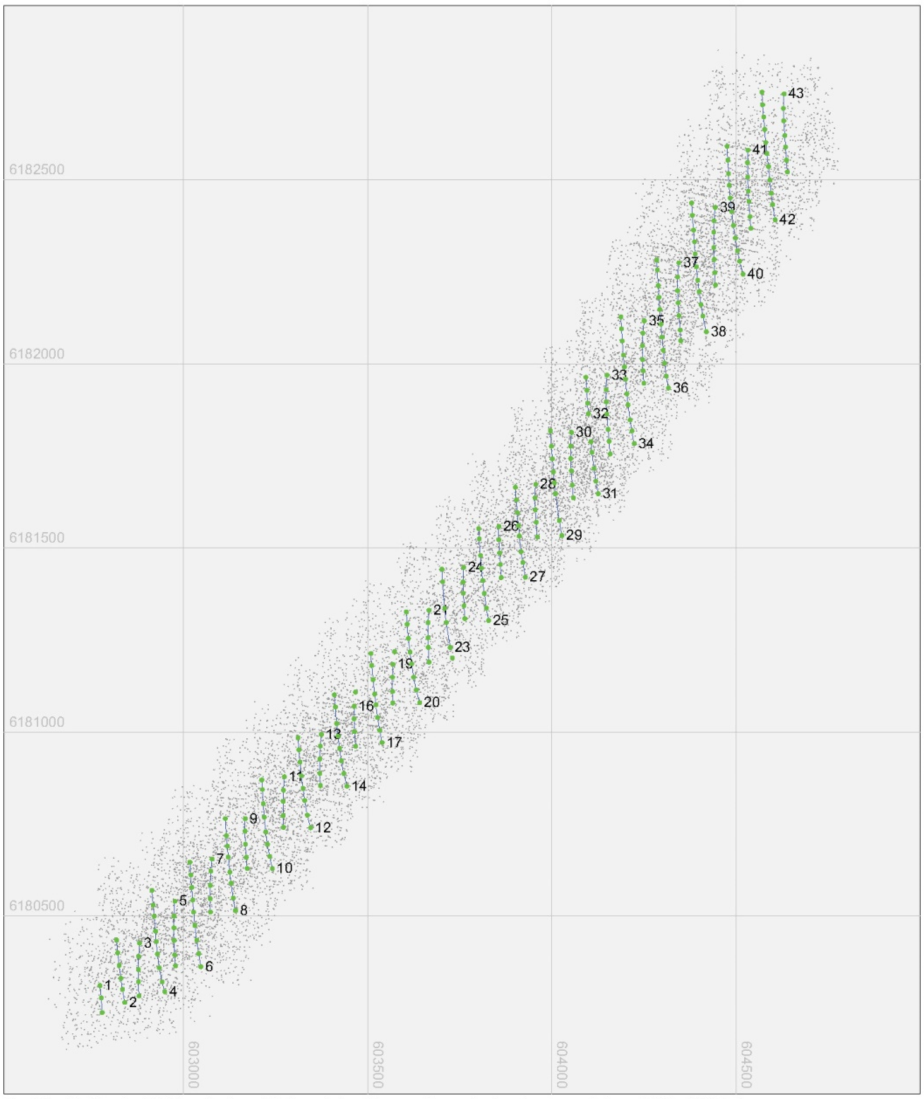
Processing Report

General project information

Project name	uasbox_iter
Process	Geo-referencing
Computer node	LPBRIL028
Operating system	Microsoft Professional (build 9200), 64-bit, version 6.2
Machine	Intel(R) Core(TM) i7-2M CPU @ 2.40GHz 8 cores 11.9 GByte RAM
User name	Anton.Breinl
Report generation time	Sat Jul 30 19:04:45 2016
Processing time	Sat Jul 30 19:04:44 2016
Result file	C:\Users\anton.breinl\AppData\Local\Temp\UASBox\10.10-Adjustment Report \uasbox_iter.prj
Number of used images	277 of 277
Number of used cameras	1 of 1
Number of strips	41
Flying height	min=617.4 / avg=626.3 / max=636.2 [m]
Terrain height	min=481.7 / avg=501.6 / max=530.8 [m]
Average photo scale	1 : 7097
Coordinate system	PROJCS["Zone_55", GEOGCS["Australia/ GDA94",DATUM["GDA94",SPHEROID["Geodetic_Ref_System_1980", 6378137,298.257222101004], TOWGS84[0,0,0,0,0,0,0]], PRIMEM["Greenwich",0.0], UNIT["Degree",0.0174532925199433]], PROJECTION["Transverse_Mercator"], PARAMETER["central_meridian",147], PARAMETER["scale_factor",0.9996], PARAMETER["latitude_of_origin",0], PARAMETER["false_easting",500000], PARAMETER["false_northing",10000000], UNIT["Meter",1]]

Page 1

Flight overview



Graphic with 41 strip definitions for the arial triangulation. The area has a planimetric extent of about: 2387 x 2956 [m].

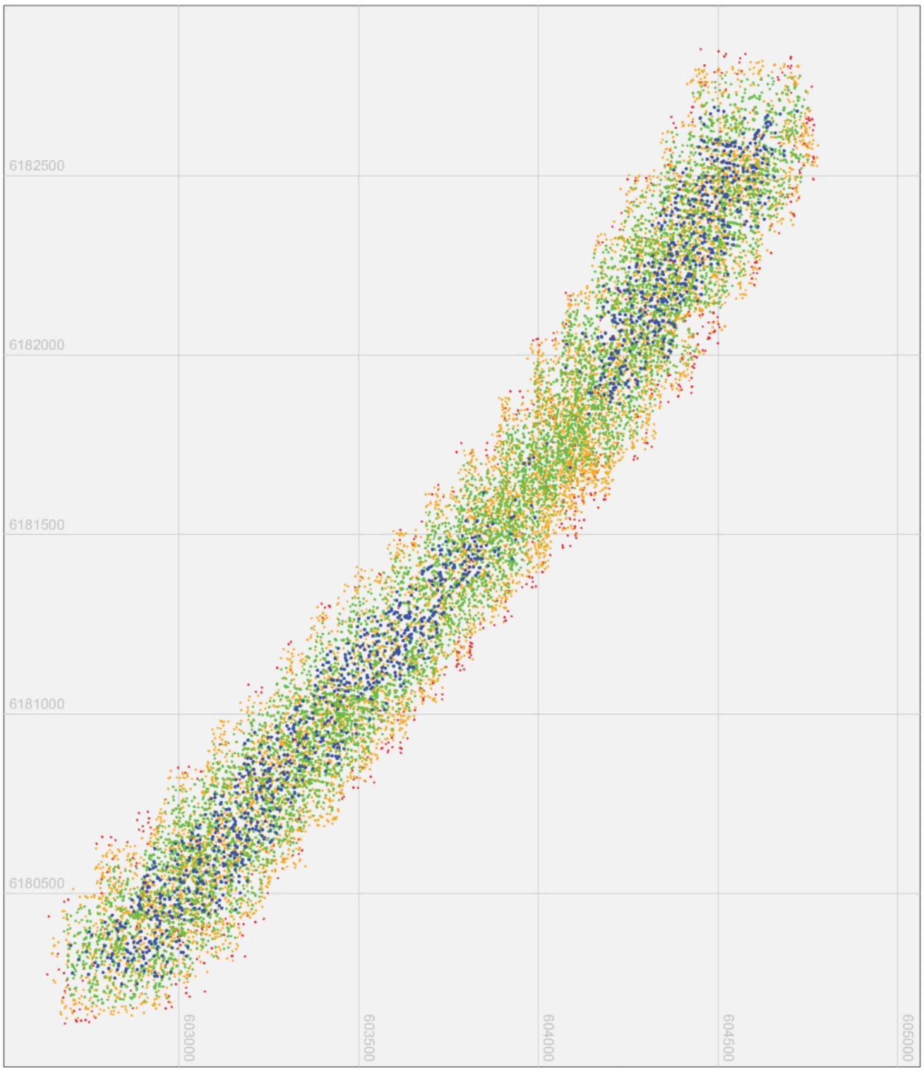
: Camera location for 277 adjusted photos.

: Camera location for 0 eliminated photos.

: Defined strip in the project.

: Tie point location for 16969 points.

Tie point distribution



Tie point distribution of 16969 points in the project. The point size and colour reflects the number of images containing the point. The area has a planimetric extent of about: 2387 x 2956 [m] and a height range of about: 482 - 531 [m].

- : Point found in (0-2) images.
- : Point found in (3-4) images.
- : Point found in (5-10) images.
- : Point found in (>10) images.

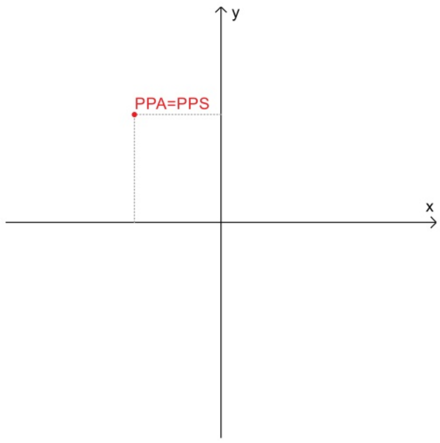
Camera calibration

Camera data (Camera: 1197)

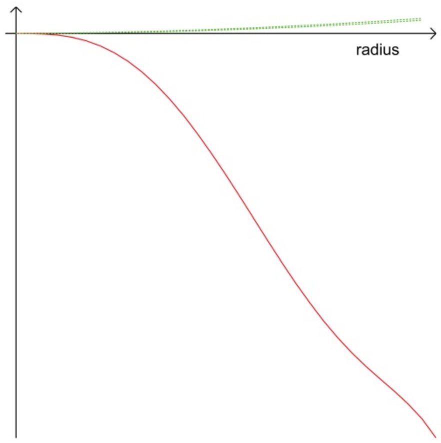
Manufacturer	UAS_Digital	
Serial number		
Sensor (width / height) [pixel]	7360	4912
Pixel size (x / y) [micron]	4.8816	4.8805
Ground sampling distance (x / y) [m]	0.0346	0.0346
Distortion type	Polynomial	
Focal length [mm / pixel]	15.5088	3177.3332
Focal length (Fx / Fy) [pixel]	3176.9800	3177.6866
Principal point (x / y) [mm | pixel]	-0.2491 | 3628.4816	0.3097 | 2392.0507
Distortion parameter: K0 / K1	0.000000E+00	-1.885497E-04
K2 / K3	5.162600E-07	-4.642777E-10
K4 / K5	0.000000E+00	0.000000E+00
P1 / P2	-1.522327E-05	-3.234262E-05

Platform data (Camera: 1197)

	X [m]	**Y [m]**	**Z [m]**
GNSS antenna offset	0.300000	-0.244000	0.014494
	Omega (X) [deg]	**Phi (Y) [deg]**	**Kappa (Z) [deg]**
IMU boresight alignment	0.000000	0.000000	0.000000
Camera mount rotation	90.000000 [deg]		



Position of the principle point (x=-0.2491, y=0.3097 [mm]) in the image.



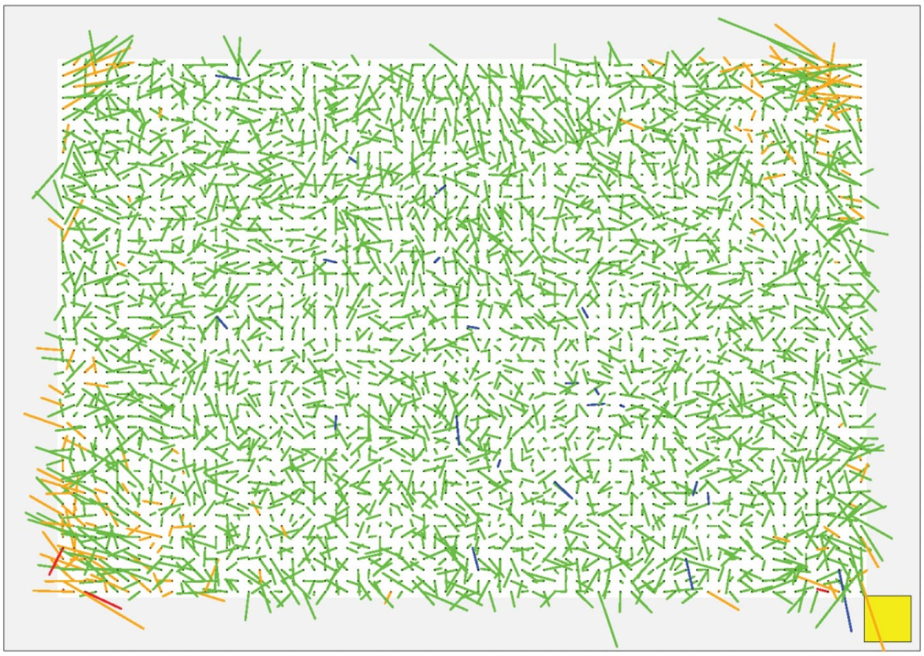
The dashed green lines show the magnitude of the decentering distortions on the four image diagonals.This gives an impression of what will be missed if only radial distortion components are used.

Distortion values (Camera: 1197)

	Radius [mm]	calibrated Distortion [micron]
1	0.0000	0.0000
2	1.0000	-0.1880
3	2.0000	-1.4919
4	3.0000	-4.9664
5	4.0000	-11.5461
6	5.0000	-21.9917
7	6.0000	-36.8423
8	7.0000	-56.3781
9	8.0000	-80.5943
10	9.0000	-109.1887
11	10.0000	-141.5665
12	11.0000	-176.8630
13	12.0000	-213.9878
14	13.0000	-251.6928
15	14.0000	-288.6646
16	15.0000	-323.6466
17	16.0000	-355.5905
18	17.0000	-383.8406
19	18.0000	-408.3538
20	19.0000	-429.9565
21	20.0000	-450.6414
22	21.0000	-473.9064
23	22.0000	-505.1384

Distortion error of radial symmetric components of parameters: K0, K1, ... and P1, P2.

Image residuals (Camera: 1197)



Average image residual vectors (min=0.002, avg=1.316, max=5.277 [pixel]) for image matrix elements. An image matrix element is defined with about (100 x 100) pixels.

: Scale for the residual vectors. Symbol in the graphic is correlated to 1 [pixel] in the image.
: Average image residual vector for points in (0-2) images.
: Average image residual vector for points in (3-4) images.
: Average image residual vector for points in (5-10) images.
: Average image residual vector for points in (>10) images.

Block adjustment results

Parameters for block adjustment

GNSS-Mode	ON
IMU-Mode	OFF
Earth curvature correction	ON
Refraction correction	ON

Accuracy of block adjustment

Sigma naught [micron]	6.2576

Mean standard deviation of translations

X [m]	Y [m]	Z [m]	Total [m]
0.0144	0.0157	0.0142	0.0256

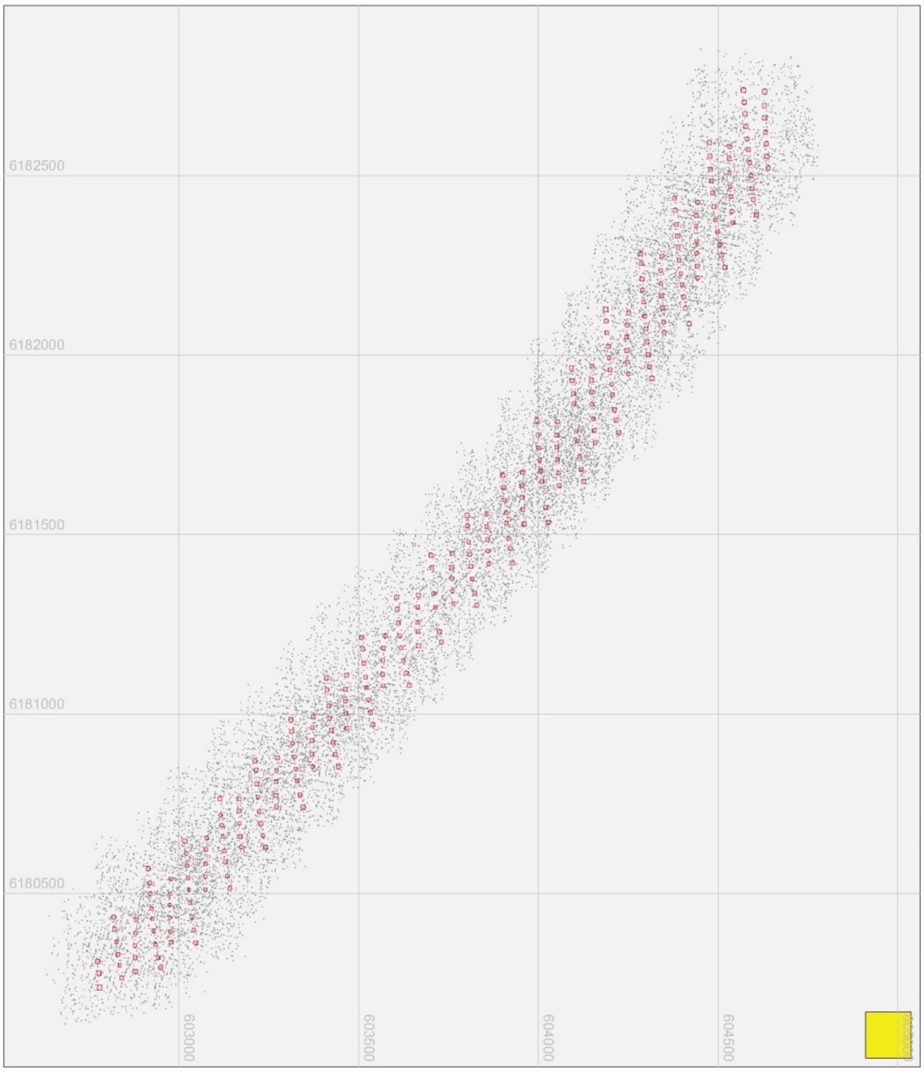
Mean standard deviation of rotations

Omega [deg/1000]	Phi [deg/1000]	Kappa [deg/1000]
5.3771	4.3659	2.8662

Mean standard deviation of terrain points

X [m]	Y [m]	Z [m]	Total [m]
0.0485	0.0359	0.0685	0.0912

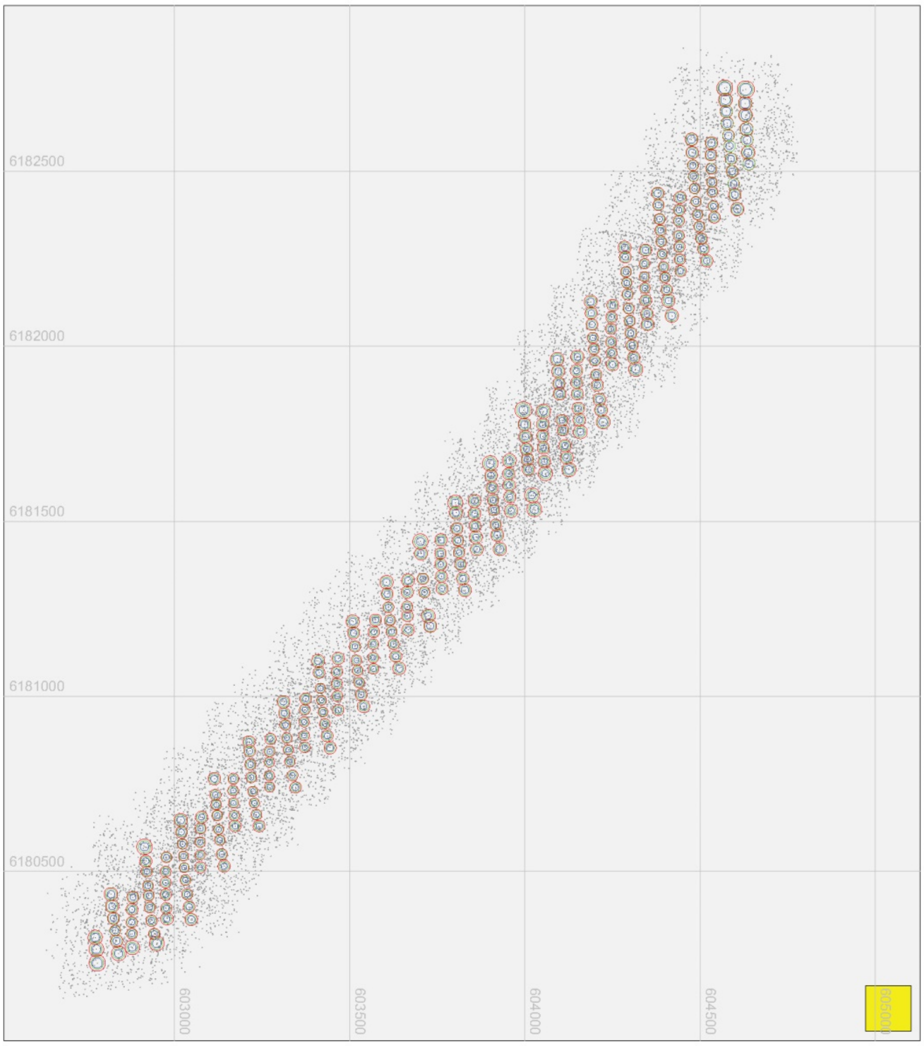
Exterior orientation (X,Y,Z) standard deviations



Graphic with 277 photos from the project. The camera locations are shown with its standard deviations for XYZ. The area has a planimetric extent of about: 2387 x 2956 [m].

- : Scale for the symbols. Symbol in the graphic is correlated to 0.173 [m] in the object.
- : Standard deviation XY for 277 projection centers (min=0.018, avg=0.021, max=0.028 [m]).
- : Standard deviation Z for 277 projection centers (min=0.012, avg=0.014, max=0.019 [m]).
- : Tie point location for 16969 points.

Exterior orientation (Omega,Phi,Kappa) standard deviations



Graphic with 277 photos from the project. The camera locations are shown with its standard deviations for omega,phi,kappa. The area has a planimetric extent of about: 2387 x 2956 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.02102 [deg] in the object.

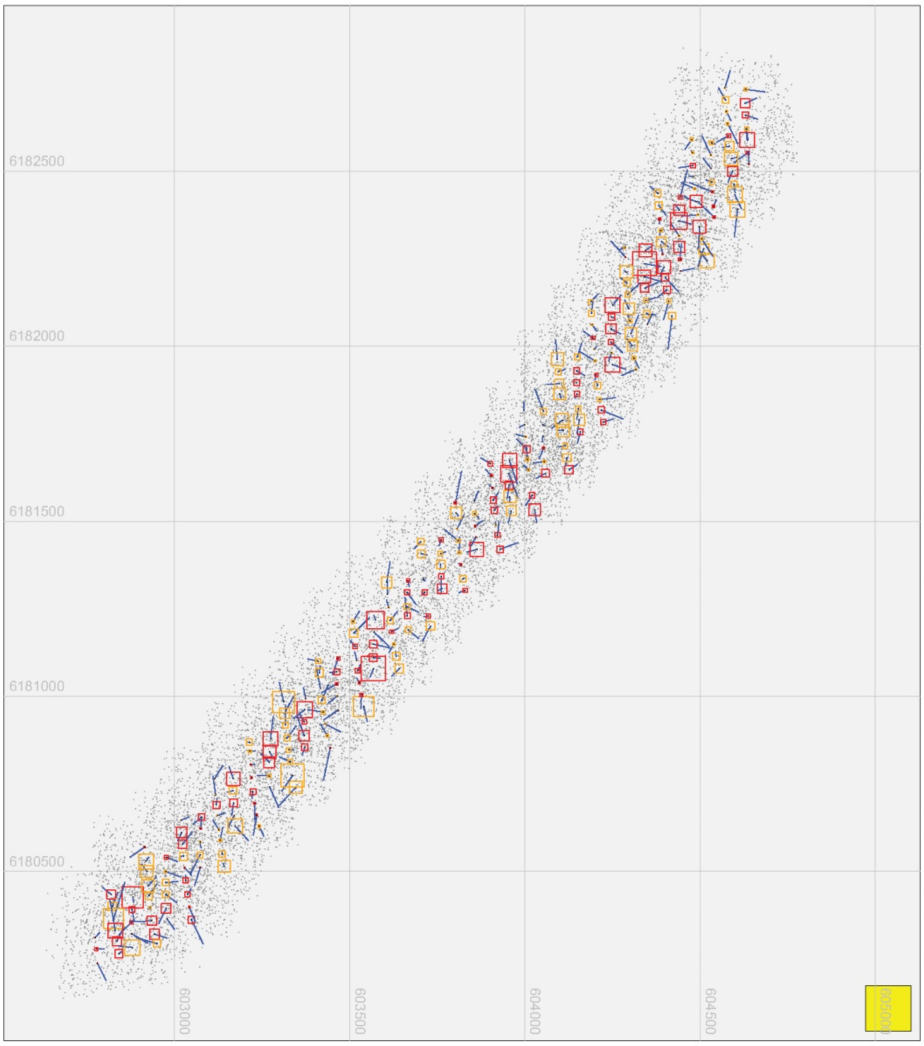
: Standard deviation omega(X) for 277 projection centers (min=0.00437, avg=0.00538, max=0.00781 [deg]).

: Standard deviation phi(Y) for 277 projection centers (min=0.00349, avg=0.00437, max=0.00628 [deg]).

: Standard deviation kappa(Z) for 277 projection centers (min=0.00214, avg=0.00287, max=0.00528 [deg]).

: Tie point location for 16969 points.

GNSS residuals



Graphic with 277 GNSS locations from the adjustment. The points are shown with its residuals for X,Y,Z from the adjustment. The area has a planimetric extent of about: 2387 x 2956 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.112 [m] in the object.

: Residual XY for (277) GNSS positions (min=0.001, avg=0.030, max=0.093 [m]).

: Residual Z for (pos.:137/neg.:140) GNSS positions (min=-0.056, avg=0.000, max=0.060 [m]).

: Extreme residual XYZ for (0) GNSS positions.

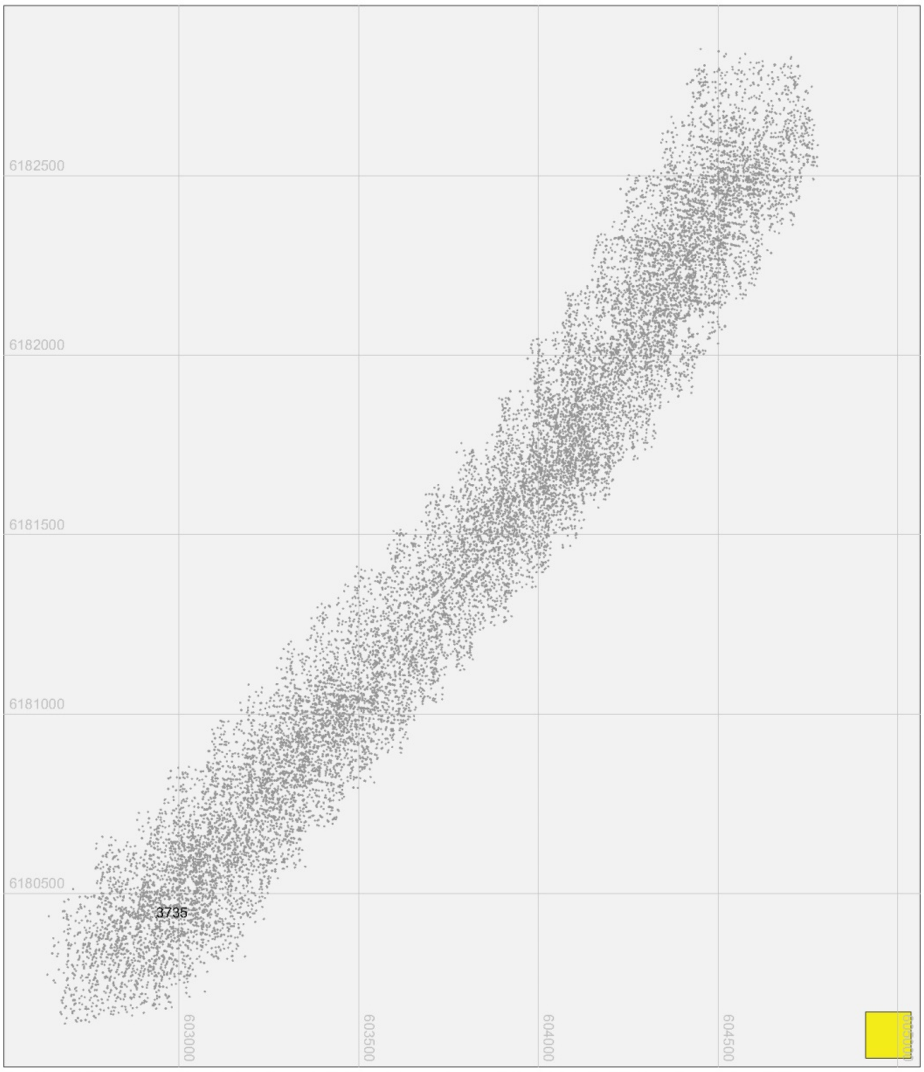
: Tie point location for 16969 points.

Ground control points

Ground control point errors

#	ID	Fold	X [m]	Y [m]	Z [m]	Total [m]	Remark
1	**3735**	27	0.0000	0.0000	-0.0000	0.0000	
	Maximum		0.0000	0.0000	-0.0000		
	Mean		0.0000	0.0000	-0.0000		
	Sigma		0.0000	0.0000	0.0000		
	RMSE(x,y,z)		0.0000	0.0000	0.0000		
	RMSEr		0.0000	SQRT(RMSEx * RMSEx + RMSEy * RMSEy)			
	ACCr (at 95% Confidence Level)		0.0000	RMSEr * 1.7308			
	ACCz (at 95% Confidence Level)		0.0000	RMSEz * 1.9600			

Ground control point residuals



Graphic with 1 ground control points from the project. The points are shown with its residuals for XYZ from the adjustment. The area has a planimetric extent of about: 2387 x 2956 [m].

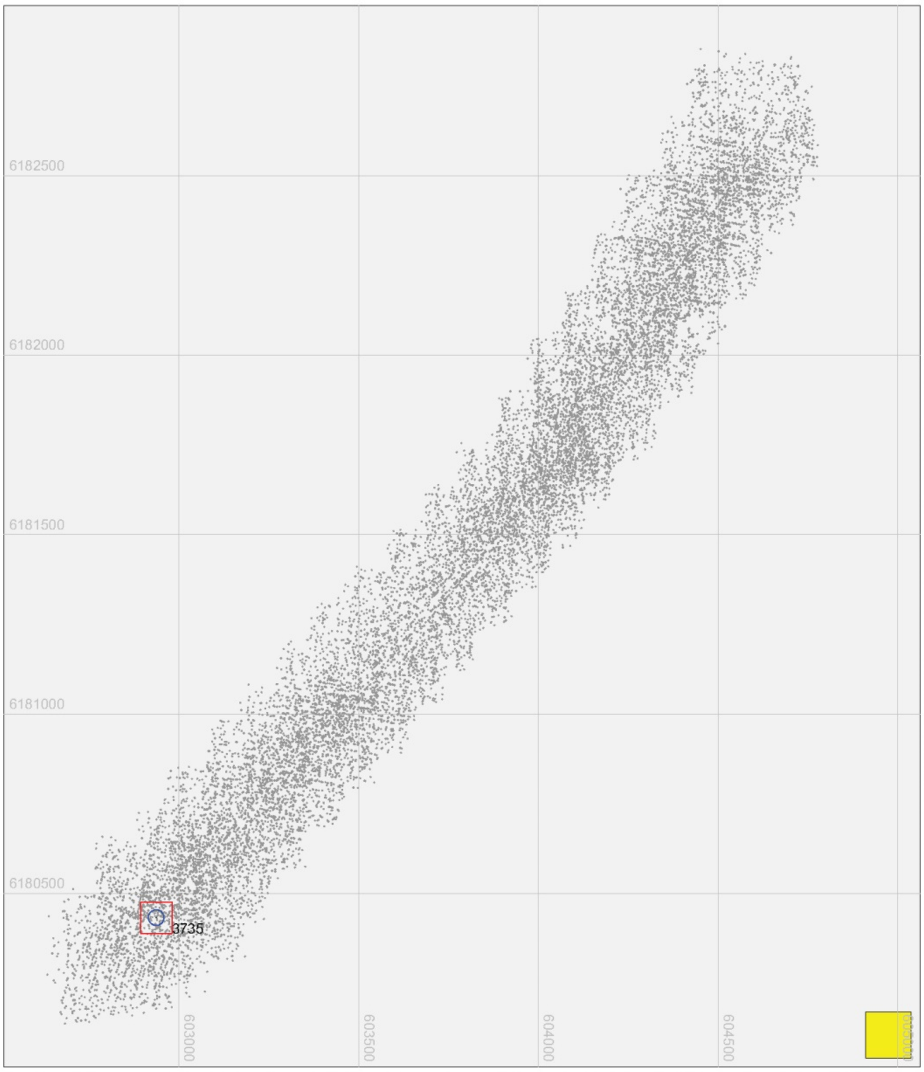
: Scale for the symbols. Symbol in the graphic is correlated to 0.013 [m] in the object.

: Residual XY (1) for ground control points (min=0.000, avg=0.000, max=0.000 [m]).

: Residual Z (pos.:1/neg.:0) for ground control points (min=0.000, avg=0.000, max=0.000 [m]).

: Tie point location for 16969 points.

Ground control point standard deviations



Graphic with 1 ground control points from the project. The points are shown with its standard deviations for XYZ from the adjustment. The area has a planimetric extent of about: 2387 x 2956 [m].

: Scale for the symbols. Symbol in the graphic is correlated to 0.013 [m] in the object.

: Standard deviation XY for 1 ground control points (min=0.006, avg=0.006, max=0.006 [m]).

: Standard deviation Z for 1 ground control points (min=0.009, avg=0.009, max=0.009 [m]).

: Tie point location for 16969 points.

Appendix C: Observation Set B

OVERALL ELEVATION (Z) VALUE RMSE ANALYSIS		
Observed Value	Predicted Value	Difference
488.216	488.407	-0.191
488.306	488.488	-0.182
488.039	488.214	-0.175
488.250	488.407	-0.157
487.989	488.137	-0.148
488.185	488.329	-0.144
488.033	488.176	-0.143
488.344	488.486	-0.142
487.661	487.801	-0.140
488.122	488.259	-0.137
488.283	488.420	-0.137
488.105	488.235	-0.130
487.128	487.257	-0.129
487.999	488.127	-0.128
486.644	486.757	-0.113
488.088	488.198	-0.110
487.108	487.218	-0.110
488.307	488.415	-0.108
488.114	488.218	-0.104
487.989	488.093	-0.104
486.943	487.047	-0.104
487.078	487.180	-0.102
488.200	488.300	-0.100
487.290	487.386	-0.096
486.640	486.734	-0.094
487.759	487.850	-0.091
487.954	488.044	-0.090
487.697	487.787	-0.090
488.154	488.239	-0.085
487.023	487.108	-0.085
488.292	488.376	-0.084
487.967	488.049	-0.082
495.308	495.387	-0.079
488.084	488.162	-0.078
490.467	490.545	-0.078
487.997	488.073	-0.076
488.191	488.263	-0.072
489.354	489.426	-0.072
488.025	488.094	-0.069

486.842	486.910	-0.068
487.755	487.822	-0.067
488.503	488.569	-0.066
488.119	488.181	-0.062
488.044	488.105	-0.061
488.129	488.189	-0.060
489.188	489.247	-0.059
486.826	486.882	-0.056
488.223	488.276	-0.053
488.197	488.250	-0.053
489.200	489.252	-0.052
488.408	488.460	-0.052
487.946	487.997	-0.051
490.519	490.570	-0.051
486.950	486.999	-0.049
490.531	490.578	-0.047
491.086	491.133	-0.047
488.996	489.042	-0.046
489.068	489.113	-0.045
486.763	486.808	-0.045
488.154	488.197	-0.043
495.003	495.045	-0.042
495.491	495.532	-0.041
486.749	486.788	-0.039
488.070	488.106	-0.036
488.563	488.595	-0.032
487.721	487.753	-0.032
491.598	491.626	-0.028
487.863	487.890	-0.027
496.202	496.229	-0.027
489.175	489.201	-0.026
490.278	490.304	-0.026
490.376	490.400	-0.024
486.875	486.899	-0.024
490.750	490.774	-0.024
490.742	490.766	-0.024
490.280	490.302	-0.022
487.985	488.007	-0.022
489.852	489.874	-0.022
495.454	495.476	-0.022
488.968	488.989	-0.021
486.820	486.841	-0.021
489.040	489.060	-0.020
490.563	490.583	-0.020
487.571	487.590	-0.019

488.144	488.163	-0.019
490.847	490.866	-0.019
490.496	490.514	-0.018
488.398	488.416	-0.018
488.261	488.277	-0.016
487.632	487.647	-0.015
486.778	486.793	-0.015
491.280	491.295	-0.015
488.038	488.052	-0.014
490.579	490.593	-0.014
492.988	493.002	-0.014
488.217	488.230	-0.013
488.090	488.103	-0.013
490.370	490.382	-0.012
490.549	490.561	-0.012
491.366	491.377	-0.011
494.829	494.839	-0.010
488.664	488.673	-0.009
495.757	495.766	-0.009
487.638	487.647	-0.009
491.825	491.833	-0.008
492.532	492.540	-0.008
488.223	488.230	-0.007
496.508	496.515	-0.007
489.132	489.138	-0.006
490.406	490.412	-0.006
492.078	492.083	-0.005
488.650	488.654	-0.004
488.248	488.249	-0.001
486.842	486.843	-0.001
490.733	490.734	-0.001
490.896	490.897	-0.001
490.386	490.386	0.000
488.599	488.598	0.001
490.727	490.726	0.001
487.676	487.674	0.002
490.274	490.271	0.003
489.374	489.370	0.004
490.048	490.044	0.004
490.948	490.944	0.004
496.617	496.613	0.004
489.163	489.158	0.005
491.962	491.957	0.005
490.570	490.564	0.006
490.002	489.995	0.007

496.005	495.995	0.010
488.112	488.101	0.011
495.771	495.759	0.012
490.696	490.682	0.014
495.724	495.710	0.014
496.630	496.616	0.014
490.487	490.472	0.015
488.558	488.542	0.016
495.885	495.869	0.016
488.463	488.446	0.017
490.386	490.367	0.019
496.073	496.054	0.019
490.274	490.254	0.020
489.027	489.006	0.021
488.618	488.597	0.021
487.710	487.688	0.022
486.672	486.650	0.022
496.348	496.325	0.023
488.520	488.496	0.024
493.499	493.475	0.024
495.414	495.390	0.024
490.301	490.275	0.026
490.412	490.386	0.026
493.500	493.474	0.026
494.107	494.081	0.026
491.514	491.487	0.027
488.765	488.737	0.028
487.001	486.973	0.028
495.110	495.082	0.028
487.034	487.003	0.031
488.605	488.572	0.033
490.692	490.655	0.037
492.349	492.312	0.037
495.404	495.367	0.037
490.095	490.057	0.038
488.610	488.571	0.039
490.241	490.202	0.039
489.923	489.883	0.040
493.042	493.001	0.041
494.444	494.403	0.041
496.337	496.296	0.041
488.405	488.363	0.042
488.572	488.530	0.042
489.298	489.256	0.042
489.393	489.350	0.043

490.480	490.437	0.043
488.526	488.482	0.044
490.146	490.102	0.044
488.994	488.949	0.045
488.433	488.388	0.045
488.694	488.648	0.046
494.879	494.833	0.046
495.872	495.825	0.047
489.149	489.101	0.048
488.496	488.448	0.048
489.311	489.258	0.053
490.514	490.461	0.053
490.584	490.530	0.054
489.747	489.691	0.056
493.331	493.274	0.057
488.594	488.536	0.058
492.984	492.926	0.058
488.435	488.376	0.059
492.983	492.924	0.059
488.230	488.169	0.061
486.889	486.827	0.062
493.346	493.281	0.065
489.759	489.693	0.066
490.397	490.329	0.068
490.385	490.317	0.068
490.632	490.564	0.068
490.657	490.588	0.069
488.210	488.140	0.070
488.520	488.448	0.072
488.522	488.448	0.074
489.259	489.184	0.075
489.437	489.361	0.076
488.670	488.593	0.077
486.790	486.711	0.079
490.065	489.985	0.080
493.652	493.569	0.083
494.520	494.436	0.084
489.297	489.206	0.091
488.560	488.468	0.092
489.210	489.115	0.095
490.403	490.297	0.106
490.484	490.377	0.107
490.481	490.363	0.118
490.526	490.395	0.131
490.543	490.408	0.135

490.325	490.188	0.137
488.184	488.042	0.142
488.192	488.041	0.151
490.474	490.318	0.156
490.564	490.388	0.176
490.458	490.278	0.180
490.505	490.317	0.188
490.455	490.256	0.199
		RMSE Z
		0.070

Appendix D: Observation Set C

REHABILITATED SURFACE ELEVATION (Z) VALUE RMSE ANALYSIS		
Observed Value	Predicted Value	Difference
486.672	486.65	0.022
486.79	486.711	0.079
486.778	486.793	-0.015
486.875	486.899	-0.024
488.144	488.163	-0.019
488.07	488.106	-0.036
488.09	488.103	-0.013
488.261	488.277	-0.016
488.398	488.416	-0.018
490.727	490.726	0.001
490.733	490.734	-0.001
490.75	490.774	-0.024
490.847	490.866	-0.019
490.896	490.897	-0.001
492.078	492.083	-0.005
491.825	491.833	-0.008
491.598	491.626	-0.028
491.366	491.377	-0.011
491.514	491.487	0.027
491.962	491.957	0.005
491.086	491.133	-0.047
490.742	490.766	-0.024
490.48	490.437	0.043
490.065	489.985	0.08
490.241	490.202	0.039
490.657	490.588	0.069
490.146	490.102	0.044
489.747	489.691	0.056
489.298	489.256	0.042
489.852	489.874	-0.022
489.923	489.883	0.04
490.002	489.995	0.007
490.696	490.682	0.014
490.274	490.271	0.003
490.095	490.057	0.038
489.759	489.693	0.066
490.048	490.044	0.004
490.386	490.386	0

490.948	490.944	0.004
490.692	490.655	0.037
490.57	490.564	0.006
490.632	490.564	0.068
490.412	490.386	0.026
491.28	491.295	-0.015
492.349	492.312	0.037
493.042	493.001	0.041
492.988	493.002	-0.014
493.499	493.475	0.024
493.5	493.474	0.026
493.346	493.281	0.065
492.532	492.54	-0.008
492.983	492.924	0.059
492.984	492.926	0.058
493.652	493.569	0.083
493.331	493.274	0.057
494.107	494.081	0.026
494.444	494.403	0.041
494.879	494.833	0.046
495.491	495.532	-0.041
495.003	495.045	-0.042
494.52	494.436	0.084
494.829	494.839	-0.01
495.454	495.476	-0.022
496.005	495.995	0.01
496.508	496.515	-0.007
495.872	495.825	0.047
495.308	495.387	-0.079
495.11	495.082	0.028
495.771	495.759	0.012
496.348	496.325	0.023
496.337	496.296	0.041
495.885	495.869	0.016
495.404	495.367	0.037
495.414	495.39	0.024
495.724	495.71	0.014
496.202	496.229	-0.027
496.617	496.613	0.004
496.63	496.616	0.014
496.073	496.054	0.019
495.757	495.766	-0.009
487.638	487.647	-0.009
		RMSE Z