University of Southern Queensland

Faculty of Health, Engineering and Sciences

An Accuracy Comparison between GPS Surveying and UAV Surveying on Seawall Monitoring

A dissertation submitted by

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Abstract

Photogrammetry has been utilised for a significant amount of time, originally being use by the military as renaissance surveys to capture information in the field. This technology has science has now progressed and is now used within the field of surveying for spatial solutions, such as Digital Surface Models (DSM) and monitoring surveys. With the introduction of small, cheap, Unmanned Aerial Systems (UAS) in more recent years, and the technology in GPS equipment and satellites available becoming ever more reliable, it makes the surveyor question, what kind of accuracy can we achieve with UAS and is it comparable to that of the GPS?

This paper focuses on a comparison of accuracy between conventional Cors RTK GPS System and the commercial based UAS photogrammetry data from a DJI Phantom 4 Drone. These systems are becoming more and more common within the work area and have become significantly more advanced but also significantly cheaper. The UAS platform (DJI Phantom 4) has all the capabilities to perform a photogrammetric survey, tethered with in-house mission planning programs such as litchi, this gives the drone and user full autonomous capabilities and to create a flight path with the ample amount of overlap required to create an accurate 3D model of the project area.

This paper will compare the data sets collected between the GPS survey and the UAS survey completed to analyse the accuracies between the two and whether this method of surveying can accurate monitor a sea wall and the movements that may occur. The accuracy can be illustrated between the two types of survey through the use of a statistical analyse of the data creating a confidence interval expressed in the form of RMSEx, RMSEy and RMSExy. This method will also be used to check the accuracy between the two types in relation to elevation, thus ensure all three dimensions of error are checked, with hopefully similar results being obtained between the two.

Photogrammetry, more so UAS, will change the survey industry. As technology continues to advance so will the methods in which data can be captured and the cameras used, this will enable the user a much more accurate result, creating better solutions and more project opportunities into the future. However with the standard of UAS or drones currently available in the market and within the price range of a DJI Phantom 4, it would of best practice to limit the range of data that is captured and the accuracies in which are required. Currently the accuracy of the UAS or drone is limited by many factors, but it would be best practice to assume the drone is accurate to +/- 30mm in distance and +/- 50mm in elevation.

Although the results of this project satisfied the aim of this project, it is recognized that these results can be improved by alternative methods mentioned in the discussion section of the report and as well as number of recommendations for future research to better understand the limitations of these systems in providing spatial data.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental works, results, analysis 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 institution, except where specifically stated.

Luke David Bartlett

[redacted]

Signature

12/10/2017

Date

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1. Introduction

Seawalls have been utilised throughout the coastal regions of Australia for many decades now, for both protection and land mitigation reasons. Seawalls can consist of many different materials and can be built using many different methods.

In the past, seawalls used to be built from concrete, rocks old car bodies, building rubble, tyres, sandbags and any other items deemed suitable at the time to try and prevent the erosion of the shoreline. As illustrated in figure 1 below, old vehicles were used in the Erosion Management of 1967.

As time has progressed on, it has become necessary to ensure the seawalls are built correctly and will not fail during the first or 100th natural event. Therefore, it has become necessary to build seawalls according to the shape required and the materials most suited for the structure. Such materials are; Reinforced Concrete, Geotextile containers, gabion baskets, mass concrete or sheet piles.

Even with seawalls being built to a higher standard, it is still a requirement to monitor the seawalls for any damage or movement over time. Previously only a visual survey could be taken of the seawalls, giving only a minor check on the whole structure, this may also include minor boreholes. However with advancements in technology it is now possible to get a more thorough screening of the seawalls by using other methods such as, but not limited to; conventional survey methods, Aerial Photogrammetry, Ground Penetrating Radar & infrared thermography.

This aim of this report is to illustrate two selected methods of surveying both used for capturing and monitoring data of a nominated seawall. The report will go onto further cover information on the previous methods and materials used the current materials and methods used, and the monitoring methods previously and currently being adopted to ensure the seawalls built are maintained and monitored.

The report will further discuss the ideal method of capturing this data and the accuracies achieved between the use of commercial based drone photography and conventional GPS Surveying. This will be illustrated during the report with a comparison of the point cloud data and RTK GPS Data captured during the practical phase.

This project is designed to provide information on the use of a commercial based Drone as a survey tool, to monitor the movement and degradation of seawalls. It will help to give guidance in to the accuracies of the data and the timeframe to complete the task.

The expected outcomes of the project include:

- Identification of the most practical survey method, either RTK GPS or Drone
- Demonstration of UAV flight path and Data capturing
- Analyse survey methods and illustrate most suitable and accurate method
- Demonstrate the productivity of Pix4D and whether the program is suitable for the task and if it is effective and accurate.
- A final comparison between the original each monitoring DTM from the 3D point clouds.

The above information will help to promote more effective ways of surveying coastal seawalls whilst still maintaining high levels of accuracy**.**

Figure 1, Erosion Management 1967

(Engineering, 2017)

1.2 Aim and Objectives

1.2.1 Aim

This report aims to give a clear and concise understanding of the previous and current methods used with capturing and monitoring the seawalls installed on the Gold Coast, whilst producing an accuracy report between two survey methods used; RTK GPS and Commercial Based Drone Photogrammetry.

1.2.2 Objectives

Below is a list of the objectives required to complete the Project? This is only a brief outline of the works involved to be able to complete the works. A more detailed list of tasks and methods required has been outlined in section 3.3 Methodology.

The Objectives of this report are;

- Review previous information on how seawalls are built and the materials used
- Review and analyse the current materials and methods used for seawall development
- To establish a project site with an open seawall to enable a monitoring survey to be conducted.
- Review and analyse the designs of UAV/Drones available to establish the drone most suitable for the task
- Evaluate and adopt or enhance the current methods used to monitor seawalls
- Establish the most suitable flight path, height, angle and speed depending on the drone/camera used
- Establish site control/datum to give accurate results during the flight phase
- Monitor Seawall using chosen methods
- Review most suitable methods to capture data using a drone for photogrammetry purposes
- Create 3D point cloud using photogrammetry survey.
- Evaluate and compare the two survey methods and the data captured for accuracy standards & comparison
- Evaluate and conclude the quickest, most reliable and most accurate method of the two

1.3 Justification

North Group has constantly been striving for excellence within the surveying industry, but also within innovation in relation to drones and even remote scanners. As they strive for quicker and more accurate ways of producing survey data for the client, conventional methods of surveying will not suffice.

With the introduction of UAS and the recent relaxation of rules and regulations associated with flying drones(CASA 2017), it helped sparked an interest into what would be a more productive way of surveying within our industry, and what better way than to compare data based on an already established area of surveying.

1.4 Scope of Research

The scope of research will help to provide a clear understanding of the Seawall Structures, their use and flaws, the methods in which were previously used to monitor the seawalls and the advancements in technology today.

A literature review was undertaken to further develop the idea towards the research project and to assist the reader with further knowledge on the topics covered. The purpose of the review was to gather all relevant information about the following:

- The General Characteristics of a Rotary Wing Drone and RTK GPS
- CASR Standards
- Design Criteria of Seawalls
- Flight Altitude & Control Points
- Monitoring & Maintenance of Seawalls
- Data Processing and DTM Generation

The above sections summarise the salient points and the literature review is provided as Section 2.

1.5 Conclusion

Surveying as whole an industry has grown significantly over time, especially with advancements in technology. With this, the surveyor isn't just required to understand land cadastral systems, but also the ca programs and other innovations too such as UAVs, UAS and scanners. Surveyors are now required to find new and innovative ways to perform daily tasks to cut costs and improve profits. Spatial scientists are faced daily with complex tasks, which would question whether the conventional means of surveying is the most efficient or effective. It is common practice for surveyors to conventional methods, including GPS to monitor survey walls; however it has not been assessed to see whether UAS would be capable for the task. UAS are lightweight, cheap and take good quality photos which can be used for photogrammetric purposes. The following paper looks at the achievable accuracy of the middle range UAS and compares those accuracies against that of the conventional GPS Surveying methods.

2 Literature Review

2.1 Introduction

The following literature review and analysis is necessary to gain a broader understanding of the research topic, fulfilling the research objectives and identifies the current gap of knowledge surrounding RTK GPS and Drone Surveying for the use of Seawall Monitoring. The focus of the literature assessment includes;

- Defining the key characteristics of a rotary wing drone and the RTK GPS Unit.
- Identifying the key elements and failure modes for small coastal seawalls.
- Survey methods and examples that may also be useful for determining the structure of an existing seawall, including flight heights and pixel quality.
- Local government asset management plan in reference to small seawalls, including monitoring & maintenance.
- Identifying the key elements of a small coastal seawall and the materials in which they are constructed.
- The CASR standards of local and private flight of UAVs and small commercial drones, in reference to public areas and occupied flight space.

2.2 Design Criteria of Seawalls

Seawalls can also be referred as a revetments, are usually considered to be sloping and flexible, whilst a seawall may be either vertical or sloping, and either rigid of flexible.

The following definitions are presented from standard coastal engineering references.

Seawall

Seawalls are onshore structures with the principal function of preventing or alleviating overtopping and flooding of the land and the structures behind due to storm surges and waves. Seawalls are built parallel to the shoreline as a reinforcement of a part of the coastal profile. (USACE, 2003, p VI-2-1)

A structure separating land and water areas, primarily designed to prevent erosion and other damage due to wave action (SPM, 1984, p A-30).

Revetment

Revetments are onshore structures with the principal function of protecting the shoreline from erosion. Revetment structures typically consist of a cladding of stone, concrete, or asphalt to armour sloping natural shoreline profiles. (USACE, 2003, p VI-2-1)

A facing of stone, concrete etc., built to protect a scarp, embankment, or shore structure against erosion by wave action or currents (SPM, 1984, p A-28).
Protective structure normally placed on an embankment or profiled fill material, normally to form a seawall (CIRIA, 2007, p 9.)

The following document was used to provide guidance on the design of coastal structures which are considered in the industry to provide current best practice methods and advice:

- Withycombe, G., Lord, D., Tomlinson, P. and Armstrong, D. (2013). *Assessment and Decision Frameworks for Seawall Structures*. 1st ed. [eBook] Manly Vale, NSW: Water Research Laboratory. Available at: http://www.sydneycoastalcouncils.com.au [Accessed 5 May 2017].

There are numerous Australian Standards which cover materials involved in coastal structures, but there are none which specifically address the design of coastal structures. AS4997 (2005) *Guidelines for the design of marine structures* excludes rubble coastal engineering structures but contains valuable information on probability and the choice of a design event. (Withycombe et al., 2013).
However due to the expense of the AS4997 Standard, this document cannot be accessed for the purpose of this report.

2.2.1 Main Types of Seawalls

Seawalls or revetments are typically located parallel to the shore line and can be either classes as a sloping-front structure or a vertical-front structure. Further descriptions of each type of seawall/ revetment are outlined below;

- Sloping Front Structure
    - Flexible rubber mound structure – self adjusting toe and crest
    - Fixed form position

    Typically built from;

        - Randomly placed amour (Rock and or concrete units)
        - Pattern-placed concrete amour units
        - Reinforced concrete
        - Geotextile containers
        - Gabion baskets
- Vertical Front Structure
    - Tied in
    - Gravity

- Cantilever
- Typically act as retaining wall

Typically built from;

- Composed of Stone or Concrete Blocks
- Reinforced Concrete
- Mass concrete
- Steel sheet piles (Withycombe et al., 2013).

Figure 2, Sloping Front Seawall Structures

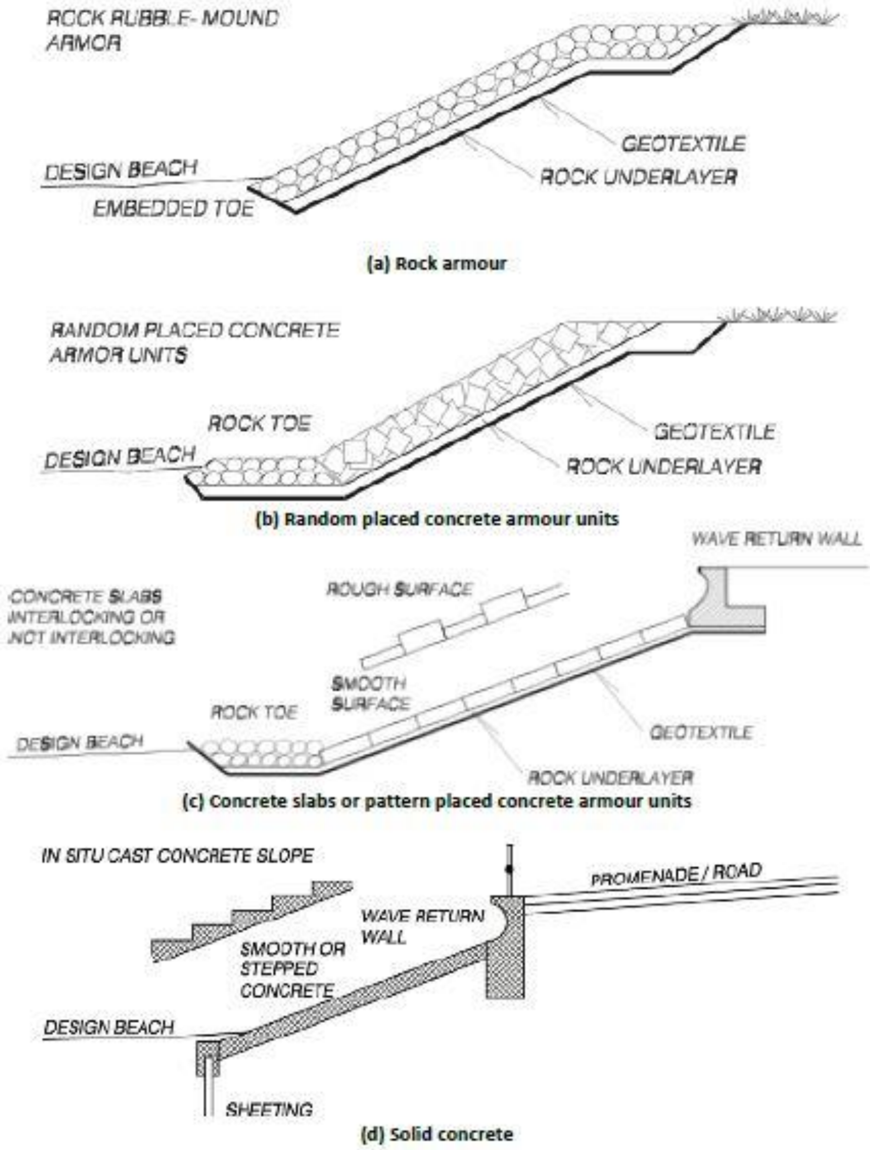
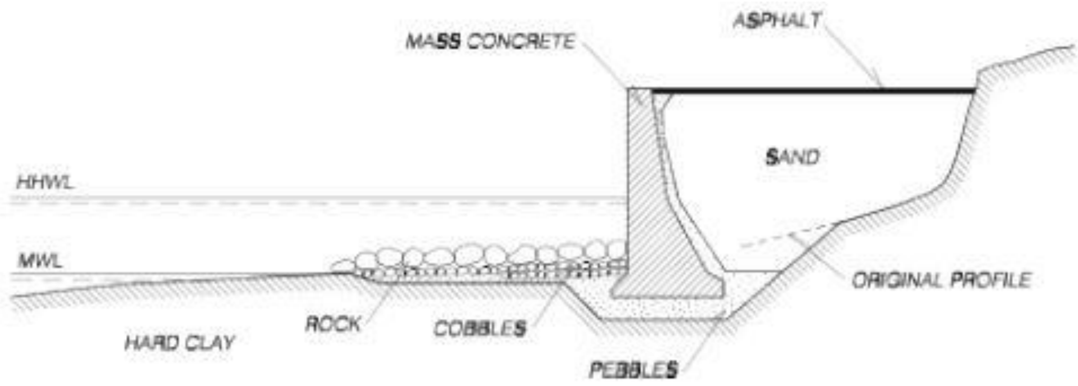
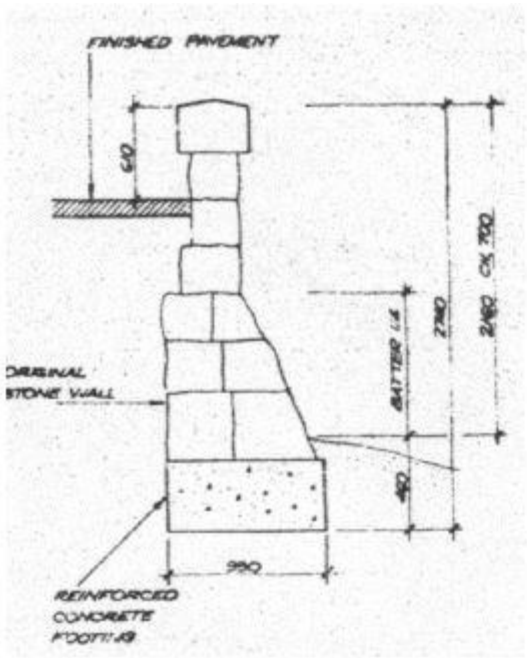


Figure 3, Vertical Concrete Gravity Sea Wall



USACE (2008)

Figure 4, Vertical Stone Gravity Wall



Withycombe et al., (2013).

2.2.2 Failed Seawalls and Causes

Seawalls, if not built correctly may have adverse effects and cause more damages than before. It is crucial to ensure the seawall is built correctly and is maintained.

The US Corps of Engineers (USACE, 2003), defines the failure of a coastal structure as;

Damage that result in the structure performance and functionality below the minimum anticipated by design.

As each seawall has been built from different materials or serves a different purpose, the failed seawall may have different reasons failing. Some of the most common reasons are outlined below, as per (Withycombe et al., 2013).

- Failure occurs when the structure, including its foundation or the individual structural components cannot withstand the current load conditions within the design criteria.
- Failure due to exceeded load. Result of underestimated design conditions.
- Failure due to build and or materials. Result of poor building materials and unsatisfactory building techniques.
- Failure due to deterioration. Result of structure deterioration over a period of time and lack of site monitoring and maintenance.

Some of the most common failure causes in rigid seawall structures as detailed by (Withycombe et al., 2013) are;

- loss of structural integrity, due to wave impact
- sliding, in which the wall moves away from the retained profile
- undermining, in which the sand or rubble toe level drops below the footing of the wall, causing the wall to subside and collapse in the hole
- slip circle failure, in which the entire embankment fails
- erosion of the backfill, caused by wave overtopping, high water table levels, or leaching through the seawall
- overturning, in which the wall topples over

(Withycombe et al., 2013)

Below are some examples of failed seawalls noted from various countries. This is to help give an understanding and the impacts caused from poor materials, underestimating and design may have.

Figure 5, Sink Hole at St Clair Sea Wall

(What if? Dunedin..., 2017)

This was caused due to an underestimation of the impacts caused from the wave impacts against the seawall causing an 'Undermining' of the sand underneath the seawall.

Below is an image of a broken and un-maintained seawall. Here you can see degradation caused from prolonged wear and tear from the natural surroundings. However it is obvious that this was neither monitored nor maintained to prevent further damages.

Figure 6, Broken and un-maintained sea-wall

(Limited, 2010)

2.2.3 Coastal hazards

The above mentioned common failures within Seawall, both vertical and sloped are usually caused by three types of coastal Hazards;

- Erosion of sand. Usually caused from storm events and noted at the front of the seawall.
- Wave overtopping. Usually caused from elevated sea levels and storm wave conditions.
- Wave Impact. Usually caused by elevated water levels and large waves, more likely during storms (Withycombe et al., 2013).

A further description of each hazard and the destruction caused is briefly outlined below.

2.2.3.1 Wave Impact & Wave Overtopping

Wave overtopping and wave impact are generally caused from an inundation of direct wave impacts on the seawall structure. During an event of a storm these wave impacts can increase significantly, causing significant and costly damage to the structure, including the parapets and concrete caps and the surrounding area. Overtopping may also cause saturation of the soil profile, increasing pore water pressure and increase chance of land sliding. See figure 7 & 8 below, illustrating the overtopping caused back in 1960 on the Gold Coast. (Withycombe et al., 2013).

Figure 7, 1960 Kirra Surf Pavilion

(Goldcoast.qld.gov.au, 2017)

Figure 8, 1960 Palm Beach Original Sea Wall

(Goldcoast.qld.gov.au, 2017)

2.2.3.2 Erosion

Erosion can have devastating effects on the coastal lines, most notably after storms. Erosion of the sand during and after storm events can cause the reduction of beach levels fronting the seawall and consequently undermine the foundations of the seawall (See Images 9 & 10). As the sand is washed away and the erosion worsens, this can be potentially devastating, causing the seawall to fail by exposing the toe of the structure to direct wave impact, or by reducing foundation support. There are several factors directly related to the undermining of seawalls outlined by (Withycombe et al., 2013).

- seawall toe design and toe levels as determined by previous geotechnical investigations or from design drawings (when available)
- average and minimum levels against the seawall, as determined through analysis of historical profile variations (photogrammetry analysis)
- storm demand or estimated volume of sand eroded (above mean sea level) during the design extreme erosion event
- typical pre-storm volume of sand above mean sea level as determined through analysis of historical profile variations (photogrammetry analysis)
- Wave conditions and exposure.

Figure 9, Gold Coast Beach Erosion

(Moore, 2015)

Figure 10, Erosion caused by Severe Storm, NSW

(Keen, 2016)

Other contributing factors such as the location of the seawall will contribute to extent of environmental influences and hazards such as waves and erosion the seawall will come in contact with. Seawalls located high up on the beach will have little daily interaction with environmental hazards and influences, but may however be final defence line for the coastal region, such as the A-Line on the Gold Coast.

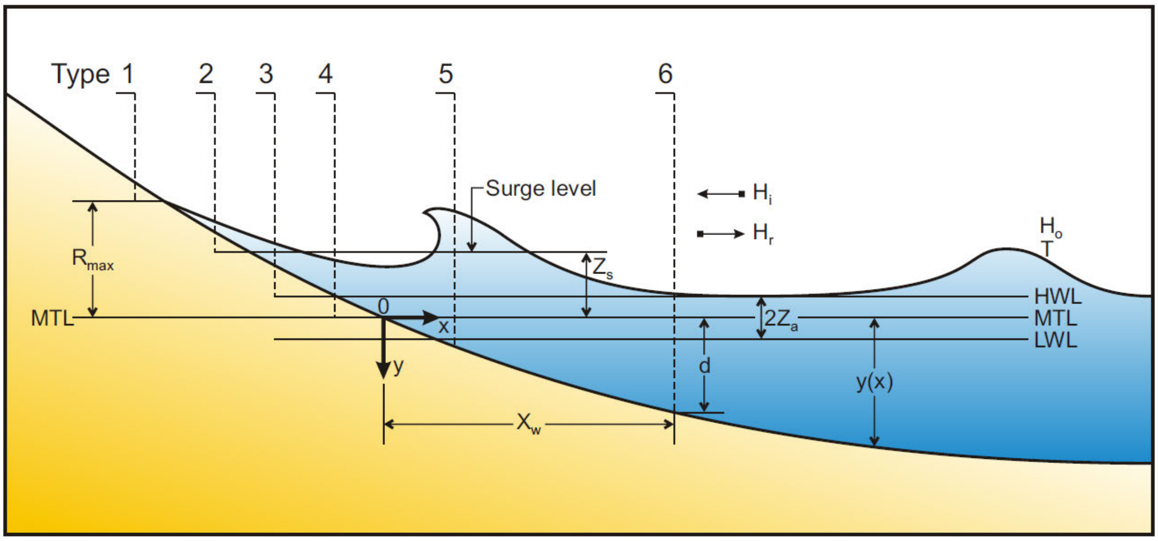
If however the seawall is short or doesn't have adequate end protection, this may leave the seawall vulnerable to erosion and recession of the beach adjacent to the structure resulting in outflanking and failure during storms. (Withycombe et al., 2013)

Figure 11, Gold Coast A-Line

(Goldcoast.qld.gov.au, 2017)

Seawalls just like any other structure must have certain classification and design parameters that it must meet. This can be illustrated below in figure 12 and table 1 using the Weggel (1988) Classification system.

Figure 12, Weggel Sea Wall Classification



(Weggel 1988)

Table 1, Weggel Sea Wall Classification

Type	Location of Seawall
1	Landward of maximum level of runup during storms. The wall does not affect either hydraulic or sedimentation processes under any wave or water level conditions, although may affect aeolian processes
2	Above still water level of maximum storm surge and below the level of maximum runup. Exposed only to the runup of waves during storm events
3	Above normal high water and below the still water level of storm surge. Base will be submerged during storms and during exceptionally high astronomical tides but will normally be above water
4	Within the normal tide range; base is submerged at high water
5	Seaward of mean low water; base is always submerged; subjected to breaking and broken waves
6	So far seaward that incident waves do not break on or seaward (of the wall)

(Weggel 1988)

2.3 Monitoring, Maintenance and Rehabilitation of Seawalls

2.3.1 Introduction

Seawalls are a man-made structure placed into an environment that is unpredictable and sometimes harsh. The materials that seawalls are made from are not permanent and are susceptible to damage and deterioration over periods of time. Depending on the nature of the event, seawalls may be damages by storms and is cause over a short period of time or may deteriorate gradually over time from environmental features such as wind, waves and sand. Generally, as a seawall gradually deteriorates, the damages often go undetected because the seawall continues to function as originally intended. However if left uncorrected, this could lead to partial or complete failure. (Withycombe et al., 2013)

It has been noted that in Withycombe et al (2013) outlines the need for an *adequate maintenance program and that it is critical in order to ensure that a seawall continues to operate during its designed life.*

Seawall maintenance consists of the following essential elements:

- The monitoring and inspection of seawalls for both environmental conditions and structure response.
- Evaluation of the inspection and monitoring data relative to the design specifications
- Evaluate an appropriate response based on the assessment of the seawall. Either take no action, rehabilitation or repair all or parts of the seawall.

(Withycombe et al., 2013).

2.3.2 Monitoring of Seawalls

Monitoring of seawalls is not an easy task and it is difficult to understand what parameters of the seawall to monitor, how to evaluate the monitoring data and consequently what preventive or corrective action needs to be undertaken.

Withycombe et al (2013) goes onto further discuss the guidance on monitoring and maintaining of coastal structures based on literature review on the following documents.

- CIRIA (2007), The Rock Manual: the use of rock in hydraulic engineering, 2nd edition, CIRIA C683, London.
- Coastal Engineering Manual (USACE, 2003), Chapter 8 Monitoring, Maintenance and Repair of Coastal Projects, EM 1110-2-1100 (Part VI) 1 June 2006, US Army Corps of Engineers.
- Bray, R N, Tatham, P F B (1992). Old Waterfront walls: Management, maintenance, and rehabilitation. E. & F.N. Spon (Imprint of Chapman and Hall), London, 1992, ISBN 0-419-17640-3, 267 pp.

At closer inspection of the documents outlined above, it is clear that seawall monitoring can be divided into two categories: Conditions Monitoring and Performance Monitoring.

Condition monitoring

Is where a successful preventative maintenance program is implemented, with visual and physical inspection required, which may include;

- Principal Inspections: These may include a detailed examination of all aspects of the seawall, including any areas underwater or with difficult access.
    - Implemented between every two and ten years. This can vary depending on the age of the structure and are carried out by qualified engineers
- General Inspections: This inspection should be carried out by trained technical staff, as it is a more formal and detailed.
    - Implemented approximately every two years
- Special Inspections: These investigations are carried out following specific events such as extreme events, floods, storms or when any other inspection indicates a cause for major concern.
- Superficial Inspections: These inspections report any defects changes or unusual features of the seawall
    - Implemented multiple times a year

Performance Monitoring

This function of monitoring requires a trained personnel to visually inspected the seawall during events of either flooding, large swells or after a large event to assess the structures behind the seawall. This will be used to assess the *performance* of the nominated seawall.

2.3.3 Current and Previous Techniques of Seawall Monitoring

There are several monitoring techniques available to asses a seawall and each technique only provides a specific amount of detail. A summary of the reviewed monitoring techniques and range of applications is illustrated below in table 2 (Withycombe et al (2013).

Aerial Photography – This method of monitoring seawalls can primarily be used to capture the sand level at the toe of the seawall/bedrock. It can also be used to monitoring the rock locations and seawall crest levels. These features will make the primary base line of this report, allowing easy access for the assessment.

RTK GPS – This method of monitoring seawalls can primarily be used to capture the seawall crest levels and the stability of the seawall. This method will also be adopted and used in conjunction with aerial photogrammetry against the baseline control installed.

Section 2.4 of this report goes into further depth and discussion of the characteristics of what a UAV is and what RTK-GPS Surveying is and how they can be used. Section 2.7 of this report outlines what Aerial Photogrammetry is and the way it is performed and also illustrates the accuracies that can be achieved.

The below figure illustrates the location of the points that captured and monitored during the project.

<u>Figure 13, Sea Wall Monitoring Points, (TPPCP, 2013)</u>

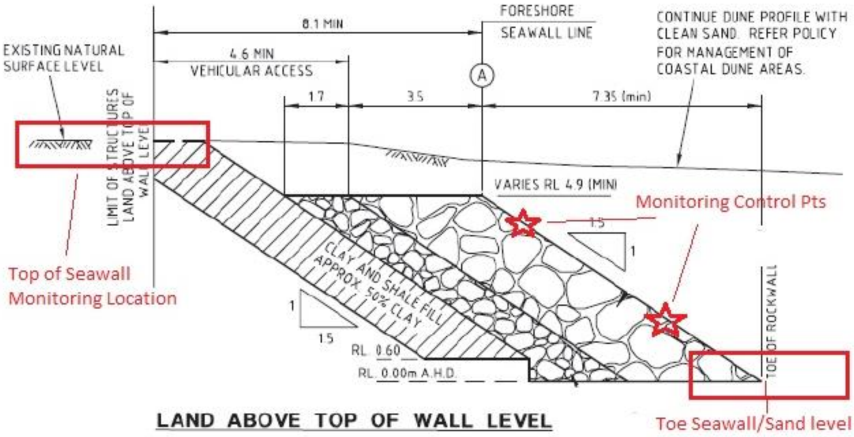


Table 2, Monitoring Techniques and Parameters

Monitoring Technique	Water Table	Stability of the seawall	Seawall Crest levels	Sand level at toe of sea wall / Bedrock	Overtopping rate /heights	Composition / Structural integrity of the seawall	Buried Toe level
Aerial Photogrammetry	✗	✗	✓	✓	✗	✗	✗
Boreholes	✓	✓	✗	✗	✗	✗	✗
CCTV cameras	✗	✓	✓	✗	✓	✗	✗
Fibre optic deformations sensors	✗	✓	✗	✗	✗	✗	✗
RTK-GPS	✗	✓	✓	✗	✗	✗	✗
Ground Penetrating Radar	✓	✗	✗	✓	✗	✓	✓
Infrared thermography	✗	✗	✗	✗	✗	✓	✗
Jet Probe	✗	✗	✗	✓	✗	✗	✓
Parallel seismic	✗	✗	✗	✓	✗	✓	✓
Pressure sensors	✓	✗	✗	✗	✓	✗	✗
Side scan sonar	✗	✗	✗	✗	✗	✓	✗
Step wave gauges	✗	✗	✗	✗	✓	✗	✗
Tail-scour monitoring	✗	✗	✗	✓	✗	✗	✗
Ultraseismic	✗	✗	✗	✗	✗	✗	✓
Volumetric tanks	✗	✗	✗	✗	✓	✗	✗

(Withycombe et al (2013).

2.3.4 Current and Previous Methods of Seawall Maintenance and Rehabilitation

There are several situations in where a seawall may fail. This may be due to severe weather conditions, over time wear, poor management and poor building and materials. If however the seawall has been completed compromised, it may be necessary to replace the seawall. This is only when the existing seawall is beyond repair.

However there are known methods to both modifying and repairing an existing seawall.

2.3.4.1 Modifying the Seawall

Modifying the seawall can assist with how the weather and other features; such as tides and public use may impede on the structure.

If a seawall has been overloaded or is at risk of exposure to severe weather conditions which may be exceeding the design load, it may be possible to alter the surrounding environmental conditions. Some methods are;

- Reduce the depth of water in front of the seawall – This creates less chance of was out under the toe of the wall.
- Modification of wave conditions – this can be done through the use of dredging which can help to break a well prior to the seawall.

Other factors such as water pore pressure or earth pressure from behind (earth side) may be contributing to the safety and stability of the structure, causing it to become unsafe, with higher potential for overturning or sliding. It may be necessary to perform other modifications to the rear of the wall, such as;

- Grouting up the backfill – This will reduce the active pressure on the wall
- Improving drainage of backfill material – this will help prevent the pooling and liquidising of the earth behind the wall, potentially compromising the wall.

Other modifications that can significantly help the longevity of the sea wall would be to increase the stability. The below methods can help to assist with preventing slide or overturn and can increase the bearing strength of the wall.

- Rocks placed at front of wall – works as a counterweight
- Ground and rock anchors – increase the resistance of seawalls to slide or overturn
- Piling – improves the strength of the wall.

(Withycombe et al (2013).

2.3.4.2 Rehabilitation and Repair of the Seawall

Seawalls without proper care and monitoring may end up getting damaged and require rehabilitation and repair. Some repairs however, such as the seawall toe, are typically carried out under water. Some methods of seawall toe repair are;

- Injected grout aggregate
- Grout-filled bags
- Cut off sheet piles – sheet piles that are driven/vibrated to a specific depth then cut off at the height of the toe.

Some protection methods for seawalls are;

- Installation of rubble toe protection
- Dredging – changes wave movements
- Concrete mattresses

If however all modifications and rehabilitation methods have failed and the wall has become either, damaged, exposed, over loaded, or just need general repairs , below is a list of some methods/practices used to repair he sea wall.

- patching of the wall structure above or below water
- grouting of wall structure
- crack and joint sealers
- masonry bonding, stitching, dowelling and wedging
- replacement of stone
- Sprayed concrete.

(Withycombe et al (2013).

2.3.5 Asset Management Policy

The Gold Coast City Council has put in place several means of policy's and plans to ensure the management of their assets and the production of further seawalls to maintain the coast line. The GCCC Asset Management Policy (Asset Management Policy, 2015), which will be reviewed in 2017, is making sure the GCCC is committed to ensuring that all infrastructure and services are provided in a sustainable manner, with appropriate levels of service to residents and visitors and taking due regard of the environment. GCCC is also committed to managing their assets from a 'whole of life' perspective in accordance with recognised industry practice (Asset Management Policy, 2015).

The policy goes onto further discuss the assets that will be maintained under the policy, these are;

- Roads, Bridges & Major Culverts
- Flood Mitigation & Drainage
- Water and Sewage Infrastructure
- Buildings
- Pathways
- Site Improvements
- Land
- Other physical assets such as fleet, plant & equipment

Under this policy the management of seawalls would be noted under flood mitigation. By ensuring there is enough protection along the coast line from harsh environmental conditions.

It is essential for a council to have in place an Asset Management Plan (AMP) and Asset Register. Under this policy it is a requirement for the council to have an up-to-date register of all the assets including seawalls. The asset register for seawalls should contain information on;

a) location
b) elevation of key parameters (toe and crest levels)
c) construction type/description
d) grade or rating of overtopping risk
e) grade or rating of stability risk
f) Last and next monitoring inspection.

Asset management under the Asset Management Policy is illustrated as 'taking a systematic approach to manage assets through all lifecycle phases. This involves applying a combination of engineering, financial and other technical practices to the management of infrastructure; costs; opportunities; risks; and performance' (Asset Management Policy, 2015).

As described by Withycombe et al (2013), an AMP would generally cover the following areas;

- Asset System Description : Objectives of the AMP, effective management strategies, improving the efficiency of maintenance actions, risk management strategies
- Standard of Service Definition - Asset Performance (i.e. maximum allowed overtopping rate, safety rate) as well as minimum condition grade
- Current Asset Performance - existing assets register (unique identifiers, including ages, estimated remaining life, current condition, current safety issues)
- Past and Planned Actions - Recent and past inspection surveys 7 overall reviews, actions planned and administered
- Costs - estimation of past and short-, medium- and long-term maintaining and/or repairing cost.

Another plan that is in place by the GCCC is the Three Point Plan (TPP) for Coastal Protection is an action plan introduced back in June 2013, to help fix, maintain and mitigate the damages caused to the Gold Coast beaches and river ways through the installation of seawalls and further dredging.

The TPP will bring forward 30 years of beach protection projects to ensure the future of the Gold Coast beaches. This plan is creating multiple small to large scale projects on the Gold Coast to ensure the beaches and creeks are safe, maintained and sustainable (TPPCP, 2013)

2.4 General Characteristics of a Rotary Wing Drone & RTK GPS

2.4.1 UAVs and Drone Characteristics

Since the release of UAV's and Commercial based drones, there has been a huge increase in types, makes and models used for the acquisition of Photogrammetric data. The main difference between styles of UAVs and Drones are the way in which they fly. The UAV/Drone can either be a fixed wing or multi-rotor. This section will outline the common differences between a fixed Wing UAV and a multi-rotor drone.

2.4.1.1 Fixed Wing UAV

A fixed wing UAV can be characterised as a comparatively simpler structure and more efficient aerodynamics that can provide both the advantages of longer flight durations and higher speeds. As the name suggested, fixed wing UAVs do not have any rotors above the wings. These UAVs use the propulsion of the rotor fixed to the rear of the craft.

UAVs like the Trimble UX5 HP and the EBee are capable of a maximum flying time of approximately 45 minutes with a cruising speed of 80km/h, depending on other environmental conditions. This makes fixed wing UAVs ideal for applications such as aerial surveys, which require the capture of geo-referenced imagery over large areas. The UX5 is also able to house a 24 MP camera with custom optics giving the UX5 the ability to capture data down to a 2.0 cm (0.79 in) resolution.

Some limitations of the fixed wing aircraft are that they are dependent upon either a launcher or a runway to facilitate take-off and landing, which can cause other subsequent implications upon the type of payloads that they may be able to carry. In some circumstances, to land a fixed wing UAV like the Trimble UX5 HP it is recommended that you have a landing space of approximately 150m x 30m. *(Trimble.com, 2016)*

To further mention, fixed wing UAVs are more ideally suited to larger scale photogrammetric solutions rather than small scale. As the UAV can travel up to speeds of 80km/h, the distances covered are much larger, including the amount of room required to change flight direction.

Figure 14, Trimble UX5 HP UAV

(Trimble.com, 2016)

2.4.1.2 Rotary Wing

A rotary wing aircraft involves a much greater mechanical complexity which translates generally into lower speeds and shorter flight ranges. As illustrated in the image below, Mutli-rotor or hex copters have rotors attached to fixed points above the platform.

A hex copter like the Aibotix X6 or Trimble ZX5 (figure 15) or a quadcopter such as the DJI Phantom 4 (Figure 16) have a maximum flying time of approximately 30 minutes with a top speed of approximately 60km/h, also depending on the environmental conditions. *(Trimble.com, 2016)*

Some advantages of the rotary wing UAV/Drone are their ability for a vertical take-off and Landing (VTOL) and their ability to hover over a specific area and perform agile manoeuvring, such as a point of interest (POI). This makes rotary wing UAVs well suited to applications like facility inspections and small scale photogrammetric solutions, which require manoeuvring around tight spaces and the ability to maintain visual on a single target for extended periods. Rotary wings also have larger capabilities with the payloads that they can deploy and the cameras they can carry. Such as the 24 MP Sony A6000 cameras, allowing users to capture high quality aerial imagery and achieve image resolution down to 1mm.

Figure 15, TrimbleZX5 UAV

(Trimble.com, 2016)

Figure 16, DJI Phantom 4

(DJI Official, 2017)

The image below will help to explain the core differences between what a *Fixed Wing Drone* is (such as the Trimble UX5) and a *Rotary UAV* (such as the DJI) have to offer. These differences are largely the same as with full-sized aircraft, such as the coverage difference, for example.

Figure 17 – Core Differences

Projects	Mapping	Small area mapping & inspection
Applications	Land surveying (rural), agriculture, GIS, mining, environmental mgt, construction, humanitarian	Inspection, cinematography/ videography, real estate, surveying (urban), construction, emergency response, law enforcement
Cruising speed	High	Low
Coverage	Large	Small
Object resolution	cm/inch per pixel	mm per pixel
Take-off/landing area	Large	Very small
Flight times & wind resistance	High	Low

© senseFly 2015

, sourced waypoint.sensefly.com

Due to expensive equipment housed within and on most UAVs and Industry Based Drones, the DJI Phantom 4 fits into the category as a commercial based drone and is affordable within the surveying industry, normally costing between $1200 - $4000 depending on the series model, the camera chosen and the software packages.

The DJI Phantom 4 will be used as the platform for the photogrammetry survey to be conducted within this report. Table 66 in Appendix A outlines the DJI Phantom 4 specifications.

2.4.2 GNSS RTK GPS Characteristics

RTK GPS Units have been available for a many years now and have enhanced the way in which surveying can be performed and achieved. With the ability to work remotely and over large distances, GNSS RTK GPS is an essential tool within a surveyor's equipment.

2.4.2.1 GPS System

Global Positioning System, also known as GPS is the navigation, timing and positioning system developed by the U.S. The GPS unit consists of three main parts: satellites, ground tracking monitoring station and customer station.

GPS satellites, which help top achieve the accuracies required are made up of a network of 24 satellites placed into orbit which then circle the earth in a precise orbit and transmit signal information to the GPS receiver. GPS receivers make use of an in built algorithm to help triangulate the user's exact location.

The GPS receiver will compare the time the signal was transmitted by a satellite with the time it was received. This time difference is then used to calculate how far away the satellite is. With distance measurements from a few more satellites, the receiver can determine the user's position. In the case of car GPS solutions, the accuracies achieved are only within a 10m area, which is evidentially not accurate enough for survey solutions.

A GPS signal contains three different bits of information –pseudorandom code, ephemeris data and almanac data.

- The pseudorandom code - is simply an I.D. code that identifies which satellite is transmitting information
- Ephemeris data - contains important information about the healthy status of the satellite, current date and time. This part of the signal is also essential for determining a position

- Almanac data - tells the GPS receiver where each GPS satellite should be at any time throughout the day *(Xu, 2012)*.

As outlined in the article 'Application of GPS-RTK Technology in the Land Change Survey' by Xu, 2012, the Global Positioning Systems or GPS can also have its negativities and complications when using satellites to position the equipment. GPS accuracy and availability all depend on many factors, including but limited to; GPS satellite drift or multipath, weather conditions, the availability of at least four satellites in the antenna view range for 3D localization.

Many methods have been developed to help overcome these obstacles to achieve the most precise, real-time positioning information for survey applications. The following methods are used to compensate for;

- GPS satellite drift - GPS providers such as Trimble, maintain the position of all the GPS satellites in view, be between 4 -24 satellites (however in most cases not all 24 are visible), and reference each GPS satellites precise orbit relative to each other. By doing so this can help to correct the GPS Satellite drift.
- Multi path errors - antennas are installed on both the base station and the receiver and are designed to search nowhere else but vertically from the receiver whilst utilising filtering software that removes all suspected "signal bounce".
- Earth's Atmosphere Error – Through the use of using a secondary receiving station, also known as a Base Station, this is to be setup over a known surveyed (co-ordinated) point, most commonly a Permanent Survey Mark (PSM). The known coordinates are then input into the base station to give it a known location. As Base Station receives satellite information, it then compares the data to its known location and continually transmits the corrected data to the Rover (roaming receiver) GPS receiver or the GPS machine control. The corrected data is then used in conjunction with the GPS satellite signals received by the Rover to provide highly precise accuracy information. This technology is currently called real-time kinematic positioning technology of RTK.

2.4.2.2 RTK GPS

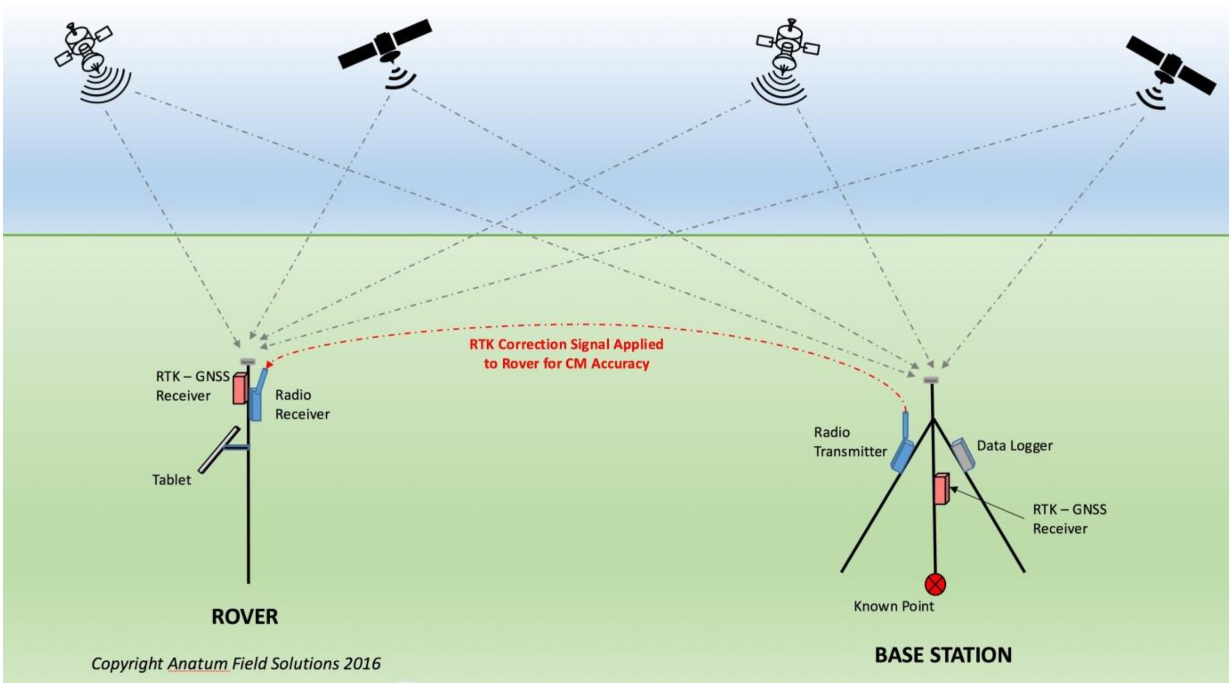
Real Time Kinematic GPS or RTK GPS can provide the real-time corrections as outlined above which can provide up to centimetre-level accuracy in either a static or roaming state. This has allowed the GPS unit to expand from generic GPS applications such as Car Based GPS units into more industries such as the construction/mining industry and the surveying industry.

The RTK GPS Systems works in similar context to that of the conventional GPS system however the. RTK GPS system receives the satellite signal simultaneously with at least two GPS receivers, the base station and the rover.

The Base Station has a known coordinate, general situated over a PSM; the Rover undertakes the measure of unknown point coordinate, as either a mobile or static unit. Therefor a whole RTK GPS System concludes of a Base Station, a Rover and a communication system, in most cases a Radio.

The method in which RTK GPS Surveying is achieved can also be seen in figure 18 below, illustrating the way in which the GPS Base communicates with the satellites which then communicates with the GPS Rover helping, to co-ordinate the position of the user, creating a more accurate network of adjustments.

Figure 18, RTK GPS Explained



(AnatumFieldSolutions, 2016)

2.5 CASR Standards

2.5.1 Rules and Regulations CASR

There are significant rules and guidelines associated with flying drone, UAVs and UAS and are regulated by the Civil Aviation Safety Authority (CASA) division of the Australian Government. Under the Civil Aviation Safety Regulations Part 101 (CASA, 2017) is all the guidelines for flying commercially under 2kg and over 2kg.

Some rules specific to the project are;

- You must not fly in a way that creates a hazard to other aircraft, so you should keep at least 5.5 km away from airfields, aerodromes and helicopter landing sites.
- You must not fly your RPA in or over prohibited / restricted area, unless you have the permission of the authority controlling the area.
- In restricted airspace, aircraft movements are reduced to those with certain specified permissions. Examples of restricted airspace include airspace around military installations or military controlled aerodromes, over Sydney Harbour, high-density flying operations or at an air show or other large public event. Restricted airspace may also be imposed by police for safety or security reasons near bushfires or major crime scenes. It is illegal to fly your RPA in these areas without permission.
- Operations within the 3nm (5.5km) radius of an aerodrome or helicopter landing site are possible and lawful providing you comply with the Standard Operating Conditions listed above and ensure that you do not operate:
  - on the approach and departure path, or
  - within the movement area, or
  - Create a hazard to aircraft that may be using those areas.
- You must not fly closer than 30 meters to vehicles, boats, buildings or people.
- Have line of sight at all times to the UAV
- No night flying (generally).
- No flying in or through cloud or fog, and you should.
- You must not fly over populous areas such as beaches, heavily populated parks, or sports ovals while they are in use.
- In controlled airspace, which covers most Australian cities, you must not fly higher than 120 meters (400 feet) above the ground.

(CASA, 2017)

2.6 Mission Planning

To ensure a correct flight is taken, it is necessary to check all parameters and consider if any extra work needs to be taken prior to commencing the flight. One important parameter to consider is to ensure there is sufficient overlap of all photos to be able to create a 3D model of the project area.

As outlined in the USQ handbook, the general minimum for required overlap for an aerial survey is 55 – 65% forward overlap and 15 – 30% side (lateral) overlap (USQ, 2012).

Flight height will also determine the accuracy that you will achieve. If the accuracies required are of a high standard, it will be necessary to fly at a lower height, as this will create a smaller pixel size during the flight, meaning a more accurate result. The common rule for this, is the higher you fly, the larger the pixel size, the larger the smallest pixel unit becomes.

Another parameter to consider is the parallax; this is determined by the location, size and number of Ground Control Points (GCP) installed. If the overlap is too large or too small, it will result in less accurate parallax measurements, there for a less accurate result.

Mission planning is an important part of Photogrammetry and should not be disregarded as it may result in loss of data, inaccurate results or wasted information or time.

2.6.1 Control Points & Flight Altitude

Ground Control Points or GCPs are one of the most important and vital parameters of a photogrammetric survey. GCPs help to register the photos to create and co-ordinate a 3D model of the project area. Without control points, the information would be deemed wasted.

The total number of GCPs has a significant impact on the accuracy of X, Y and XY of a survey (Agüera-Vega, F., et al. 2017). As illustrated by Agüera-Vega, F., et al. 2017, it was found that over approximately 150 m2 that a combination of 50m flight altitude and 10 GCPs yielded the best RMSE values at 0.038 RMSEx, 0.035 RMSEy, 0.053 RMSExy, and 0.049 RMSEzd and 0.035 RMSEzo. It was also noted that an increase of altitude to 80, 100 and 120m did not have a large effect on the horizontal RMSE value but did effect the vertical ones significantly at 0.074, 0.069 and 0.068 respectively (Agüera-Vega, F., et al. 2017).

As the report will be testing the accuracy between the creations of a digital point cloud against that of a GPS Rover, it will be necessary to install more control points and establish the best RMSE through the registration process on the photogrammetric program. By increasing the amount of control situated on the ground within the survey, it will help to create a more accurate survey whilst maintaining a height closer to the ground, producing smaller pixel size.

2.6.2 Camera Calibration

Camera calibration is an essential part of Photogrammetry and can determine the accuracy and results of the flight. If the camera is not calibrated to the right conditions or the correct camera type, this could affect how the images are stitched together in the photogrammetry program in a process known as '*Registration*'. However, as the study is based around the use of a DJI Phantom 4, the chosen camera is permanently calibrated to that housing, with no option for zoom. All the details of the camera are also captured within the photo properties during the flight.

2.6.3 Photo Resolution

Ideally, it is best practice to fly with the best resolution you can achieve. This report is based around a commercial based drone. Due to weight restrictions it will be flown with the in house camera which should be more than ample. To ensure the Photo Resolution is of a higher quality, the drone will be flown closer to the ground, trying to achieve a 2cm per pixel accuracy.

2.6.4 Photo Redundancy

To ensure an accurate result is achieved, it is necessary that there is sufficient control (GCPs) are captured within the overlap of the photos. This will assist with the registration phase and assist with stitching the photos together. Due to the nature of the program, it will be necessary to remove any unwanted photos, or excess amount of overlap, to help achieve the accuracy required. It's ideal to remove unwanted (noise) data from the program prior to the registration phase; this will assist with the registration and creating a more accurate result.

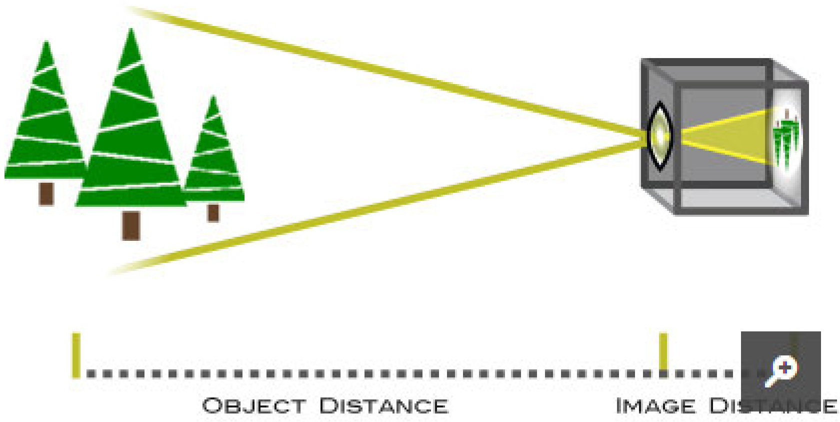
2.6.5 Focal Length

Focal length can be defined as the distance between the centre of a lens or curved mirror and its focus. The focal length is generally represented in millimetres (mm) and is the basic description of a photographic lens. The focal length can be determined when the lens is focused at infinity (Nikonusa.com, n.d.).

The focal length can help distinguish;

- Angle of View – how much scene will be captured
- Magnification – how large the elements will be

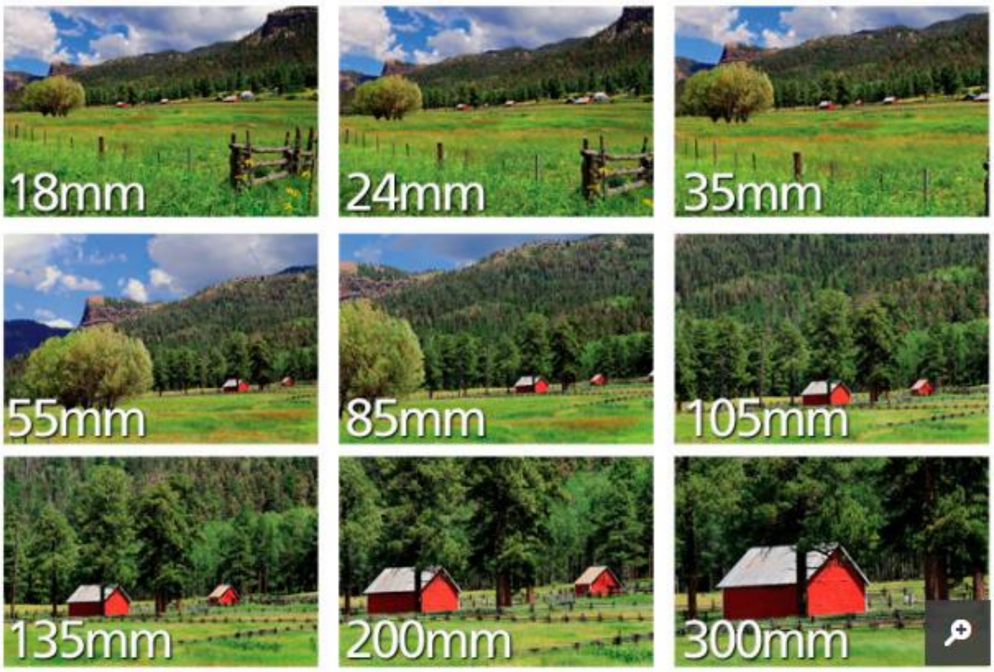
Figure 19, Lens Focal Length



(Nikonusa.com, n.d.)

As described by Nikonusa.com, (n.d.) *'the longer the focal length, the narrower the angle of view and the higher the magnification. The shorter the focal length, the wider the angle of view and the lower the magnification'.*

Figure 20, Focal Length Illustration, (Dave Black, n,d.)



There are also two known different types of lenses, lenses prime and lenses zoom.

- Lenses Prime – fixed focal length
- Lenses Zoom – variable focal length

Zoomed lenses are more ideal for generic users as it gives them a wide variety of choices, giving them the freedom to be able to zoom on focal point rather than having to get closer. However, in photogrammetry it is better practice to use a fixed focal lens

2.7 Photogrammetry, Data Processing and DTM Generation

2.7.1 Photogrammetry

Photogrammetry is the science of obtaining accurate spatial, temporal and physical information through recording, measuring and interpreting electromagnetic radiant created by photographic imagery (USQ 2012).

Through the use of photogrammetry, we are able to construct a 3D model of any land surface and manipulate its shape, size and positions of objects.

Photogrammetry has been in practice as an accurate spatial application since 1851, when the science became an application of technology through the process of recording, measuring and interpreting electromagnetic radiant created by photogrammetry imagery (USQ, 2012).

There are many different phases of photogrammetry which have developed over time;

- Plant Table Photogrammetry
- Analogue Photogrammetry
- Analytical Photogrammetry
- Digital Photogrammetry

2.7.2 Aerial Photogrammetry

The first known aerial photograph was taken in 1858 by French photographer and balloonist, Gaspar Felix Tournachon, known as "Nadar". In 1855 he had patented the idea of using aerial photographs in mapmaking and surveying, but it took him 3 years of experimenting before he successfully produced the very first aerial photograph (Professionalaerialphotographers.com, n.d.)

During and after world war one, aerial photography quickly developed, as it was demonstrated as an easier and cheaper method of capturing large areas of land for the creation of maps and other survey resources. This brought about the introduction of a camera mounted plane, which was able to cover larger area of land in quicker time than that of a balloon (Professionalaerialphotographers.com, n.d.)

With the development of camera mounted planes, this has been down sized and has seen the introduction of Unmanned Aerial Vehicles (UAVs) or Unmanned Aerial Systems (UAS). These will be discussed further in the literature review.

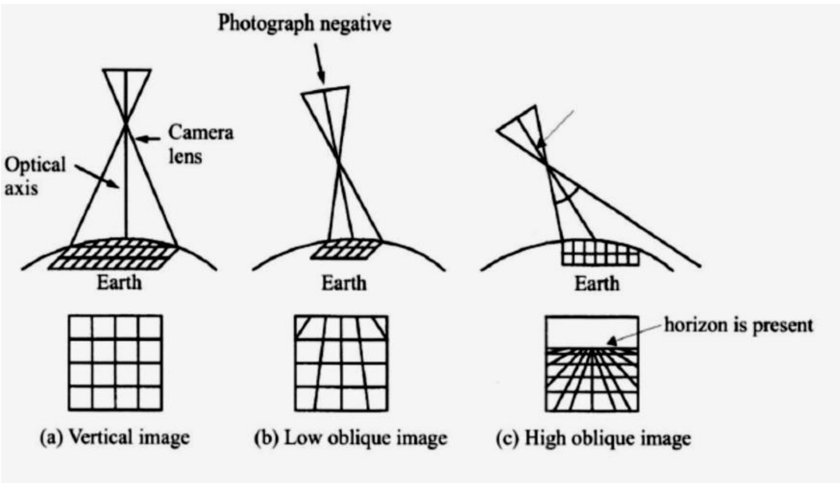
There are three main types of Aerial Photogrammetry, these are;

1. High Oblique
    - Shot from 8,000 to 13,000 feet above ground level (AGL)
    - Shot at a 30 to 60° angle from an aircraft
    - Horizon is present in high oblique images only
    - Good way to map 2 to 20 square miles
2. Low Oblique
    - Shot from 300 to 1000 feet AGL
    - Shot at 5 to 30° angle from aircraft
    - Good angle for face of structures
3. Vertical
    - Shot straight down from the mounted aircraft from appropriate altitude
    - Impossible to achieve full verticality (Aim to be +/- 3° of the axis)
    - Good way to capture ½ square mile to 3 square miles

(Aboveallphoto.com, 2006)

This can also be clearly illustrated in the figure below.

<u>Figure 21, Aerial Photography Camera Angles</u>



(USQ, 2012)

The aerial cameras used for aerial photogrammetry are generally very expensive and have very delicate and expensive instruments installed within them.

2.7.3 Data Processing & DTM Generation

There are a growing number of programs available to help process data produced from Drone & UAV photogrammetry applications. Below is a list of some available programs, some more autonomous than others.

- **Pix4D Mapper**
- Agisofts Photo Scan
- Photomodeler & Scanner
- Visual SFM
- Mic-Mac and Apero
- 3DF Zephyr
- 123D Catch
- Python Photogrammetry Toolbox
- SFM Toolkit
- Arc3D
- 3DM Analyst
- Trimble's Inpho
- My3D Scanner
- Cubify Capture
- Insight 3D

The main aim of data processing and DTM generation is to produce a georeferenced 3D point cloud by processing irregular and overlapping aerial image data captured from the Drone. There is existing software which can generate a 3D point cloud with minimal effort required. One specific program of interest is the Pix4D; a commercial grade software package. This will be discussed further in this section.

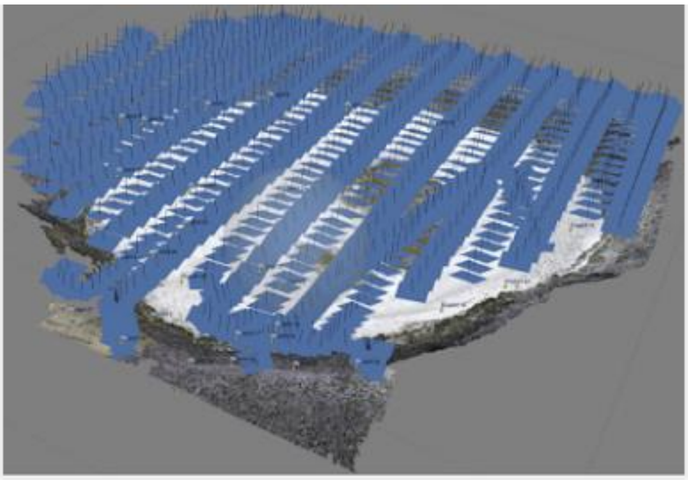
Pix4D Mapper turns your images into highly precise, georeferenced 2D maps and 3D models (Pix4D, 2017).

Pix4D is a software product that computes a spatial 3D reconstruction of any scene out of digital images as input data. The simple automated way to arrange the camera alignment up to a detailed 3D model makes the software user friendly, even for non-specialists. Mapper uses well implemented algorithms to analyse each input image for special features in order to create a relation between the images of the entire scene. Photogrammetric operations like bundle adjustment are used to solve the inner- and outer orientation of each camera, reconstructing their spatial position/orientation to each other. Once the camera alignment is solved, a dense point cloud and a subsequent textured 3D model of the captured scene can be computed and exported. Aerial mapping and close range scans of faces, bodies and structures are part of the task field of this software. (Pix4D, 2017).

Pix4d Mapper will be used to post process the data. The software is a stand-alone photogrammetric software solution for automatic generation of textured polygonal models, georeferenced true orthomosaics and DTMs from still images. *(Partners, P. (2016) UAV post-processing software)*

As these programs can be quite large and require a significant amount of RAM, it is recommended to use a powerful computer; this will ensure the program runs at full performance throughout the post processing stage. The data processing is a relatively easy process. It starts with uploading photos from the chosen camera to a computer and eliminating all the distorted or blurred photos prior to processing the data. The interior orientation of photos can be determined in Photo Modeller software. The next process is to aligning all the photos, building the geometry and texture for a realistic appearance.

Figure 22 – Example of flight path and overlap of Photos



(Carrera 2007)

The automated software will generate an assessment report for each of the steps during processing. It is then necessary to georeferenced all the data for geo-matic applications. There are two common ways in which this can be achieved.

1. Directly geo reference.
2. Indirect geo reference.

This all depends on the simultaneity of the GPS time, RTK and the camera inertial time. After the data has been adjusted, the 3D georeferenced point cloud can be generated directly. The previously surveyed Ground Control Points (GCP) that was measured before the flight by the method of RTK GPS surveying, are used to georeferenced the data. However the colour and size of GCPs must be suitable and easy to distinguish at the natural colour of study area. This can be achieved by marking them during the process. As illustrated by *(Barnes, Simon, and Wiewel, 2012)*

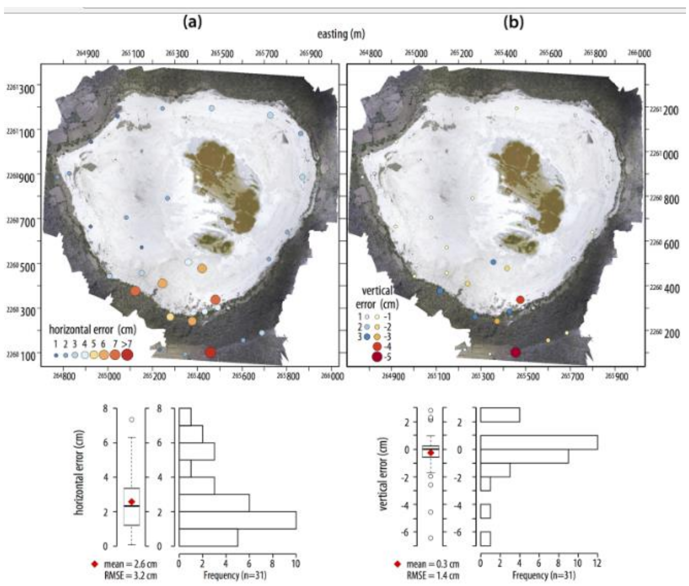
<u>Figure 23 – Dense point cloud</u>

(Barnes, Simon, and Wiewel, 2012)

As it is necessary to get an accurate result of the terrain below, if this cannot be achieved then conventional survey methods will have to be adopted. It is important to ensure this accuracy is met; therefor there will be a necessary test prior to commencing with the project.

After reading an article created by Carrera, J. (2007) UAV DEM. Available at: http://oshydrogeomatics.blogspot.com.au/p/uav-projects.html (Accessed: 2016), this article clearly shows the levels of accuracy achieved for a DEM from a UAV. "To quantify the errors of the generated DEM (with a resolution of 4.7 cm), the 31 Control Points were used, yielding a horizontal RMSE=3.3 cm and a vertical RMSE=1.8 cm, as shown below:

<u>Figure 24 – point cloud accuracies from UAV Photogrammetry of an open quarry</u>



Errors obtained on the ground control points: (a) horizontally, and (b) vertically. The spatial distribution of errors is shown on top with their corresponding histogram and box plot. Negative values on the vertical indicate that the obtained DEM had lower elevations that those registered with the RTK GPS. The background image is the final orthophoto obtained.

3 Methodology

3.1 Introduction

To be able to accurately demonstrate the survey methods being utilised and the technological differences between the survey methods, a specific Study Area has been chosen to conduct the 3 Comparison monitoring surveys. This area will be used as the project area for capturing all site control, digital data and images that are necessary to make these comparisons, whilst ensuring all the public and personnel involved are safe.

This section will illustrate the method used to choose the site, the phases used to conduct the study and the methods used to capture and reduce the data.

3.2 Study Area

The original site chosen as the study area was located on the corner of Main Beach Parade and Beulah Lane, Surfers Paradise, Gold Coast, Queensland. (See Image 25).

Figure 25, Site Location and Layout

(GoogleEarth, 2017)

This site was originally chosen as it was central to the works being currently completed and has a newly built seawall, one that was still exposed and potentially provided a suitable project area. The Seawall in mention is also located adjacent to the A-Line seawall which runs parallel to the shore line along the length of the gold coast.

Unfortunately, during further inspection of the chosen site, it was noted that more construction had been completed within the area, covering the seawall in a large thick layer of sand, covering all exposed areas. The chosen area did not meet the criteria required to complete the task.

Further investigations were conducted to find a seawall that was exposed to the elements including wave movements but did not pose any risk to people or air traffic.

After further inspections of the Gold Coast Seawalls, a new site was chosen, which is located at the Tallebudgera Creek Southern Seawall or Training wall. This can be seen in figure 26 below.

<u>Figure 26, Tallebudgera Creek Seawall</u>

3.2.1 Background

Training walls were constructed back in the late 1960's, following the recommendations of a study into the erosion problems of Gold Coast beaches. This investigation was conducted by Delft Hydraulics Laboratory. Other training walls have been constructed at the Tweed River entrance.

Training walls are constructed to stabilise our creek entrances and water ways, keeping them in one place to benefit development, navigation, flood management, erosion and water quality. The construction of training walls results in the coastal inlet or river maintaining one position along the coastline. Training walls, once built or extended, interrupt the natural longshore transport of sand by waves, which often result in rapid changes to adjacent shorelines (Caring for our Coast, n.d.)

Located approximately at -28.09549 latitude and 153.46123 longitude (Google Earth, 2017), the Tallebudgera Training wall is an ideal structure (seawall) to conduct this research report. This seawall was built back in 1976 and 1981 and it is approximately of 215m in length and 35m in width and is made entirely of large rock. It is also situated parallel to the Tallebudgera Creek with a small section located within the ocean (Caring for our Coast, n.d.). This seawall (training wall) will be the location in which the report will be based around.

3.2.2 Site Justification

Tallebudgera Creek training wall is located on the southern end of the Gold Coast in Queensland. It was built almost 36 years ago and has endued this whole time.

This report is to establish the accuracy comparison between conventional GPS Surveying and Drone based photogrammetric surveys on the monitoring of seawalls and their movements over time. As this seawall is positioned adjacent to a tidal creek and positioned within the ocean, this seawall is exposed to a large variety of natural elements, such as; wind, water, waves, sand degradation and tidal movements. With this taken into consideration, this makes this seawall an ideal structure to monitor for movement.

3.2.3 Site Restrictions and Safety

The Tallebudgera Seawall is open to public access for all recreational purposes, such as running, fishing and even other drone enthusiasts. As there is public movement within the area, it is necessary to ensure both the personnel are safe from any hazards caused during the flight as well as the equipment and the operators (Surveyors).

There are minimal restrictions to the site, as being a public pace, the only limitations for this site is full access with the GPS Receiver. As the seawall is predominately made of large rocks and can be submerged during high tides, this can limit the access of the user and the photo coverage. To avoid this situation, flights were aimed to be done during a low tide.

A thorough risk assessment of the project and the hazards and their prevention methods that can be encountered during the project flight and survey is illustrated in Appendix C.

3.3 Methods

Among surveying methods currently used for documentation of surface objects, the most frequently used are, GNSS method, laser scanning, photogrammetric methods and remote sensing. These methods differ in accuracy, financial demands on the instrumentation and software, and the speed of surveying of a specific object. The chosen methods to complete this task are; GNSS RTK (Cors Network) and Drone based Photogrammetry.

This project has been planned to be conducted over 3 phases. Each phase plays an integral part in the completion of this project. Due to certain elements requiring larger periods of time to complete, there will be noted overlaps of tasks. However all considerations have been made with time frames, University requirements and work requirements taken into consideration.
In order for these phases to be completed it was necessary to create a project task description and Gantt chart, which can be viewed in Appendix B.

3.3.1 Data Storage Phase

In order for the data to be captured, it is necessary that all software has been calibrated, and the correct memory formats have been chosen. As the DJI Phantom 4 can store multiple formats, a JPEG format will be chosen rather than a RAW image. By choosing a JPEG format this format is all compatible with the Pix4D Mapper program for the data reductions. All Images will be stored with a digital stamp of the approximate location from the DJI GPS, and the camera calibration settings. The calibrated images will be stored on a micro SD card in the Drone and all RTK raw data will be stored on a generic SD card inside the Trimble Survey Controller. All information for the Cors RTK GPS will be stored as a raw data file and processed after the survey is complete within Terra Model.

3.3.2 Drone & GPS Testing Phase

This phase will be an initial testing phase of the GPS Survey equipment and DJI Phantom 4 drone. It will include checking of equipment, ensure all systems are functional and equipment is calibrated for the tests.

- GPS Equipment Calibration
    a) Ensure the GPS Unit is synced correctly with the controller
    b) Ensure a secure and clear connection with internet through web based device (Mobile)
    c) Ensure Rover Cors sim is active and connects
    d) Check initialisation of GPS Equipment Prior to Survey

- DJI Phantom 4 Calibration
    a) Turn on DJI and follow safety directions
    b) Connect all rotors to Drone
    c) Let IMU Unit Calibrate all internal settings
    d) Ensure DJI is set to precision mode
    e) Ensure IPAD Mini is attached to the DJI Controller via usb to lightning adapter.

Once all equipment has been calibrated and checked, a test flight will be conducted over an open space to establish the different camera angles, flight heights, flight speeds and camera shutter speeds. This will all help to test for size of the photo and pixels. This will be used to check that 80% forward overlap and 60% side overlap is achieved, that a decent parallax is achieved, that there will be sufficient GCPs and hat he pixel sixe will be small enough for the accuracies wanted.

3.3.2.1 Test Flight

The initial test flight was over a large flat park area (Wonga Park) located in Burleigh Heads to establish drone capabilities, photo sizes from specific heights and travel & photo speeds. Below is a detailed list of the activities completed during the test flight;

1. ***Start Up DJI Phantom 4 Drone***

Ensure to follow all procedures outlined in the DJI Phantom 4 User Manual, accessible from dji.com

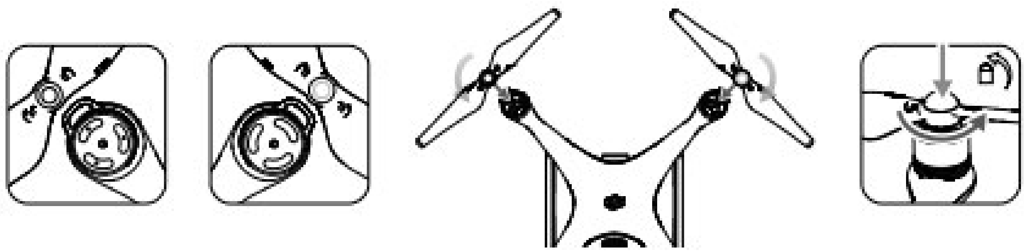
A. Turn on and establish drone start-up requirements. Wait for the Inertia Measurement Unit (IMU) to heat appropriate temperature prior to commencing any flight.

An IMU is a single unit in the electronics module which collects angular velocity and linear acceleration data which is sent to the main processor. IMU housing contains two separate sensors.
The first sensor is the accelerometer triad. It generates three analogue signals describing the accelerations along each of its axes produced by, and acting on the vehicle. Due to thruster system and physical limitations, the most significant of these sensed accelerations is caused by gravity.
The second sensor is the angular rate sensor triad. It also outputs three analogue signals. These signals describe the vehicle angular rate about each of the sensor axes. Even though the IMU is not located at the vehicle centre of mass, the angular rate measurements are not effected by linear or angular accelerations.
The data from these sensors is collected by the IMU and returned to a main processor (DJI Official, 2017).

B. Attach props to rotors, ensuring that the props are aligned with coloured tabs on the motors.

This will ensure the rotors are securely attached, thus making the drone able to fly and safe to the user/public.

Figure 27, DJI Drone Props



(Phantom 4 User Manual, 2016)

C. Gimble holder is removed to ensure full movement of gimble.

This allows full control over the housed camera, located directly under the drone. Be removing the supplied holder, the camera can then be positioned to any angle, in this case vertical (180°) and 45° for the oblique flight.

(Attach images of drone)

D. Start up and setup DJI Phantom 4 controller. Ensuring controller is set to precision mode, allowing for higher accuracy flights and camera precision.

This mode changes the internal properties of the drone, from standard to a higher, more precise setting. It changes the drone's flight stabilising systems as well as the camera accuracy/focus, ensuring more stable flight whilst capturing high quality photos. The only drawback is there is more power used in this mode, causing less flight time.

E. IPAD Mini is attached to the DJI Controller via usb to lightning adapter.

This allows the user to activate the Litchi Flight Assistance APP and to give the operator fully customisable flight paths and vison during flights. This also helps with giving the operator full vison of the drone during the flight.

F. Begin flight to stating height

Begin bringing the drone up to speed, ensuring all personnel and users are a safe distance from the drone. Once drone is ready, bring up to stating height.

2. Test Flight Height and Camera Picture Size

In this section of the test flight, it was essential to test the flight height and camera picture size depending on that. Therefor the drone was flown to a height of 20m, 40m, 60m & 80m. This gave a broad variety of heights to choose from depending on the size of the area to be flown. 100m was not chosen as it is too high and conflicts with CASR Standards. The picture sizes were measured by using a 50m Tap, ad walking to the edges of the camera screen when stationary at the chosen height. Below is a list of the heights and associated photo size.

Figure 28, 20m = 35.5m Horizontally & 17m Vertically

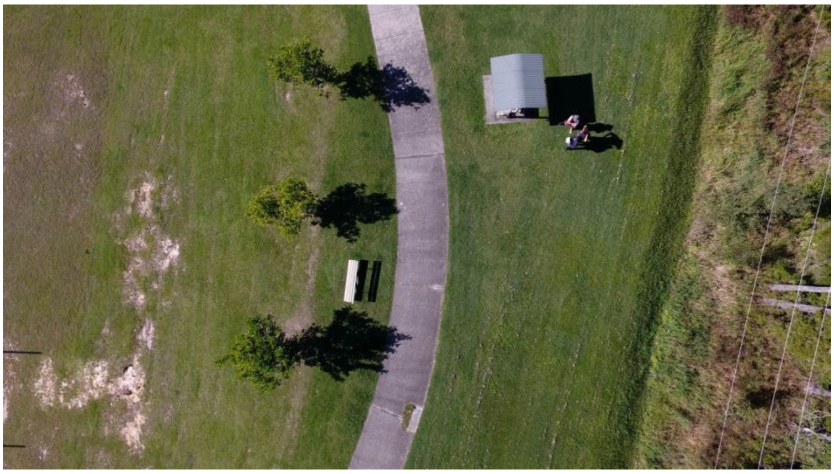


Figure 29, 40m = 70m Horizontally & 35.5m Vertically

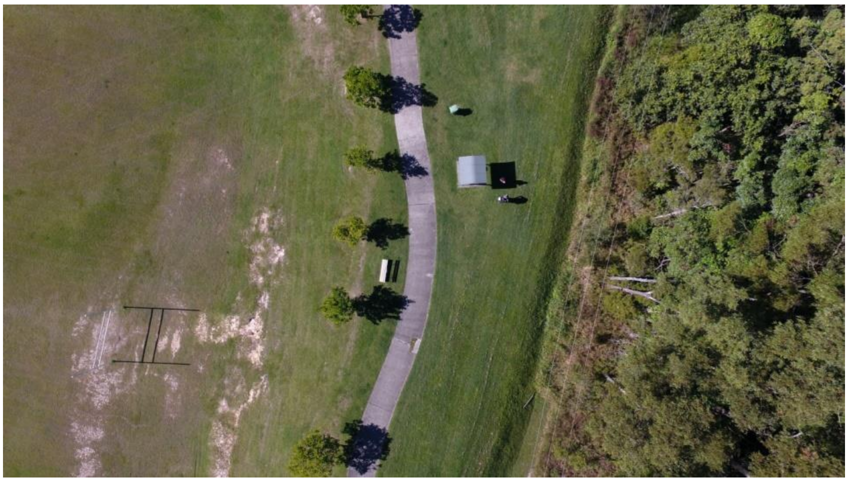
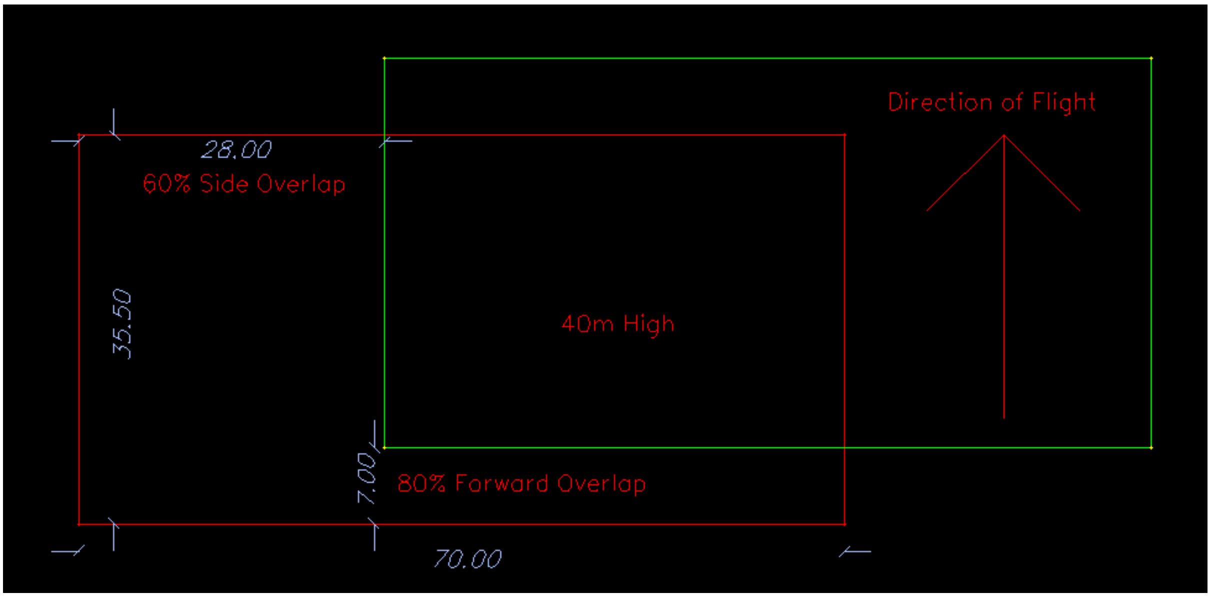


Figure 30, 60m = 104.5m Horizontally & 54m Vertically

Figure 31, 80m = 139m Horizontally & 72.5m Vertically

The camera picture size is wider than it is long (rectangle) thus covering more distance horizontally than vertically, meaning more distance travelled horizontal per photo than vertically illustrated below.

Figure 32, Picture length and width including Overlap



(TerraModel, 2017)

The chosen flight height for the project is 40m high; this gives sufficient coverage, GCPs overlap and a smaller pixel size for better accuracy.

3. Test Flight Speed

With the picture size & height established, it was necessary to access the drone flight speed and its capabilities. As the drone could reach a maximum top speed of 20m/s or 72kmph in sports mode, this was not necessary for the flight. Therefore it was proposed to delineate the drone flight speed based on the camera shutter speed, set at 1 photo every 5 seconds. This meant the drone would need to travel a minimum of 7m every 5 seconds to achieve the 80% forward overlap based on a 40m high photo. Therefor 7/5sec = 1.4m per sec = 5kmph flight speed.

After further manipulation of the flights, it was decided to fly at a speed of 7.5kmph to speed the process up. This meant less time in the air, and less time near the public. Therefor 7.5kmph = 2m per second, 10m per Photo.

4. ***Test Camera Shutter Speed***

To allow the drone to capture the required distance specified, the drone was flown at a speed of 7.5kmph and had the camera shutter speed set to 1 photo every 5seconds. This was done within the Litchi App. However during the test flight, it was noted that within the Litchi App, having the picture format set to JPEG and Raw, made not possible to use the interval timer. Therefor RAW imagery was disabled and only the JPEG was captured to allow the interval timer to be used.

3.3.3 Data Collection Phase

This phase will be completed during a low tide. This will ensure that majority of the seawall is exposed and control marks can be placed.

An initial test fly will be performed to ensure all systems are functional and all relevant data is captured.

This phase will include the setting up of the chosen site, including site control and calibrations. It will also include all three flights and GPS Surveys.

Below is a step by step procedure that will be undertaken to ensure the Drone & GPS Monitoring surveys are completed efficiently and accurately.

A. Test and calibrate Drone and GPS Gear to ensure all equipment is up to date, accuracies are met and equipment safe.
B. Once the drone has been calibrated (previous step) and tested an initial pre-flight will be undertaken to ensure the correct height, angle, speed and camera shutter speed is set. This will also include checking the amount of overlap achieved and creating a suitable flight path for the area, using Litchi, a DJI friendly software program.

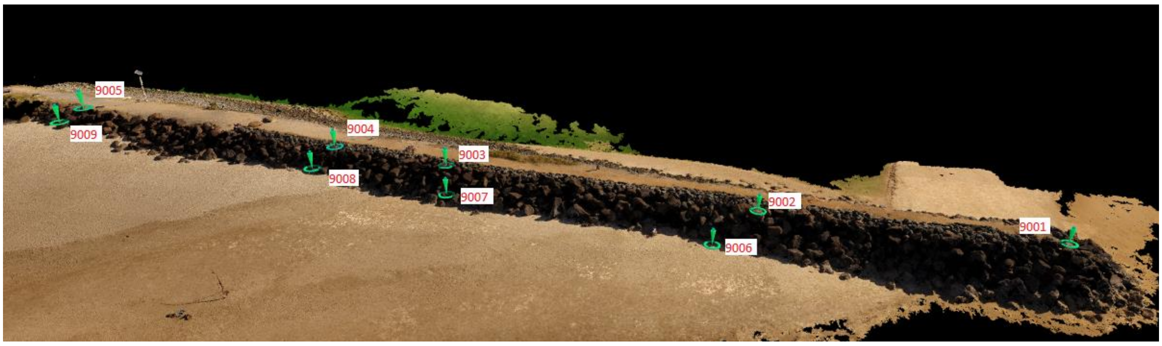
C. As completed with the Drone, the GPS equipment will be setup and calibrated according to the area/zone in which the works will be completed. This will be Zone 56 on MGA94 (previous step)

D. Create flight paths using Litchi (DJI Phantom 4) flight path program and configure flights to correct specifications.

E. Install site control Marks and Seawall Monitoring Points. These will be installed along the top of the seawall, along the base of the seawall and along the sand situated to the south of the seawall. The Photogrammetry points will be fixed in position by pegs to ensure they don't move.

   - Monitoring Control Points (MCP) – screw installed into rock surface
   - Photogrammetry Control Points or the Ground Control Points (GCPs) – A white cross aligned with a white dumpy or white or black square tile.
   - All MPs will be surveyed using convention survey methods (total station) to establish a base control network. These points will be used as the monitoring points and photogrammetry points for the duration of the project.

Figure 33, overall 3D point Cloud Model



F. Conventional Survey of all control marks and establishes site base data line. (Conducted on 1st survey only). This will be completed using the Trimble S8 Total Station.

G. Use cors network R8 GPS Rover to conduct site survey of all monitoring control points.

H. Conduct Site Photogrammetric Survey of seawall.

   - Flight 1 – Perpendicular Survey using vertical camera angle

Figure 34, Flight 1 Example

(Litchi, 2017)

- Flight 2 – Parallel Survey using vertical camera angle

Figure 35, Flight 2 Example

(Litchi, 2017)

- Flight 3 – Oblique Flight of central focus point (centre seawall) with a 45° degree camera angle

Figure 36, Flight 3 Example

(Litchi, 2017)

I. Complete GPS and Drone surveys three times and ensure all monitoring points are captured each time.

With control established and all GPS and drone calibrations completed and a flight path established, it will then be possible to proceed with the initial flight, changing only the location of the control between each monitoring flight.

3.3.4 Data Analysis Phase

The Data Analysis Phase is where all the data captured during the flight and conventional survey will be compiled, plotted into a 3D point cloud, reviewed and analysed using Pix4D program.

Once each flight is completed, all data will be removed from the DJI Phantom or Trimble Survey controller and copied to the nominated work station. This data will then be separated into its individual folders, keeping all information separated.

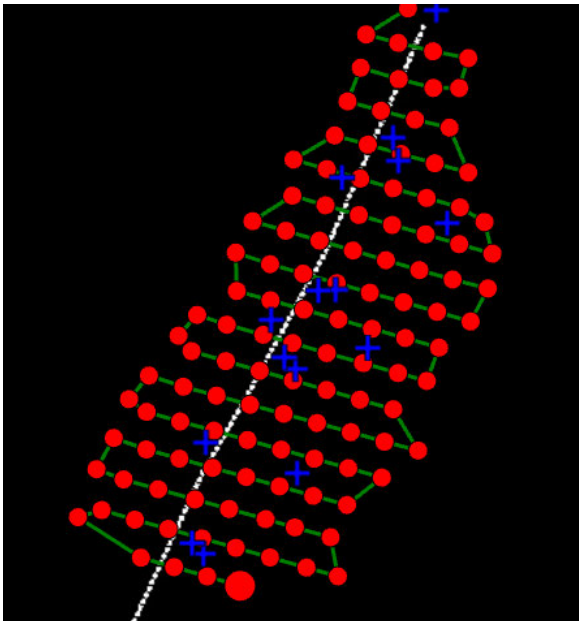
The flight photos will then be processed in the Pix4D program to create the 3D point cloud, whilst the Cors GPS data will be processed using convention reduction methods, such as CAD.

All data processing will be done as a post process scenario in an office using the Pix4D Program and Magnet Office. Once all data sets have been compiled and checked for image quality and overlap, these data sets will then be compared between each monitoring survey for accuracies and discrepancies using the initial Monitoring survey as the base file. A number of comparisons will be made between the data to ensure the results are true and accurate. A point to point comparison will be conducted between the original bae survey points and that of the nominated point achieved in the data sets. This comparison will be used to check the RMSEx, RMSEy and the RMSEz of the data. This phase will also include liaising with the Project supervisors ensuring all methods and techniques used are correct and up to standard.

3.3.4.1 Photogrammetry Data Processing

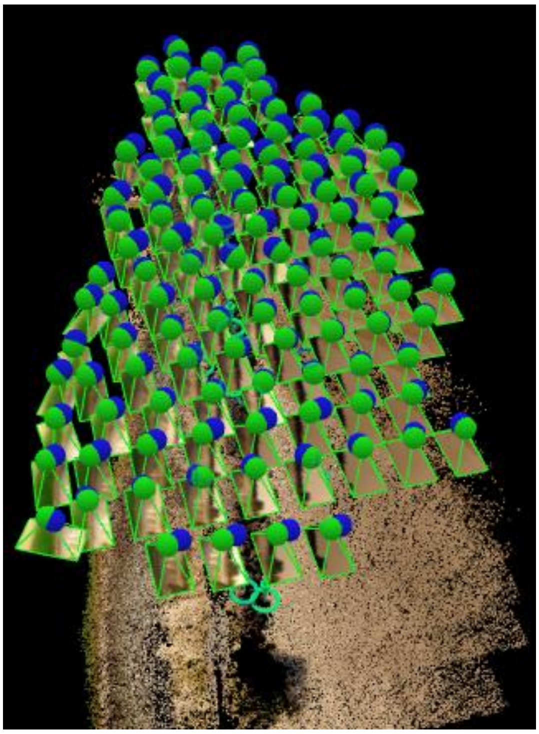
1. Program - Use Pix4D to process the captured photos. This program will provide an in depth communication procedure on how to begin the photogrammetric process and how to register the photos for further reductions
2. Geo-Referencing - Before geo-referencing the photos it is necessary to review and analyse photos for overlap and GCPs, ensuring there is sufficient overlap and GCPs captured, remove any waste photos (noise data). Once completed the photos for the initial step need to be geo-referenced. This is within the parameters of the JPEG. Input: WGS 1984. This needs to be output to MGA Zone 56.
3. Stitch Photos – Once photos have a specific input and output, it's necessary to be sure the photos were uploaded in the sequence flown. View the flight path and photos, then begin stitching. The program will automatically stitch all photos to common tie-points.

Figure 37, Flight Path a Photos



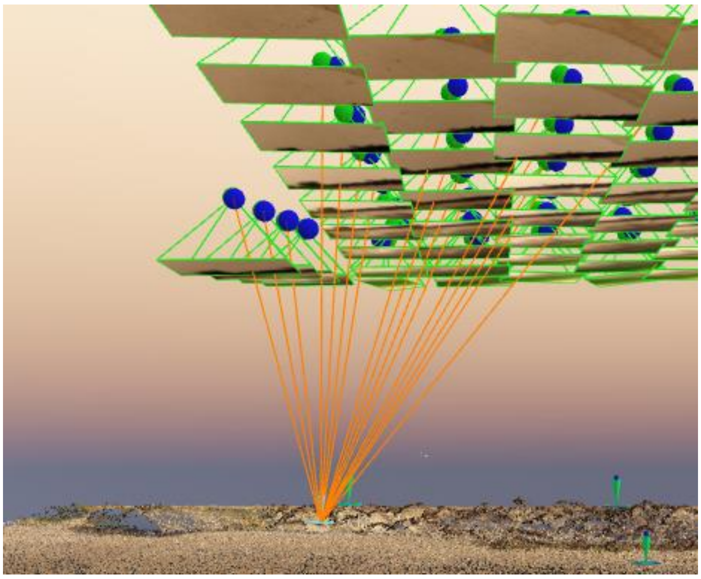
With the photos stitched by the common tie-points a *Ray Cloud* of photos and corresponding tie-points will be created.

Figure 38, Ray Cloud of Tie-Points and Images



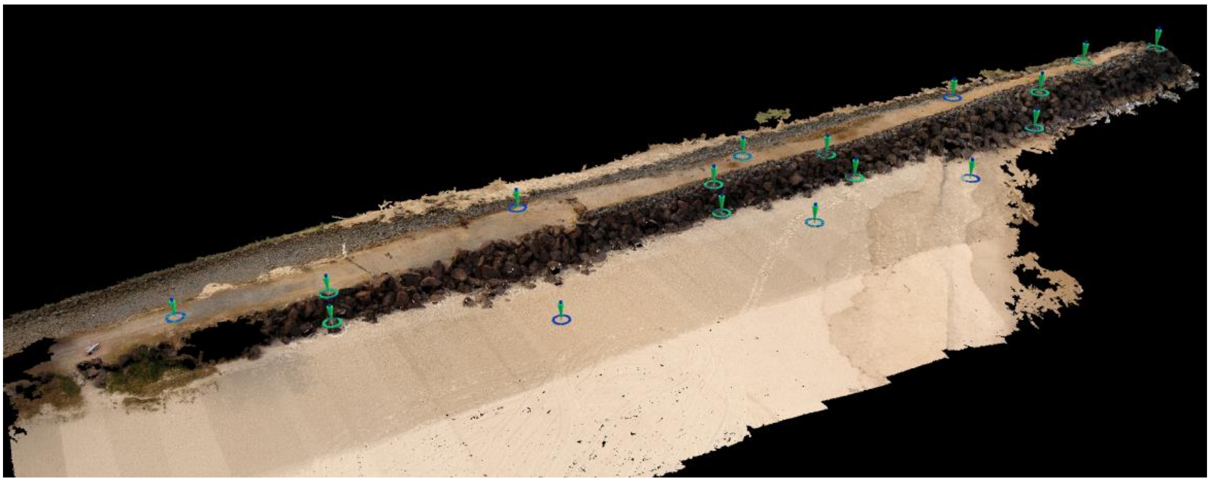
4. Establish GCPs – it is now essential to establish the known GCPs into the data, to create a more accurate result. As the data currently is, it's only basically referenced by the in house GPS Unit. Using the already established control, Import the data and relate the Tie-point to the control. This will produce a better RMSE and Pixel result.

Figure 39, GCPs and referenced images



5. Create Point Cloud – using the already referenced images and GCPs, the imagery and accuracy will be reduced to the most achievable unit. Now processing the photos will create a 3D point cloud, illustrating the overall captured data for review and analysing. Ensure to check results through each process.

Figure 40, 3D Point Cloud



Further details of the methodology and time frames associated are provided in table ??? & ??? And Gantt Chart 1 in Appendix B.

3.4 Resource Requirements

The table below outlines briefly the equipment and their purpose for the duration of the project. Due to the nature of the Students work and the employer, the RTK Corse GPS Survey equipment is quite readily available and requires minor scheduling to ensure its availability. However this will be communicated with prior to each Project Flight to ensure all equipment is available and in working order. The DJI Phantom 4, which is owned by Thomas Bartlett, will be readily available also and will be communicated at the same time to ensure its availability. This will give all personnel ample time to check and maintain equipment prior to any flight, ensuring all safety measures are in place.

Table 2: Project Equipment and Resource Analysis

Person/Company	Equipment	Purpose
Bennett & Bennett	Trimble R8 Rover	GPS Rover to survey sea wall
	TSC3 (Cors Network)	Required to give rover position
Thomas Bartlett	DJI Phantom 4	Used to fly nominated camera
	In house camera	To take all photos of sea wall
	Litchi	DJI Phantom Flight Path Program
Luke Bartlett	Magnet Office	Used to create standard CAD Drawing
	Pix4D	To stitch, draw and create 3D point cloud
	Trimble S8	Total Station for base survey

4 Results

4.1 Introduction

The following section will cover the results achieved from the Conventional survey, the GPS Monitoring survey and the accuracies achieved from each associated flight. This will include the ground pixel size achieved and the RMSE value to illustrate the accuracy of the drone survey.

4.2 Conventional Survey (Base Line)

An initial convention survey of the base control points was conducted to create a base line of control and monitoring points for the project. The control was established using an arbitrary datum and datum shift was completed to correct the orientation and height using the GPS during the second flight. The below control is the base line control points (GCPs) that will be used to check the comparison between the surveys and flights and for monitoring rock wall movement. The Trimble S8 total station was used to complete the survey and Terramodel was used to reduce the data. However using an arbitrary datum and reducing to height based upon the GPS Survey means the height will be based upon the GPS accuracies of +/- 30mm.

Table 3, Base Control/Monitoring Points

Sea Wall TS Base Control Points				
Pt Number	**Easting**	**Northing**	**Elevation**	**Code**
9000	545277.725	6892072.889	5.657	SIC (9000)
9001	545364.746	6892244.477	5.349	SIR
9002	545351.713	6892206.669	5.921	SIR
9003	545329.262	6892161.387	5.903	SIR
9004	545319.004	6892141.566	6.11	SIR
9005	545291.263	6892086.512	6.297	SIR
9006	545353.277	6892199.788	1.67	SIR
9007	545334.395	6892161.563	2.891	SIR
9008	545322.337	6892138.11	3.521	SIR
9009	545294.648	6892083.351	4.551	SIR

4.3 Ground Control Points/GCPs

The Monitoring GCPs used for the surveys were installed into rock and concrete and are listed above, however further dumpy pegs and tiles were installed to be used to stitch the photos together. Certain parameters had to be met in order to use these photos; such as not blurred photos, clear view of marks and straight alignment of camera.

Pix4D the program used will create automatic tie-points when stitching the photos together, however the nominated GCPs are picked and Pix4D will then use these points to create a model of best fit suited to the marks. Below are the some of the results of the accuracies before GCPs are utilised and after, providing tighter adjustment to the survey.

Figure 41 – Quality Check Prior to GCPs, Day 3 Flight 1

median of 31904 keypoints per image
36 out of 36 images calibrated (100%), all images enabled
0.48% relative difference between initial and optimized internal camera parameters
median of 16539.3 matches per calibrated image
no, no 3D GCP

Figure 42 – Quality Check After to GCPs, Day 3 Flight 1

median of 31904 keypoints per image
36 out of 36 images calibrated (100%), all images enabled
1.27% relative difference between initial and optimized internal camera parameters
median of 16537.3 matches per calibrated image
yes, 17 GCPs (17 3D), mean RMS error = 0.01 m

Figure 43, GCPs Accuracies after Processed, Day 3 Flights 1

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]
5000 (3D)	0.020/ 0.020	0.029	-0.000	-0.009	0.430
5001 (3D)	0.020/ 0.020	0.007	-0.012	0.006	0.540
5002 (3D)	0.020/ 0.020	0.013	0.001	0.007	0.509
5003 (3D)	0.020/ 0.020	0.000	0.004	-0.002	0.848
5005 (3D)	0.020/ 0.020	0.008	0.004	-0.010	0.478
5006 (3D)	0.020/ 0.020	-0.004	0.015	0.006	0.390
5007 (3D)	0.020/ 0.020	0.005	0.004	0.001	0.317
5008 (3D)	0.020/ 0.020	-0.002	0.002	0.004	0.473
5010 (3D)	0.020/ 0.020	-0.003	-0.010	0.009	0.579
5011 (3D)	0.020/ 0.020	-0.005	0.012	-0.007	0.315
5012 (3D)	0.020/ 0.020	-0.011	0.005	0.015	0.506
5013 (3D)	0.020/ 0.020	-0.005	-0.001	-0.011	0.458
5014 (3D)	0.020/ 0.020	-0.024	0.014	0.013	0.408
5015 (3D)	0.020/ 0.020	-0.020	-0.011	-0.018	0.445
5016 (3D)	0.020/ 0.020	0.008	0.001	0.005	0.525
5017 (3D)	0.020/ 0.020	0.005	-0.013	-0.006	0.271
5018 (3D)	0.020/ 0.020	-0.007	-0.023	-0.012	0.527
Mean [m]		-0.000377	-0.000507	-0.000611	
Sigma [m]		0.012000	0.009987	0.009338	
RMS Error [m]		0.012006	0.009999	0.009358	

4.5 GPS Ground Control Points

All 10 GCPs or monitoring points were installed into the rock surface of into concrete as illustrated below. These were used to monitor movement in the rock wall, and to ascertain whether it is accurate and possible to utilise a drone rather than GPS to monitor the points. Below are the results obtained from the GPS Surveys, the movements noted and the accuracies achieved.

Figure 44, GCP 9005, installed in Rock

4.6 GPS vs UAV GCPs Horizontal and Vertical Accuracies

This section will outline the accuracies between the GPS points surveyed against those computed by the Photogrammetric survey.

4.6.1 Day 1 Photogrammetric Flight 1 GCPs Horizontal and Vertical Results

Table 4, GCPs vs Photogrammetric GCP Co-ordinates

GCP	EASTING	NORTHING	PCP	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.720	6892072.875
9001	545364.746	6892244.477	9001	545364.738	6892244.465
9002	545351.713	6892206.669	9002	545351.711	6892206.669
9003	545329.262	6892161.387	9003	545329.275	6892161.385
9004	545319.004	6892141.566	9004	545318.994	6892141.561
9005	545291.263	6892086.512	9005	545291.262	6892086.520
9006	545353.277	6892199.788	9006	545353.268	6892199.802
9007	545334.395	6892161.563	9007	545334.401	6892161.559

9008	545322.337	6892138.11	9008	545322.325	6892138.101
9009	545294.648	6892083.351	9009	545294.665	6892083.343

Table 5, GCPs vs Photogrammetric GCP Co-ordinates Horizontal Differences

POINT ID	Diff East	Absolute Diff	Diff North	Absolute Diff	Distance/RMSE
9000	-0.005	0.005	-0.014	0.014	0.015
9001	-0.008	0.008	-0.012	0.012	0.014
9002	-0.002	0.002	0.000	0.000	0.002
9003	0.013	0.013	-0.002	0.002	0.013
9004	-0.010	0.010	-0.005	0.005	0.011
9005	-0.001	0.001	0.008	0.008	0.008
9006	-0.009	0.009	0.014	0.014	0.017
9007	0.006	0.006	-0.004	0.004	0.007
9008	-0.012	0.012	-0.009	0.009	0.015
9009	0.017	0.017	-0.008	0.008	0.019
Mean	**-0.001**	0.008	**-0.003**	0.008	**0.012**
Median	-0.003		-0.004		0.014
Max	0.017		0.014		0.019
Min	-0.012		-0.014		0.002
St Dev	0.009		0.008		**0.005**
Variation	0.000		0.000		0.000

Table 6, GCPs vs Photogrammetric GCP Elevations

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.650
9001	5.349	9001	5.366
9002	5.921	9002	5.905
9003	5.903	9003	5.899
9004	6.11	9004	6.102
9005	6.297	9005	6.290
9006	1.67	9006	1.696
9007	2.891	9007	2.900
9008	3.521	9008	3.522
9009	4.551	9009	4.561

Table 7, GCPs vs Photogrammetric GCP Elevations Differences

POINT ID	Elevation Diff	Absolute Diff
9000	-0.007	0.007
9001	0.017	0.017
9002	-0.016	0.016
9003	-0.004	0.004
9004	-0.008	0.008
9005	-0.007	0.007
9006	0.026	0.026
9007	0.009	0.009
9008	0.001	0.001
9009	0.010	0.010
	Mean	**0.002**
	Median	0.008
	Max	0.026
	Min	0.001
	St Dev	0.007
	Variation	0.000

95% Confidence for RMSExy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 4.56145

T-value x SE = 9.4148

Small Tail End = 3

Large Tail End = 22

Therefor the **95% confident results lie between 3mm & 22mm**

95% Confidence for RMSEx

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 3.2458

T-value x SE = 6.6994

Small Tail End = 2mm

Large Tail End = 15mm

Therefor the **95% confident results lie between 2mm & 15mm**

95% Confidence for RMSEy

Sample Size **Degrees of Freedom** **t value for 95% Confidence** **Standard Error**

Sample Size	Degrees of Freedom	t value for 95% Confidence	Standard Error
10	9	2.064	3.4726

T-value x SE = 7.1676

Small Tail End = 0mm

Large Tail End = 15mm

Therefor the **95% confident results lie between 0mm & 15mm**

Figure 45, Day 1 Flight 1 GPS vs Photogrammetric GCP Check (xy)

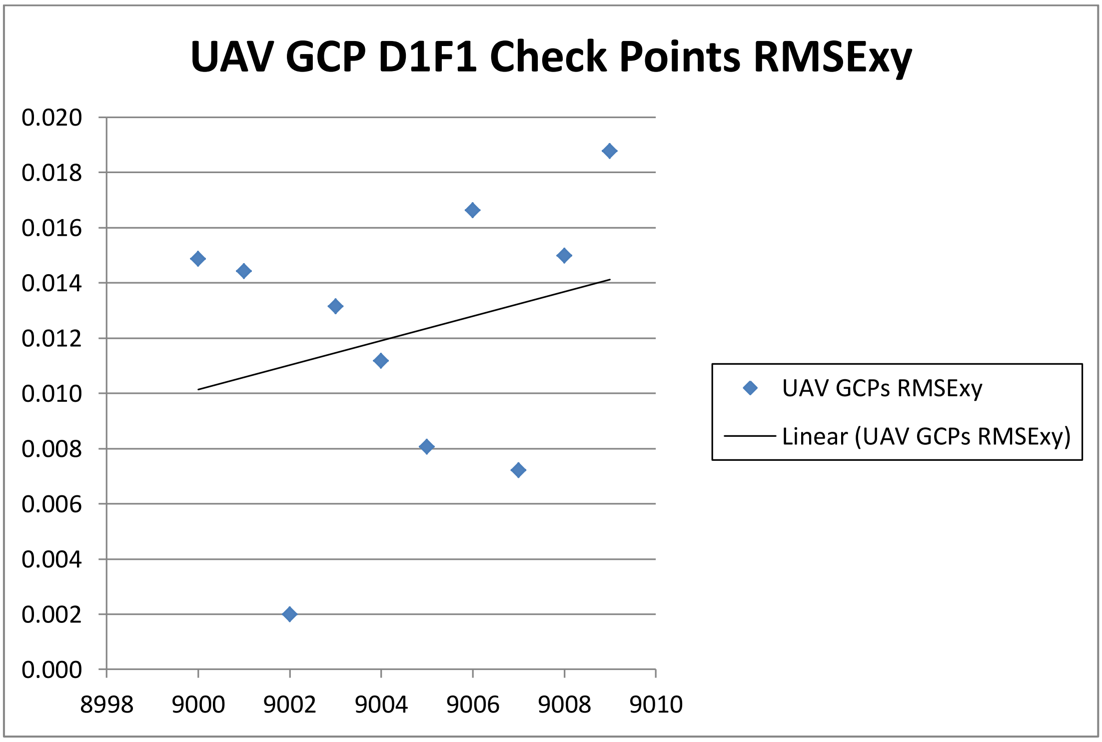


Figure 46, Day 1 Flight 1 GPS vs Photogrammetric GCP Check (x)

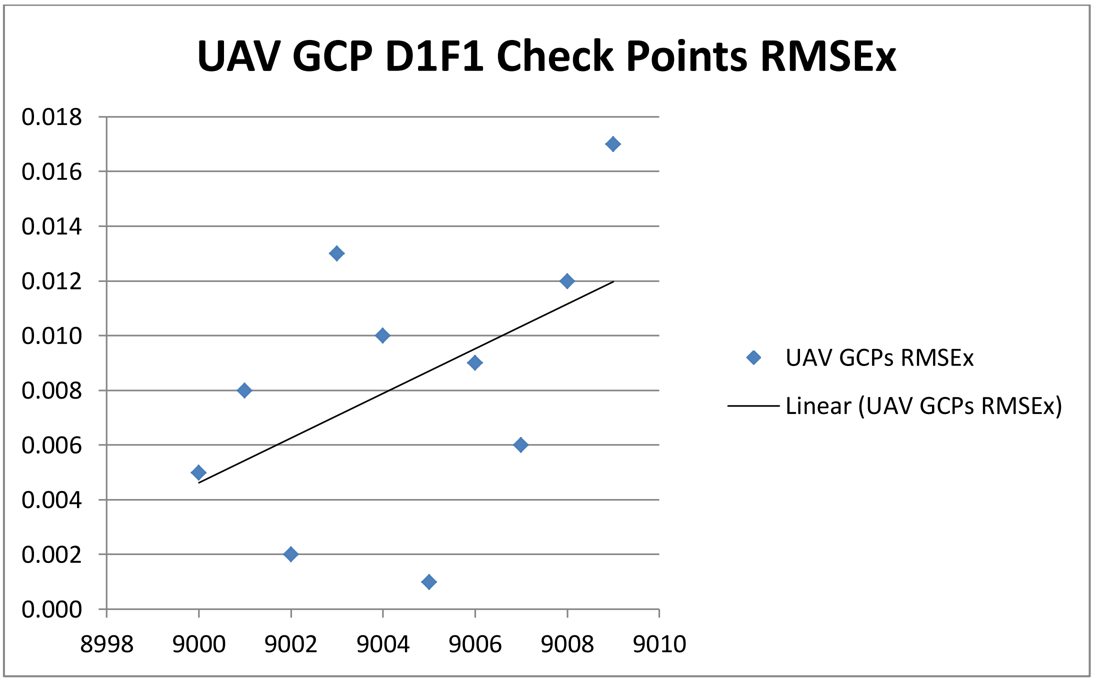


Figure 47, Day 1 Flight 1 GPS vs Photogrammetric GCP Check (y)

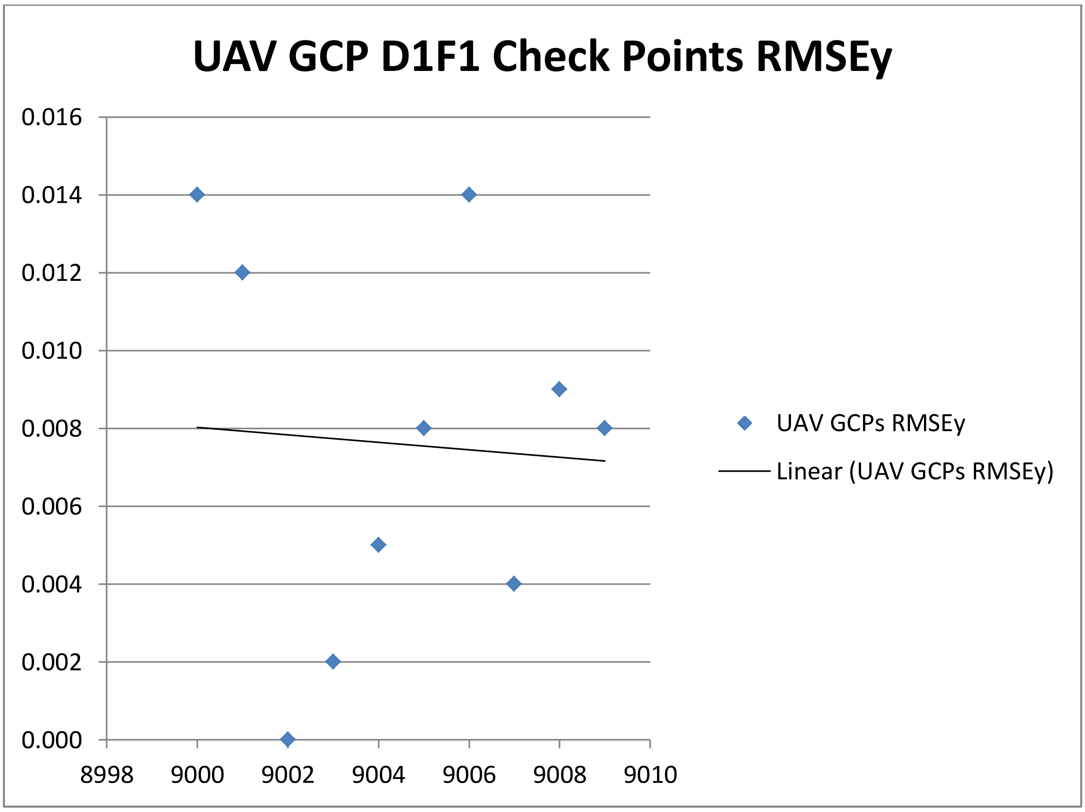
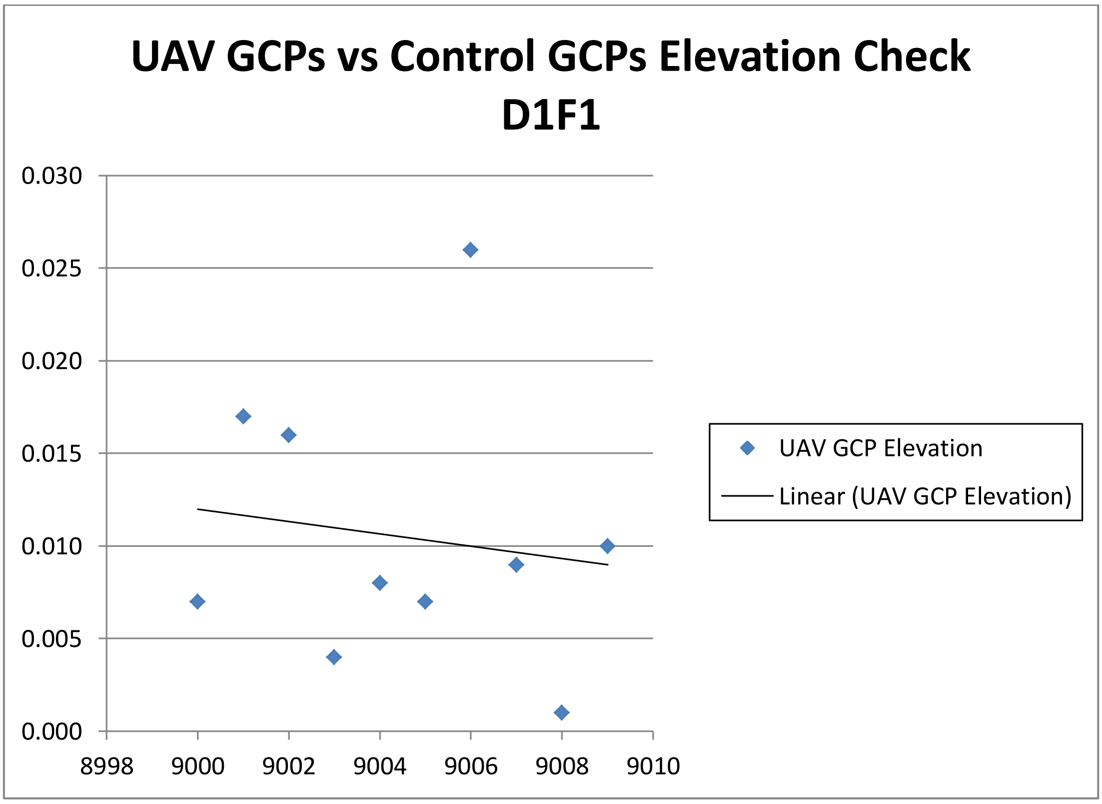


Figure 48, Day 1 Flight 1 GPS vs Photogrammetric GCP Check (Elevation)



4.6.2 Day 1 Photogrammetric Flight 2 GCPs Horizontal and Vertical Results

Table 8, GCPs vs Photogrammetric GCP Co-ordinates

GCP	EASTING	NORTHING	PCP	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.723	6892072.889
9001	545364.746	6892244.477	9001	545364.748	6892244.478
9002	545351.713	6892206.669	9002	545351.713	6892206.672
9003	545329.262	6892161.387	9003	545329.280	6892161.387
9004	545319.004	6892141.566	9004	545318.998	6892141.558
9005	545291.263	6892086.512	9005	545291.260	6892086.513
9006	545353.277	6892199.788	9006	545353.274	6892199.805
9007	545334.395	6892161.563	9007	545334.400	6892161.560
9008	545322.337	6892138.11	9008	545322.322	6892138.100
9009	545294.648	6892083.351	9009	545294.657	6892083.332

Table 9, GCPs vs Photogrammetric GCP Co-ordinates Horizontal Differences

POINT ID	Diff East	Absolute Diff	Diff North	Absolute Diff	Distance/RMSE
9000	-0.002	0.002	0.000	0.000	0.002
9001	0.002	0.002	0.001	0.001	0.002
9002	0.000	0.000	0.003	0.003	0.003
9003	0.018	0.018	0.000	0.000	0.018
9004	-0.006	0.006	-0.008	0.008	0.010
9005	-0.003	0.003	0.001	0.001	0.003
9006	-0.003	0.003	0.017	0.017	0.017
9007	0.005	0.005	-0.003	0.003	0.006
9008	-0.015	0.015	-0.010	0.010	0.018
9009	0.009	0.009	-0.019	0.019	0.021
Mean	**0.001**	0.006	**-0.002**	0.006	**0.010**
Median	-0.001		0.000		0.008
Max	0.018		0.017		0.021
Min	-0.015		-0.019		0.002
St Dev	0.008		0.009		**0.007**
Variation	0.000		0.000		0.000

Table 10, GCPs vs Photogrammetric GCP Elevations

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.654
9001	5.349	9001	5.352
9002	5.921	9002	5.915
9003	5.903	9003	5.900
9004	6.11	9004	6.105
9005	6.297	9005	6.298
9006	1.67	9006	1.665
9007	2.891	9007	2.877
9008	3.521	9008	3.516
9009	4.551	9009	4.554

Table 11, GCPs vs Photogrammetric GCP Elevations Differences

POINT ID	Elevation Diff	Absolute Diff
9000	-0.003	0.003
9001	0.003	0.003
9002	-0.006	0.006
9003	-0.003	0.003

9004	-0.005	0.005
9005	0.001	0.001
9006	-0.005	0.005
9007	-0.014	0.014
9008	-0.005	0.005
9009	0.003	0.003
	Mean	**-0.003**
	Median	0.004
	Max	0.014
	Min	0.001
	St Dev	0.003
	Variation	0.000

95% Confidence for RMSExy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10	9	2.064	3.6887

T-value x SE = 7.6136

Small Tail End = 2mm

Large Tail End = 18mm

Therefor the **95% confident results lie between 2mm & 18mm**

95% Confidence for RMSEx

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10	9	2.064	3.4395

T-value x SE = 7.0991

Small Tail End = -1mm

Large Tail End = 13mm

Therefor the **95% confident results lie between -1mm & 13mm**

95% Confidence for RMSEy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10	9	2.064	3.34203

T-value x SE = 6.8979

Small Tail End = -1mm

Large Tail End = 13mm

Therefor the **95% confident results lie between -1mm & 13mm**

Figure 49, Day 1 Flight 2 GPS vs Photogrammetric GCP Check (xy)

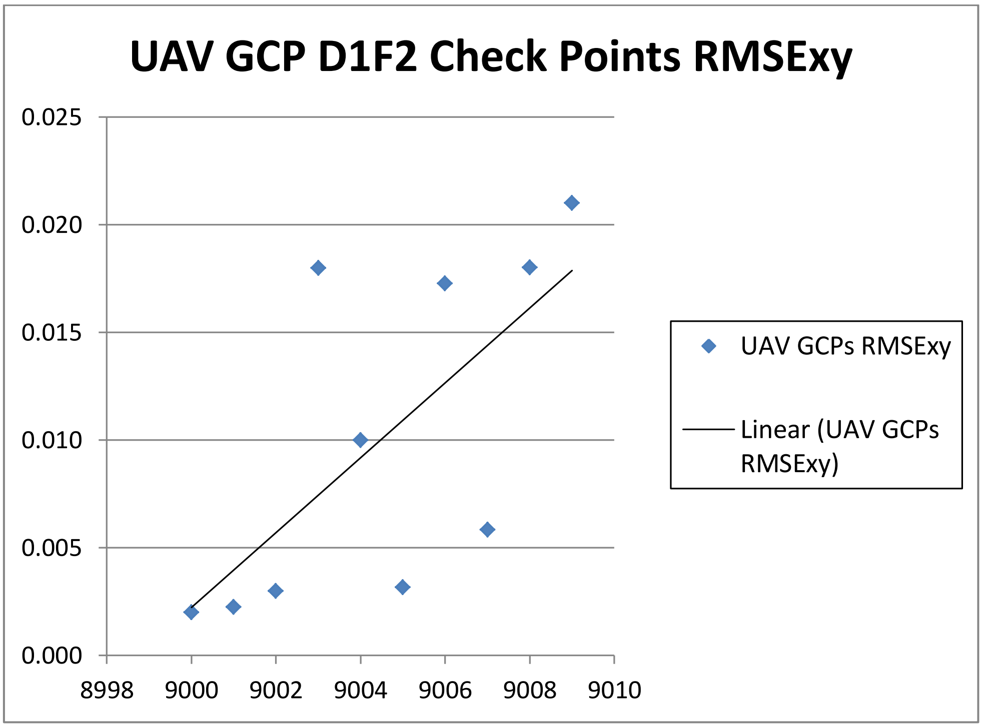


Figure 50, Day 1 Flight 2 GPS vs Photogrammetric GCP Check (x)

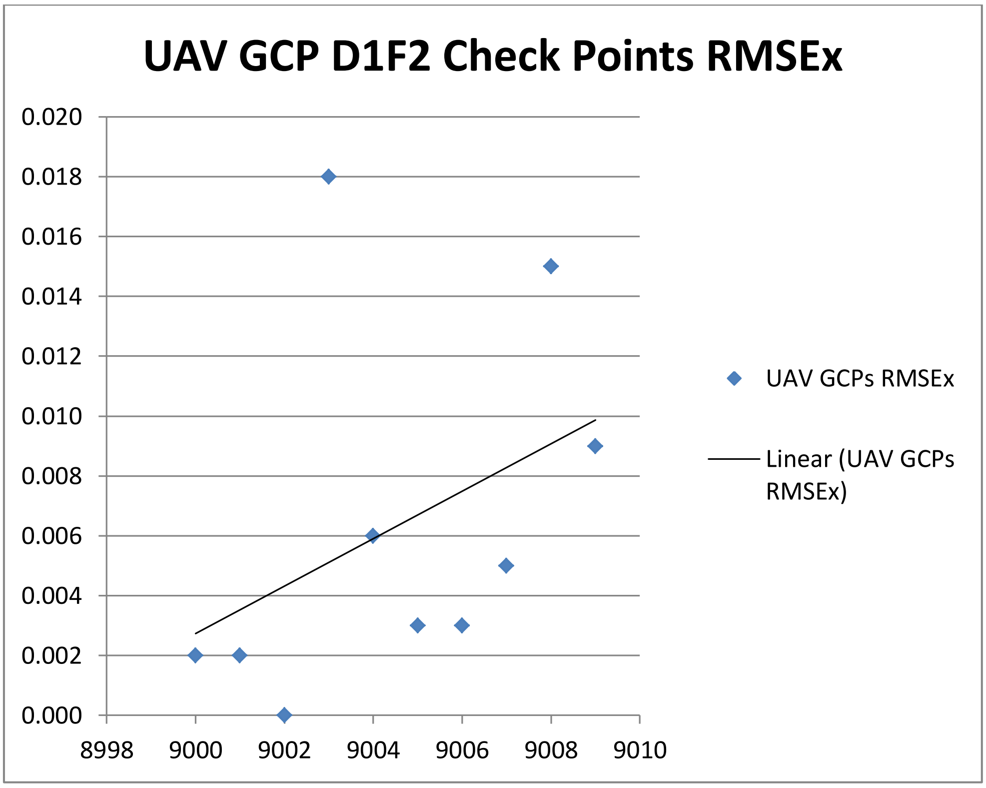


Figure 51, Day 1 Flight 2 GPS vs Photogrammetric GCP Check (y)

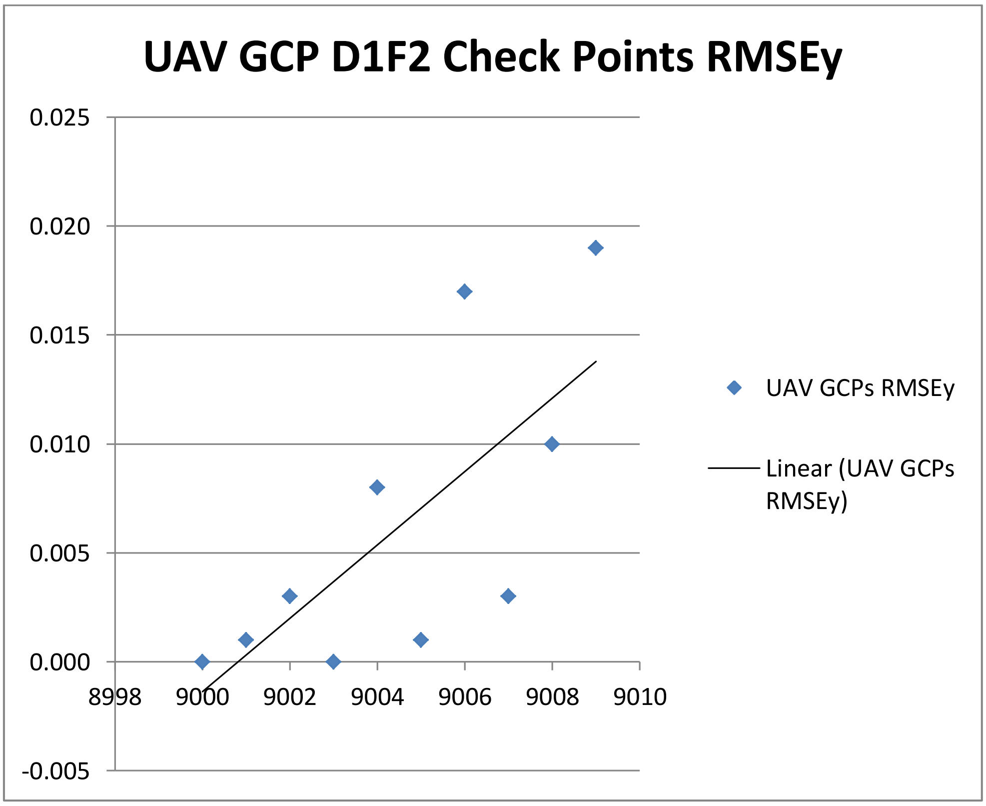
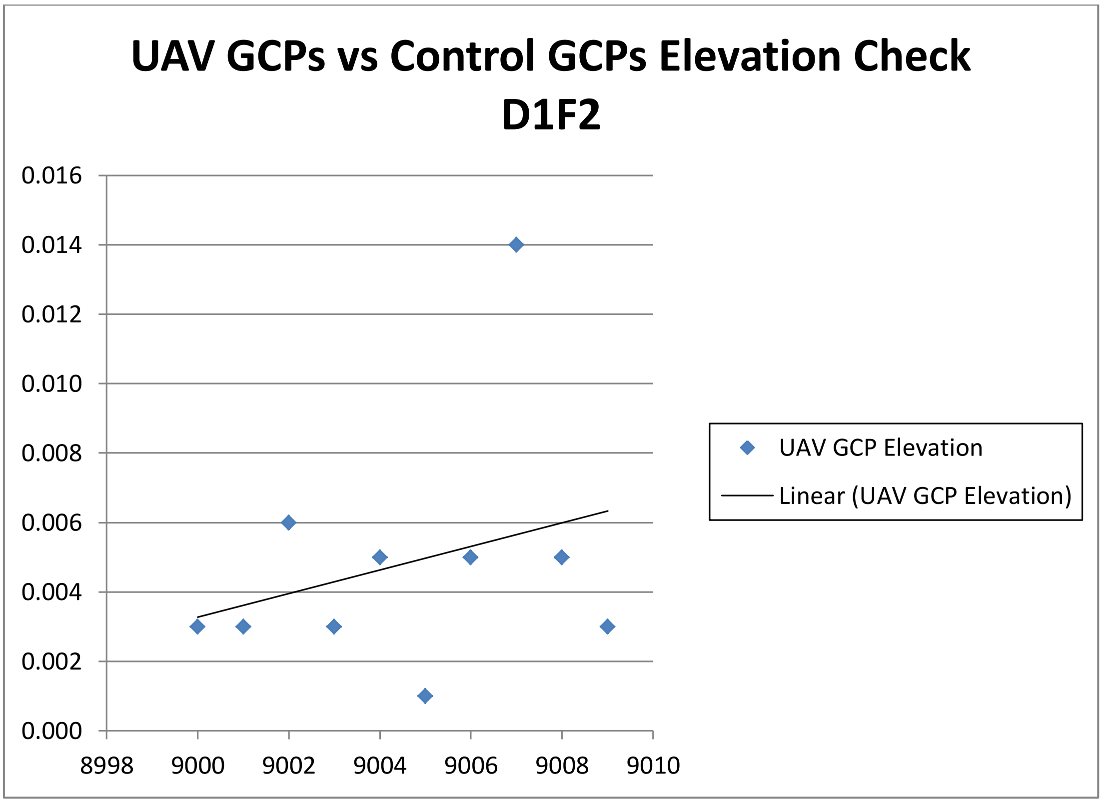


Figure 52, Day 1 Flight 2 GPS vs Photogrammetric GCP Check (elevation)



4.6.3 Day 2 Photogrammetric Flight 1 GCPs Horizontal and Vertical Results

Table 12, GCPs vs Photogrammetric GCP Co-ordinates

GCP	EASTING	NORTHING	PCP	EASTING	NORTHING
9000	545277.724	6892072.89	9000	545277.716	6892072.909
9001	545364.756	6892244.466	9001	545364.762	6892244.463
9002	545351.728	6892206.665	9002	545351.723	6892206.661
9003	545329.308	6892161.382	9003	545329.294	6892161.383
9004	545319.009	6892141.564	9004	545319.013	6892141.565
9005	545291.266	6892086.514	9005	545291.271	6892086.515
9006	545353.289	6892199.79	9006	545353.298	6892199.883
9007	545334.4	6892161.566	9007	545334.392	6892161.566
9008	545322.347	6892138.102	9008	545322.343	6892138.101
9009	545294.672	6892083.339	9009	545294.673	6892083.332

Table 13, GCPs vs Photogrammetric GCP Co-ordinates Horizontal Differences

POINT ID	Diff East	Absolute Diff	Diff North	Absolute Diff	Distance/RMSE
9000	-0.008	0.008	0.019	0.019	0.021
9001	0.006	0.006	-0.003	0.003	0.007
9002	-0.005	0.005	-0.004	0.004	0.006
9003	-0.014	0.014	0.001	0.001	0.014
9004	0.004	0.004	0.001	0.001	0.004
9005	0.005	0.005	0.001	0.001	0.005
9006	0.009	0.009	0.093	0.093	0.093
9007	-0.008	0.008	0.000	0.000	0.008
9008	-0.004	0.004	-0.001	0.001	0.004
9009	0.001	0.001	-0.007	0.007	0.007
Mean	**-0.001**	0.006	**0.010**	0.013	**0.017**
Median	-0.002		0.000		0.007
Max	0.009		0.093		0.093
Min	-0.014		-0.007		0.004
St Dev	0.007		0.028		**0.026**
Variation	0.000		0.001		0.001

Table 14, GCPs vs Photogrammetric GCP Elevations

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.655	9000	5.675
9001	5.324	9001	5.319
9002	5.913	9002	5.901
9003	5.905	9003	5.910
9004	6.11	9004	6.099
9005	6.302	9005	6.284
9006	1.668	9006	1.744
9007	2.891	9007	2.878
9008	3.504	9008	3.494
9009	4.533	9009	4.536

Table 15, GCPs vs Photogrammetric GCP Elevations Differences

POINT ID	Elevation Diff	Absolute Diff
9000	0.020	0.020

9001	-0.005	0.005
9002	-0.012	0.012
9003	0.005	0.005
9004	-0.011	0.011
9005	-0.018	0.018
9006	0.076	0.076
9007	-0.013	0.013
9008	-0.010	0.010
9009	0.003	0.003
	Mean	**0.003**
	Median	0.012
	Max	0.076
	Min	0.003
	St Dev	0.020
	Variation	0.000

95% Confidence for RMSExy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 1.9629

T-value x SE = 4.05156

Small Tail End = 13mm

Large Tail End = 21mm

Therefor the **95% confident results lie between 13mm & 21mm**

95% Confidence for RMSEx

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 3.7523

T-value x SE = 7.7449

Small Tail End = -1mm

Large Tail End = 14mm

Therefor the **95% confident results lie between -1mm & 14mm**

95% Confidence for RMSEy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10	9	2.064	1.87516

T-value x SE = 3.87034

Small Tail End = 9mm

Large Tail End = 17mm

Therefor the **95% confident results lie between 9mm & 17mm**

Figure 53, Day 2 Flight 1 GPS vs Photogrammetric GCP Check (xy)

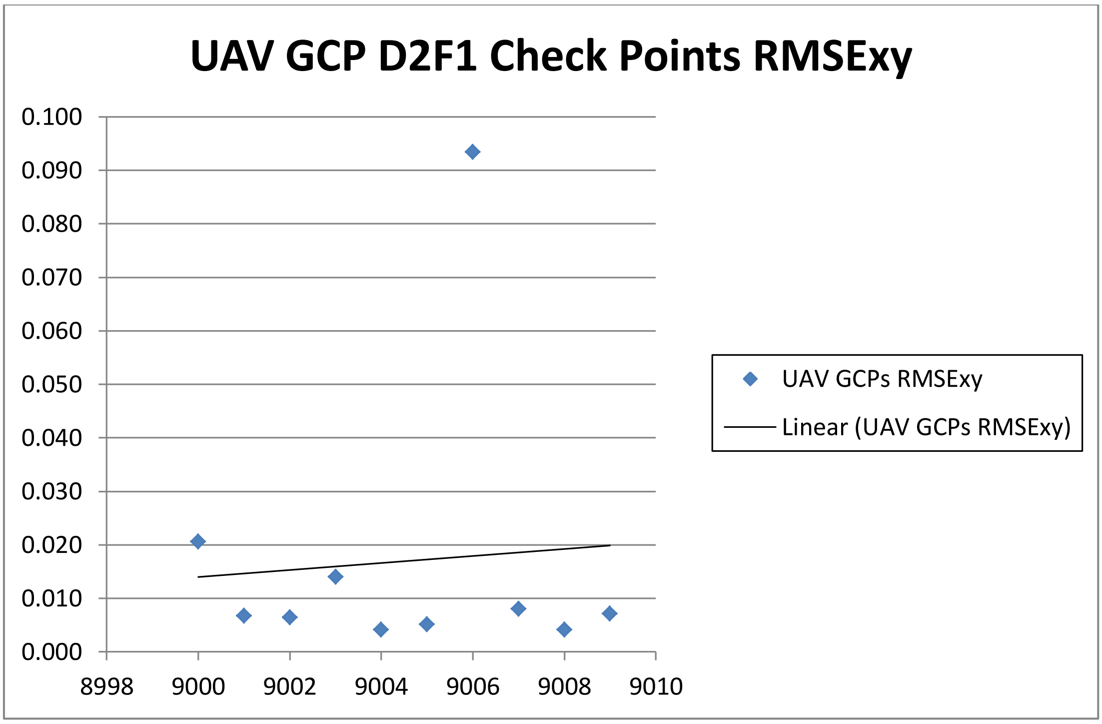


Figure 54, Day 2 Flight 1 GPS vs Photogrammetric GCP Check (x)

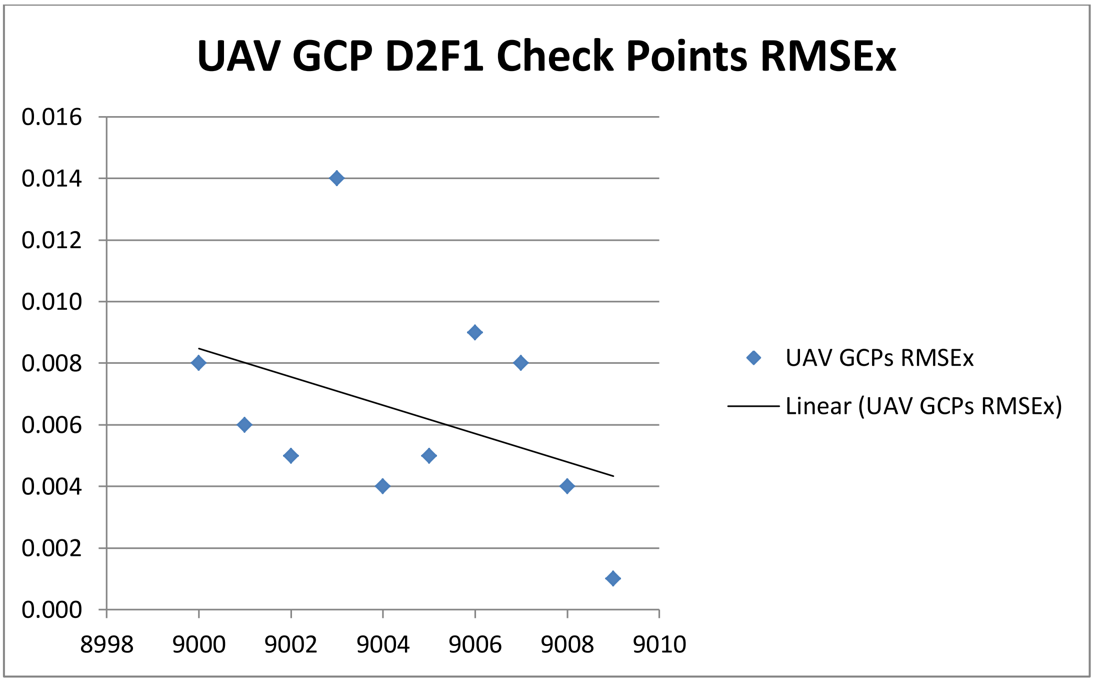


Figure 55, Day 2 Flight 1 GPS vs Photogrammetric GCP Check (y)

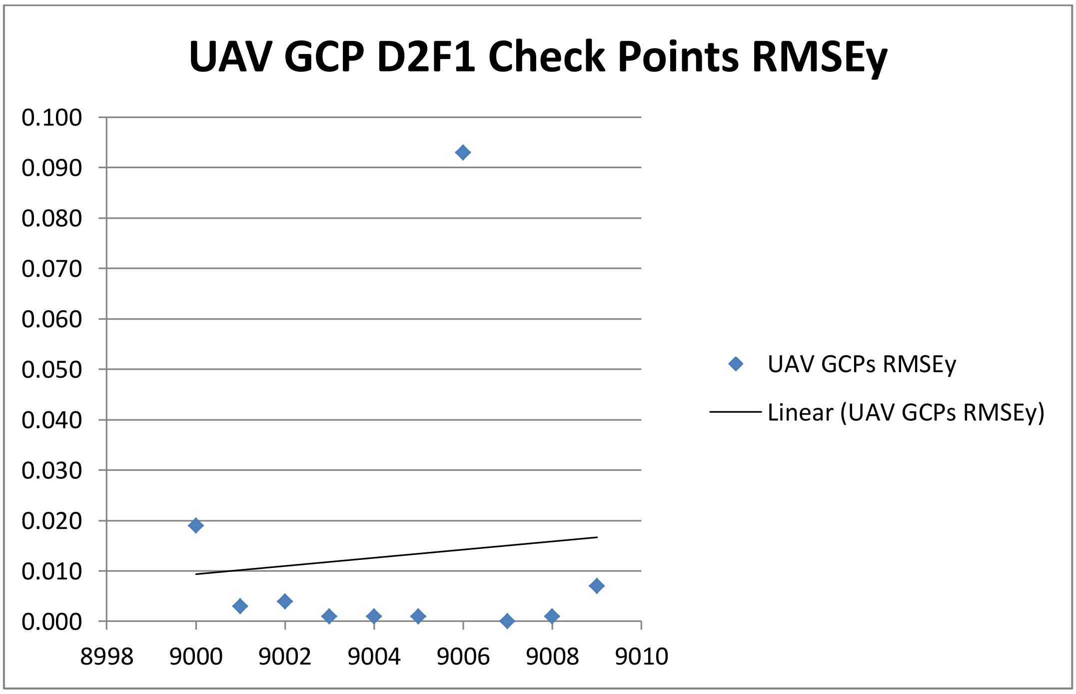
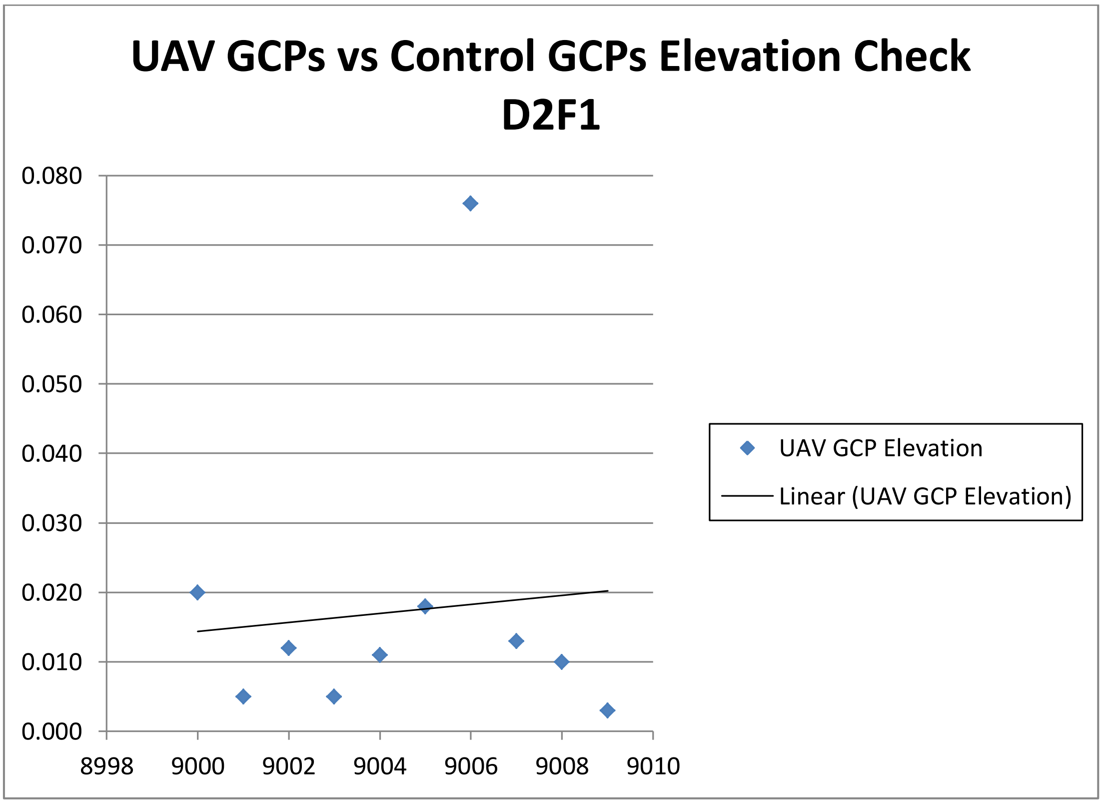


Figure 56, Day 2 Flight 1 GPS vs Photogrammetric GCP Check (elevation)



4.6.4 Day 2 Photogrammetric Flight 2 GCPs Horizontal and Vertical Results

Table 16, GCPs vs Photogrammetric GCP Co-ordinates

GCP	EASTING	NORTHING	PCP	EASTING	NORTHING
9000	545277.724	6892072.89	9000	545277.738	6892072.881
9001	545364.756	6892244.466	9001	545364.764	6892244.457
9002	545351.728	6892206.665	9002	545351.717	6892206.665
9003	545329.308	6892161.382	9003	545329.287	6892161.390
9004	545319.009	6892141.564	9004	545319.011	6892141.567
9005	545291.266	6892086.514	9005	545291.273	6892086.515
9006	545353.289	6892199.79	9006	545353.301	6892199.865
9007	545334.4	6892161.566	9007	545334.401	6892161.567
9008	545322.347	6892138.102	9008	545322.333	6892138.105
9009	545294.672	6892083.339	9009	545294.664	6892083.336

Table 17, GCPs vs Photogrammetric GCP Co-ordinates Horizontal Differences

POINT ID	Diff East	Absolute Diff	Diff North	Absolute Diff	Distance/RMSE
9000	0.014	0.014	-0.009	0.009	0.017
9001	0.008	0.008	-0.009	0.009	0.012
9002	-0.011	0.011	0.000	0.000	0.011
9003	-0.021	0.021	0.008	0.008	0.022
9004	0.002	0.002	0.003	0.003	0.004
9005	0.007	0.007	0.001	0.001	0.007
9006	0.012	0.012	0.075	0.075	0.076
9007	0.001	0.001	0.001	0.001	0.001
9008	-0.014	0.014	0.003	0.003	0.014
9009	-0.008	0.008	-0.003	0.003	0.009
Mean	**-0.001**	0.010	**0.007**	0.011	**0.017**
Median	0.002		0.001		0.012
Max	0.014		0.075		0.076
Min	-0.021		-0.009		0.001
St Dev	0.011		0.023		**0.020**
Variation	0.000		0.001		0.000

Table 18, GCPs vs Photogrammetric GCP Elevations

GCP ID	CONTROL ELEVATION	PCP ID	UAV ELEVATION
9000	5.655	9000	5.643
9001	5.324	9001	5.326
9002	5.913	9002	5.917
9003	5.905	9003	5.917
9004	6.11	9004	6.110
9005	6.302	9005	6.306
9006	1.668	9006	1.703
9007	2.891	9007	2.866
9008	3.504	9008	3.507
9009	4.533	9009	4.547

Table 19, GCPs vs Photogrammetric GCP Elevations Differences

POINT ID	Elevation Diff	Absolute Diff
9000	-0.012	0.012
9001	0.002	0.002
9002	0.004	0.004
9003	0.012	0.012

9004	0.000	0.000
9005	0.004	0.004
9006	0.035	0.035
9007	-0.025	0.025
9008	0.003	0.003
9009	0.014	0.014
	Mean	**0.004**
	Median	0.008
	Max	0.035
	Min	0.000
	St Dev	0.011
	Variation	0.000

95% Confidence for RMSExy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

Sample Size	Degrees of Freedom	t value for 95% Confidence	Standard Error
10	9	2.064	2.2135

T-value x SE = 4.5688

Small Tail End = 13mm

Large Tail End = 22mm

Therefor the **95% confident results lie between 13mm & 22mm**

95% Confidence for RMSEx

Sample Size	Degrees of Freedom	t value for 95% Confidence	Standard Error
10	9	2.064	2.9788

T-value x SE = 6.1483

Small Tail End = 4mm

Large Tail End = 16mm

Therefor the **95% confident results lie between 4mm & 16mm**

95% Confidence for RMSEy

Sample Size	Degrees of Freedom	t value for 95% Confidence	Standard Error
10	9	2.064	2.075

T-value x SE = 4.2836

Small Tail End = 7mm

Large Tail End = 15mm

Therefor the **95% confident results lie between 7mm & 15mm**

Figure 57, Day 2 Flight 2 GPS vs Photogrammetric GCP Check (xy)

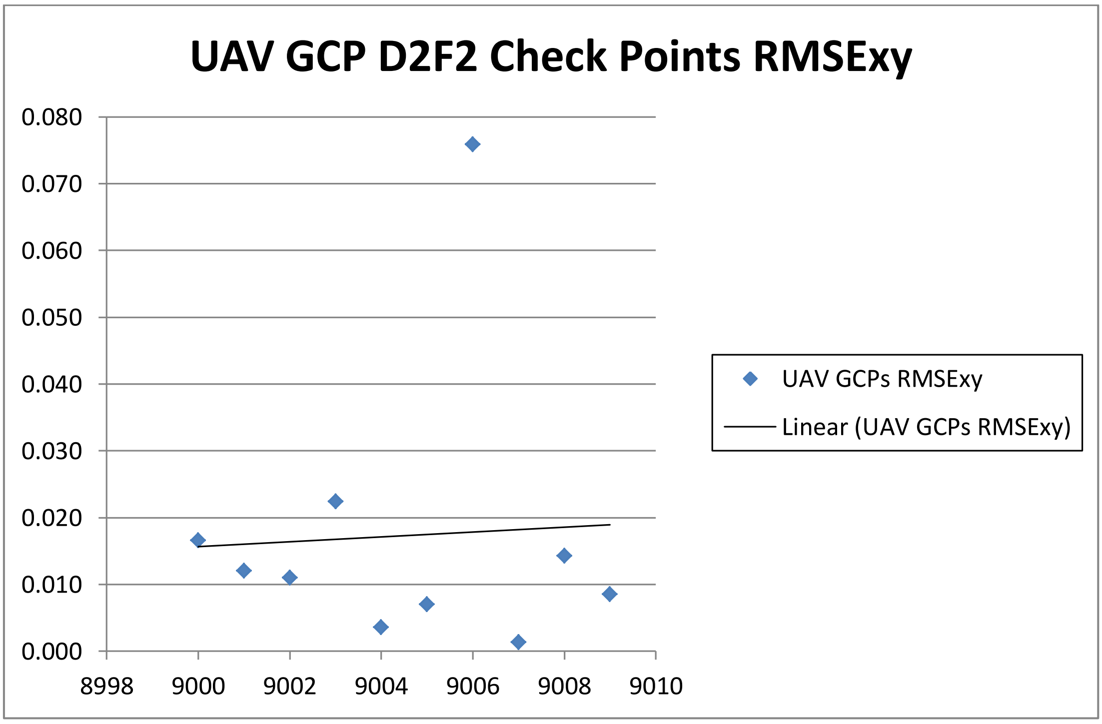


Figure 58, Day 2 Flight 2 GPS vs Photogrammetric GCP Check (x)

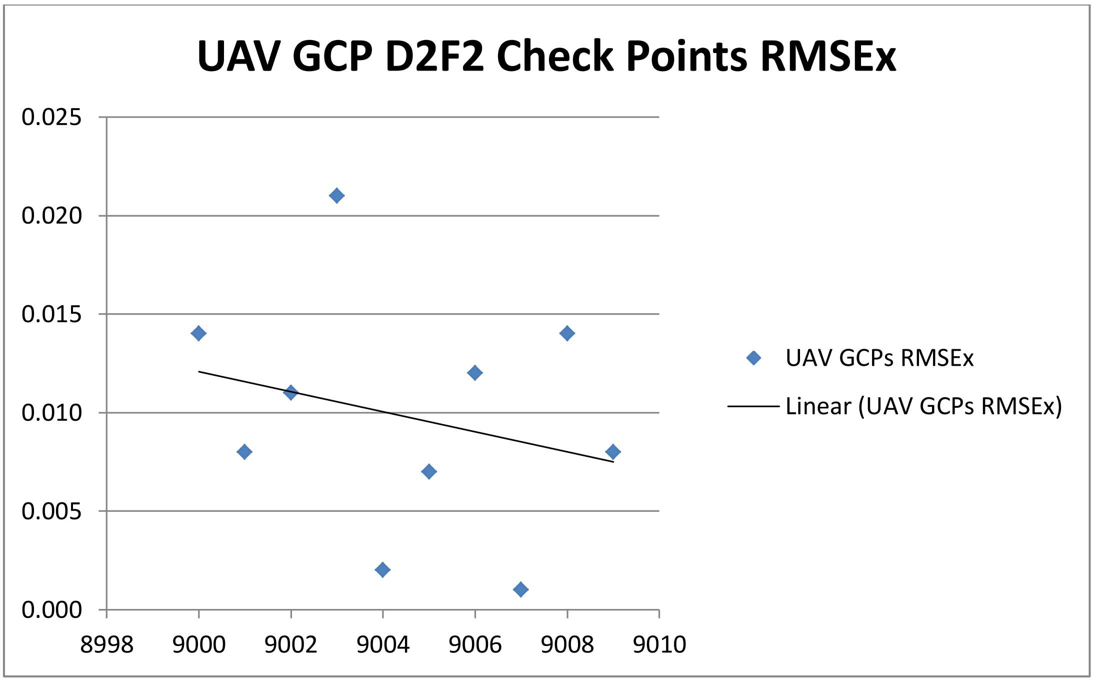


Figure 59, Day 2 Flight 2 GPS vs Photogrammetric GCP Check (y)

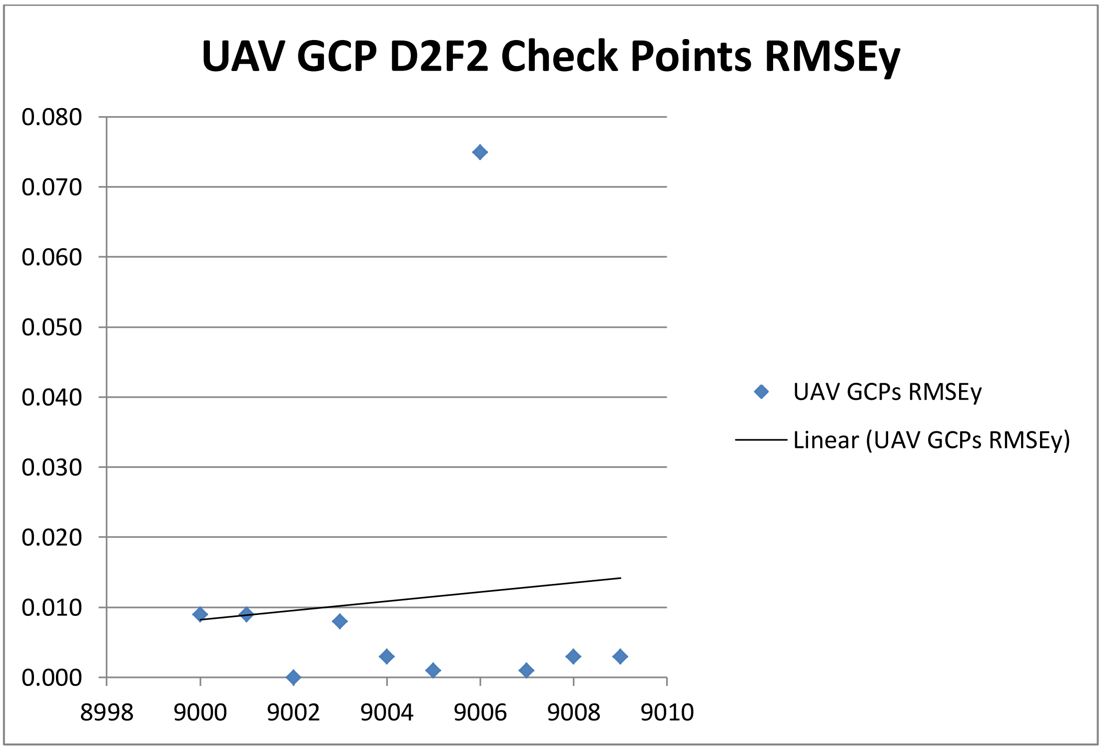
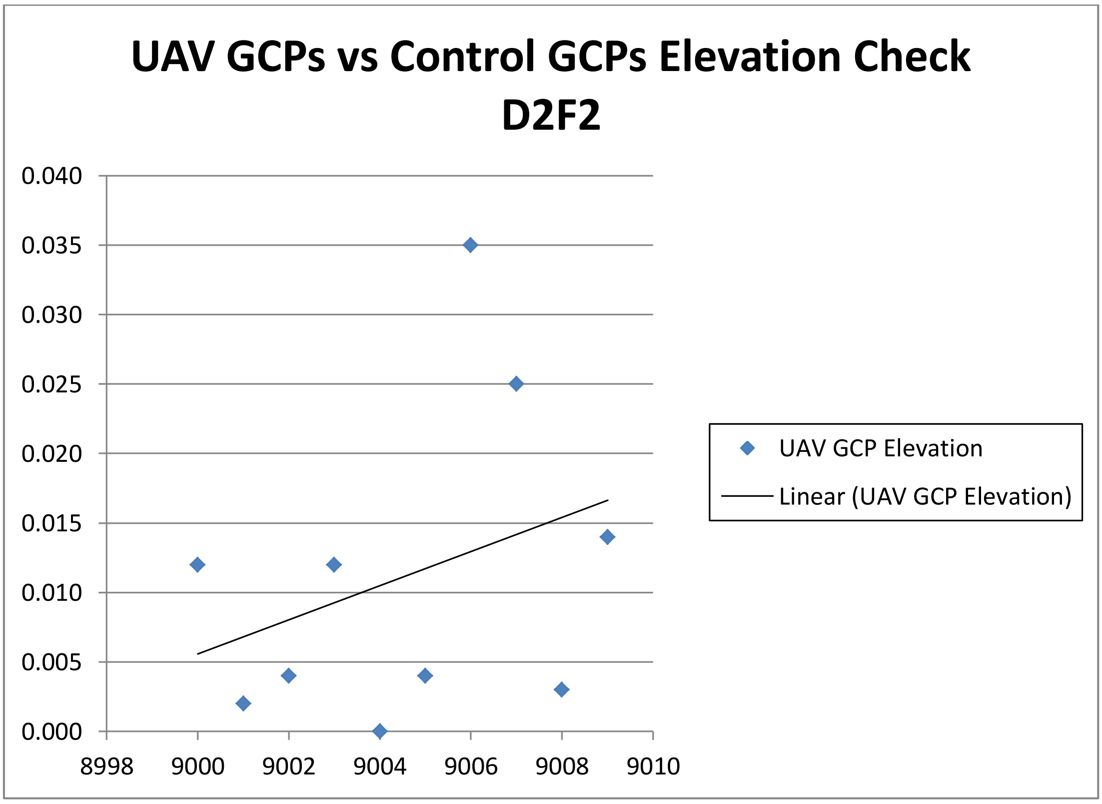


Figure 60, Day 2 Flight 2 GPS vs Photogrammetric GCP Check (elevation)



4.6.5 Day 3 Photogrammetric Flight 1 GCPs Horizontal and Vertical Results

Table 20, GCPs vs Photogrammetric GCP Co-ordinates

GCP	EASTING	NORTHING	PCP	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.720	6892072.902
9001	545364.732	6892244.45	9001	545364.734	6892244.448
9002	545351.693	6892206.652	9002	545351.697	6892206.637
9003	545329.27	6892161.367	9003	545329.270	6892161.363
9004	545318.995	6892141.538	9004	545318.988	6892141.550
9005	545291.273	6892086.516	9005	545291.265	6892086.515
9006	545353.251	6892199.74	9006	545353.258	6892199.763
9007	545334.383	6892161.543	9007	545334.388	6892161.531
9008	545322.325	6892138.074	9008	545322.330	6892138.075
9009	545294.66	6892083.334	9009	545294.680	6892083.345

Table 21, GCPs vs Photogrammetric GCP Co-ordinates Horizontal Differences

POINT ID	Diff East	Absolute Diff	Diff North	Absolute Diff	Distance/RMSE
9000	-0.005	0.005	0.013	0.013	0.014
9001	0.002	0.002	-0.002	0.002	0.003
9002	0.004	0.004	-0.015	0.015	0.016
9003	0.000	0.000	-0.004	0.004	0.004
9004	-0.007	0.007	0.012	0.012	0.014
9005	-0.008	0.008	-0.001	0.001	0.008
9006	0.007	0.007	0.023	0.023	0.024
9007	0.005	0.005	-0.012	0.012	0.013
9008	0.005	0.005	0.001	0.001	0.005
9009	0.020	0.020	0.011	0.011	0.023
Mean	**0.002**	0.006	**0.003**	0.009	**0.012**
Median	0.003		0.000		0.013
Max	0.020		0.023		0.024
Min	-0.008		-0.015		0.003
St Dev	0.008		0.011		**0.007**
Variation	0.000		0.000		0.000

Table 22, GCPs vs Photogrammetric GCP Elevations

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.681
9001	5.339	9001	5.353
9002	5.936	9002	5.948
9003	5.929	9003	5.949
9004	6.128	9004	6.140

9005	6.313	9005	6.326
9006	1.673	9006	1.703
9007	2.9	9007	2.925
9008	3.524	9008	3.553
9009	4.555	9009	4.591

Table 23, GCPs vs Photogrammetric GCP Elevations Differences

POINT ID	Elevation Diff	Absolute Diff
9000	0.024	0.024
9001	0.014	0.014
9002	0.012	0.012
9003	0.020	0.020
9004	0.012	0.012
9005	0.013	0.013
9006	0.030	0.030
9007	0.025	0.025
9008	0.029	0.029
9009	0.036	0.036
	Mean	**0.021**
	Median	0.022
	Max	0.036
	Min	0.012
	St Dev	0.008
	Variation	0.000

95% Confidence for RMSExy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 3.7736

T-value x SE = 7.7887

Small Tail End = 5mm

Large Tail End = 20mm

Therefor the **95% confident results lie between 5mm & 20mm**

95% Confidence for RMSEx

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 3.5686

T-value x SE = 7.4034

Small Tail End = -1mm

Large Tail End = 14mm

Therefor the **95% confident results lie between -1mm & 14mm**

<u>95% Confidence for RMSEy</u>

Sample Size	Degrees of Freedom	t value for 95% Confidence	Standard Error
10	9	2.064	2.9693

T-value x SE = 6.1286

Small Tail End = 3mm

Large Tail End = 16mm

Therefor the **95% confident results lie between 3mm & 16mm**

<u>Figure 61, Day 3 Flight 1 GPS vs Photogrammetric GCP Check (xy)</u>

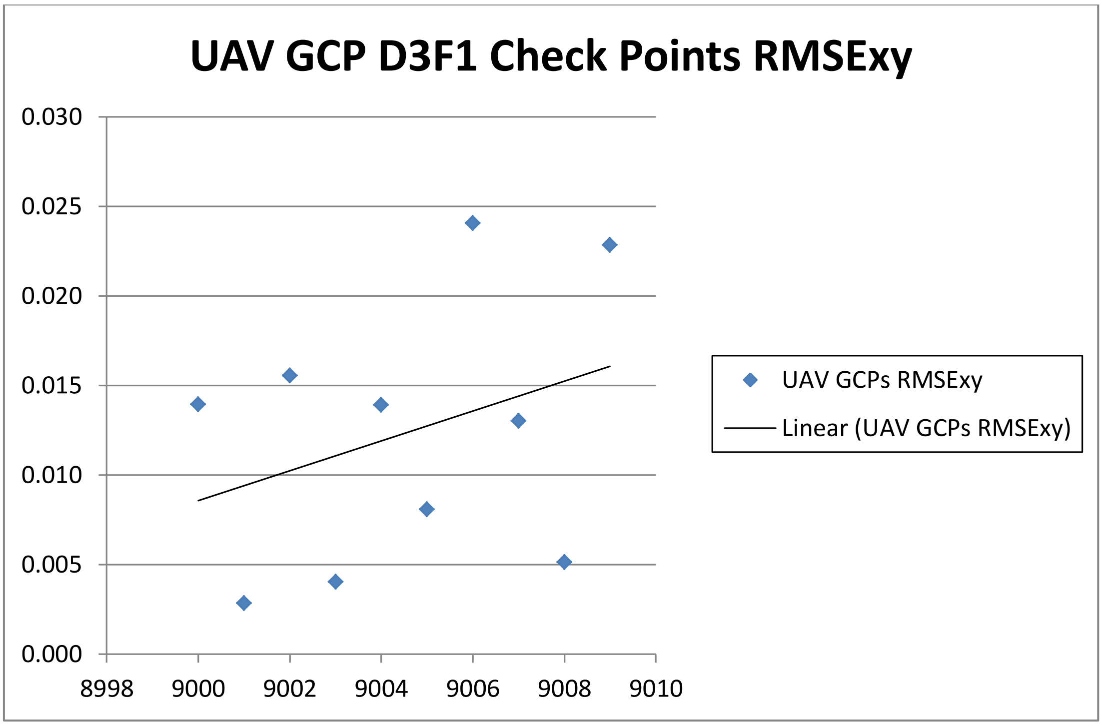


Figure 62, Day 3 Flight 1 GPS vs Photogrammetric GCP Check (x)

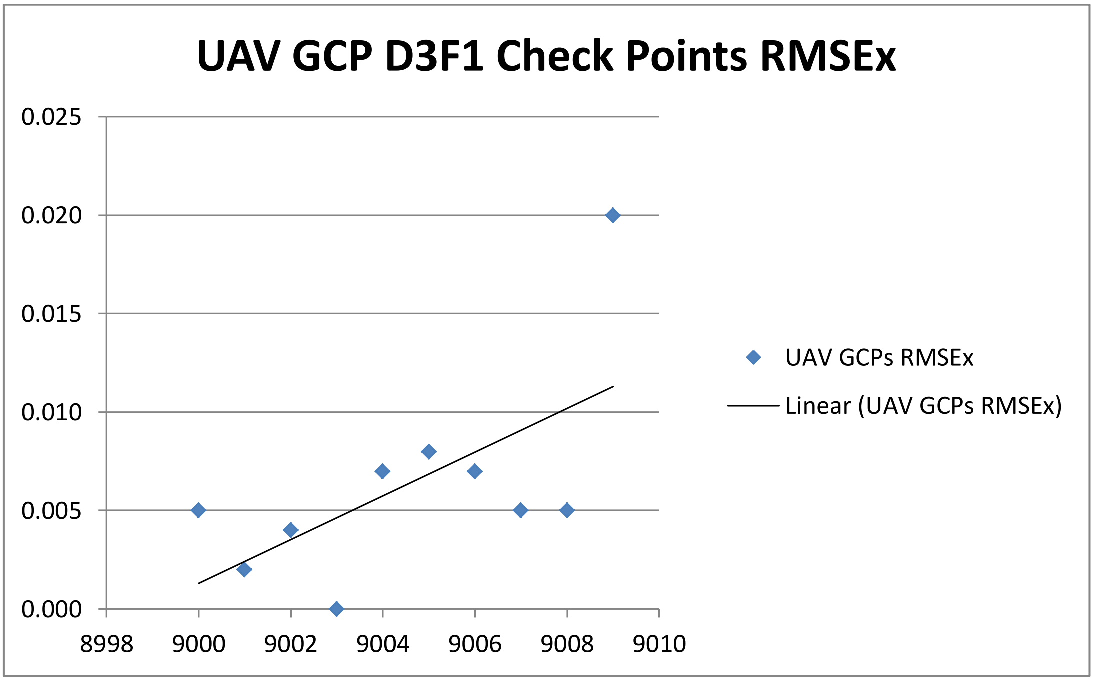


Figure 63, Day 3 Flight 1 GPS vs Photogrammetric GCP Check (y)

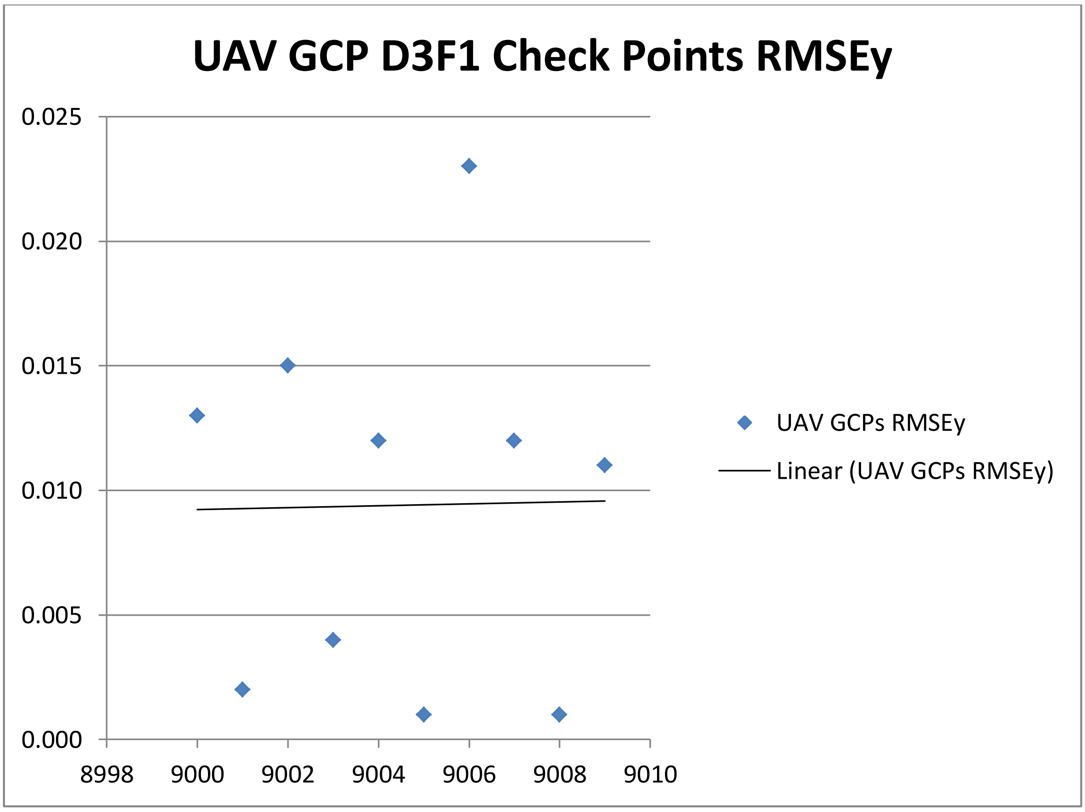
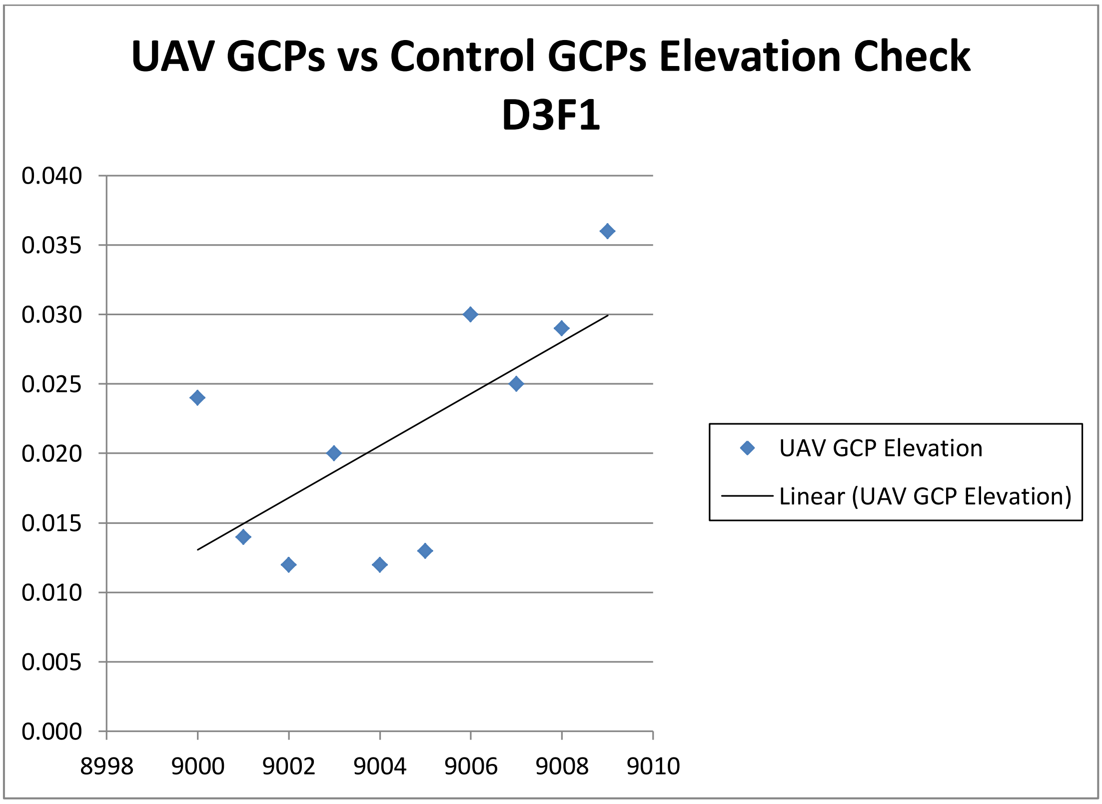


Figure 64, Day 3 Flight 1 GPS vs Photogrammetric GCP Check (elevation)



4.6.6 Day 3 Photogrammetric Flight 2 GCPs Horizontal and Vertical Results

Table 24, GCPs vs Photogrammetric GCP Co-ordinates

GCP	EASTING	NORTHING	PCP	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.735	6892072.885
9001	545364.732	6892244.45	9001	545364.731	6892244.445
9002	545351.693	6892206.652	9002	545351.684	6892206.653
9003	545329.27	6892161.367	9003	545329.269	6892161.362
9004	545318.995	6892141.538	9004	545318.987	6892141.549
9005	545291.273	6892086.516	9005	545291.263	6892086.511
9006	545353.251	6892199.74	9006	545353.254	6892199.774
9007	545334.383	6892161.543	9007	545334.389	6892161.538
9008	545322.325	6892138.074	9008	545322.318	6892138.085
9009	545294.66	6892083.334	9009	545294.662	6892083.333

Table 25, GCPs vs Photogrammetric GCP Co-ordinates Horizontal Differences

POINT ID	Diff East	Absolute Diff	Diff North	Absolute Diff	Distance/RMSE
9000	0.010	0.010	-0.004	0.004	0.011
9001	-0.001	0.001	-0.005	0.005	0.005
9002	-0.009	0.009	0.001	0.001	0.009
9003	-0.001	0.001	-0.005	0.005	0.005
9004	-0.008	0.008	0.011	0.011	0.014
9005	-0.010	0.010	-0.005	0.005	0.011
9006	0.003	0.003	0.034	0.034	0.034
9007	0.006	0.006	-0.005	0.005	0.008
9008	-0.007	0.007	0.011	0.011	0.013
9009	0.002	0.002	-0.001	0.001	0.002
Mean	**-0.002**	0.006	**0.003**	0.008	**0.011**
Median	-0.001		-0.003		0.010
Max	0.010		0.034		0.034
Min	-0.010		-0.005		0.002
St Dev	0.006		0.012		**0.008**
Variation	0.000		0.000		0.000

Table 26, GCPs vs Photogrammetric GCP Elevations

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.651
9001	5.339	9001	5.338
9002	5.936	9002	5.941
9003	5.929	9003	5.929
9004	6.128	9004	6.144
9005	6.313	9005	6.315
9006	1.673	9006	1.686
9007	2.9	9007	2.906
9008	3.524	9008	3.547
9009	4.555	9009	4.570

Table 27, GCPs vs Photogrammetric GCP Elevations Differences

POINT ID	Elevation Diff	Absolute Diff
9000	-0.006	0.006
9001	-0.001	0.001
9002	0.005	0.005
9003	0.000	0.000
9004	0.016	0.016

9005	0.002	0.002
9006	0.013	0.013
9007	0.006	0.006
9008	0.023	0.023
9009	0.015	0.015
	Mean	**0.007**
	Median	0.006
	Max	0.023
	Min	0.000
	St Dev	0.007
	Variation	0.000

95% Confidence for RMSExy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 3.4497

T-value x SE = 7.1202

Small Tail End = 4mm

Large Tail End = 18mm

Therefor the **95% confident results lie between 4mm & 18mm**

95% Confidence for RMSEx

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 3.9223

T-value x SE = 8.0956

Small Tail End = -2mm

Large Tail End = 14mm

Therefor the **95% confident results lie between -2mm & 14mm**

95% Confidence for RMSEy

Sample Size Degrees of Freedom t value for 95% Confidence Standard Error

10 9 2.064 2.9001

T-value x SE = 5.9858

Small Tail End = 2mm

Large Tail End = 14mm

Therefor the **95% confident results lie between 2mm & 14mm**

Figure 65, Day 3 Flight 2 GPS vs Photogrammetric GCP Check (xy)

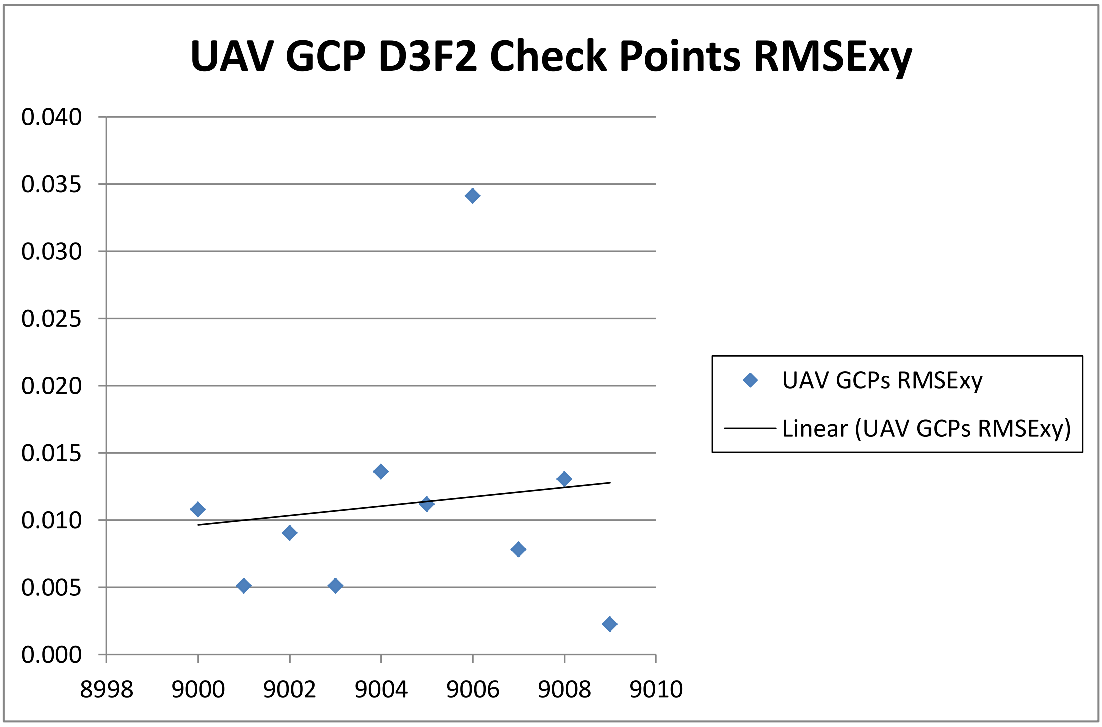


Figure 66, Day 3 Flight 2 GPS vs Photogrammetric GCP Check (x)

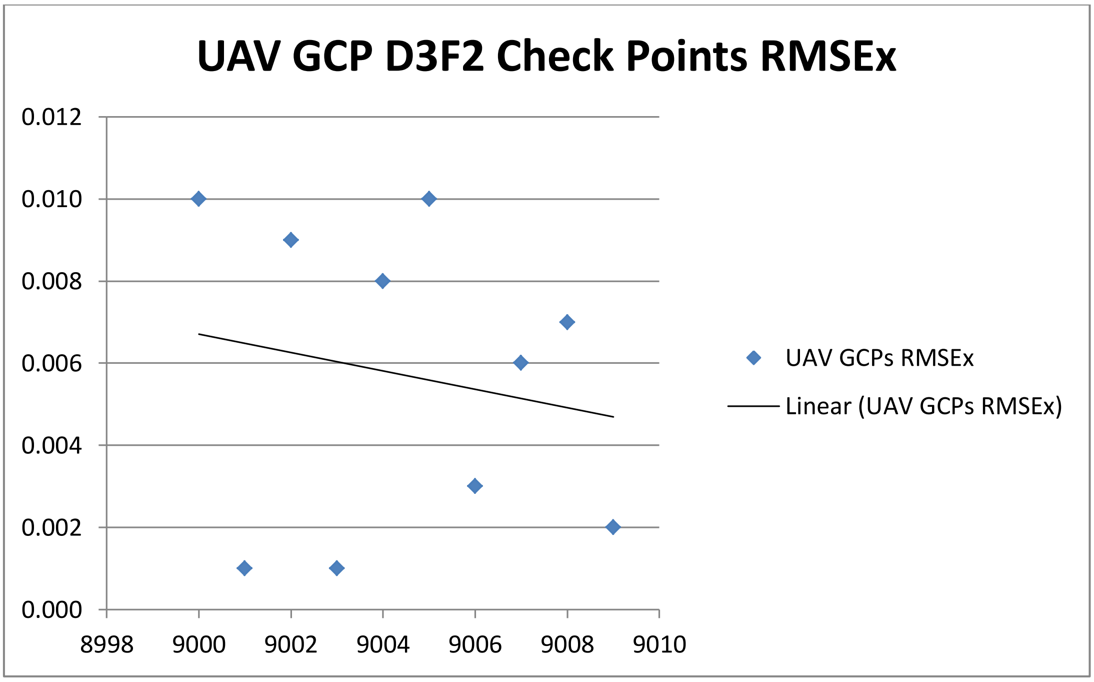


Figure 67, Day 3 Flight 2 GPS vs Photogrammetric GCP Check (y)

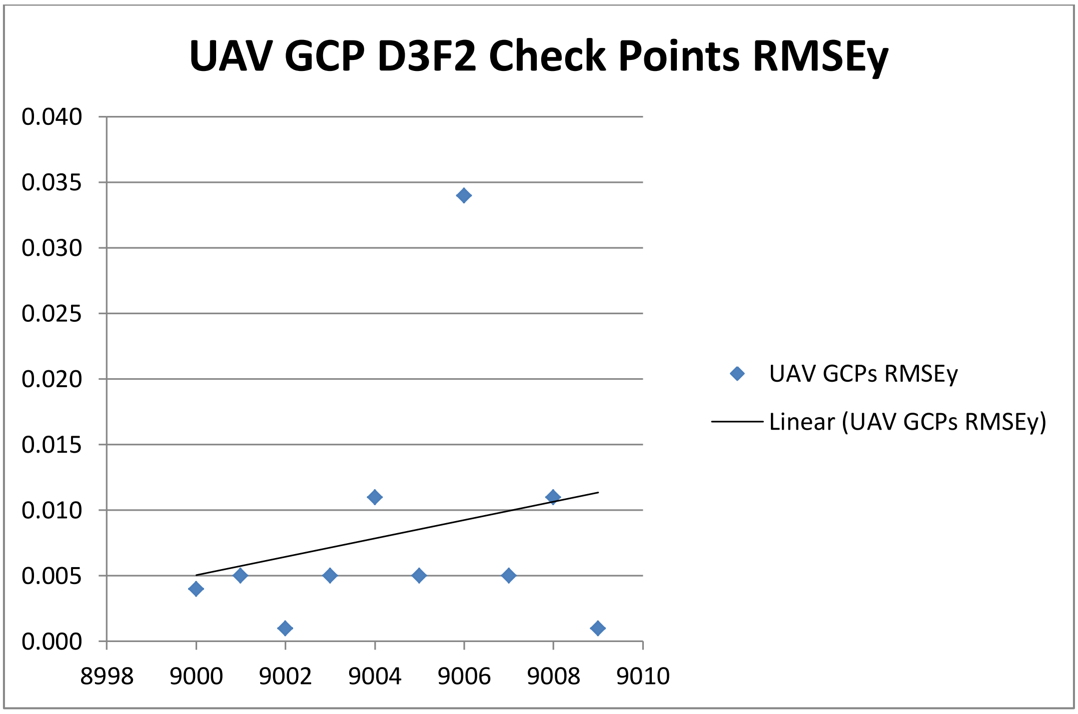
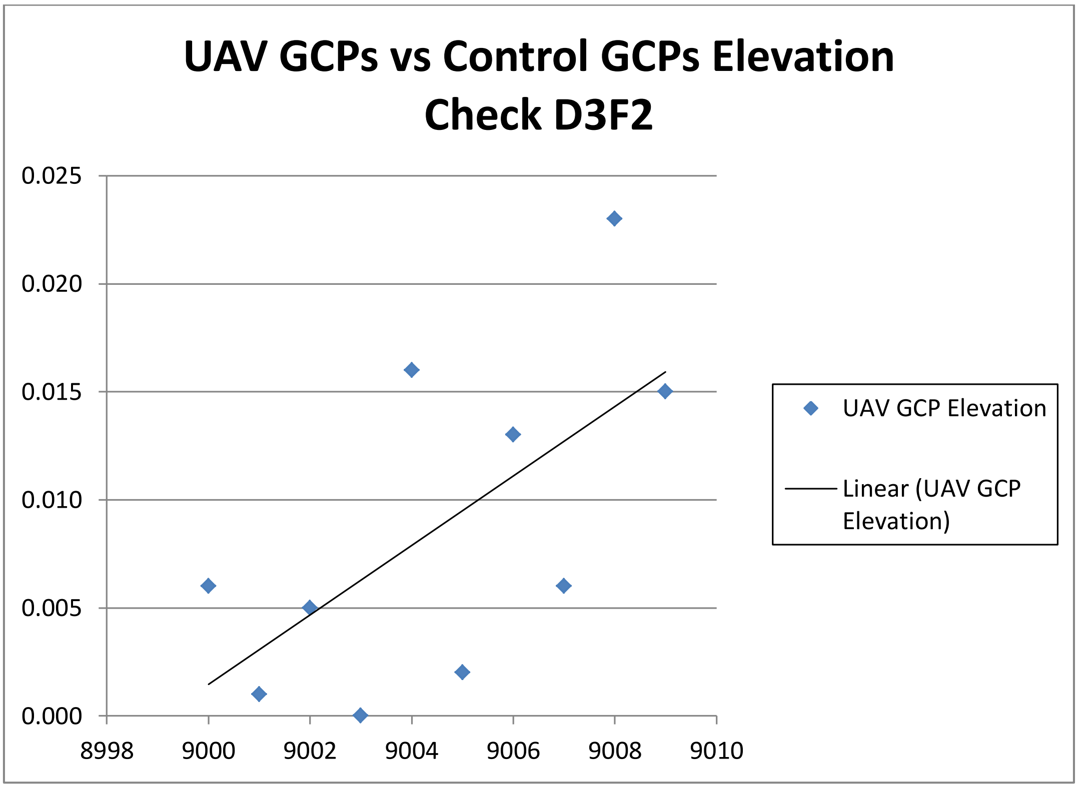


Figure 68, Day 3 Flight 2 GPS vs Photogrammetric GCP Check (elevation)



4.7 Pix4D 3D Point Cloud &Photogrammetric Survey Accuracies

4.7.1 Day 1 Flight 1 3D Point Cloud Model Accuracies

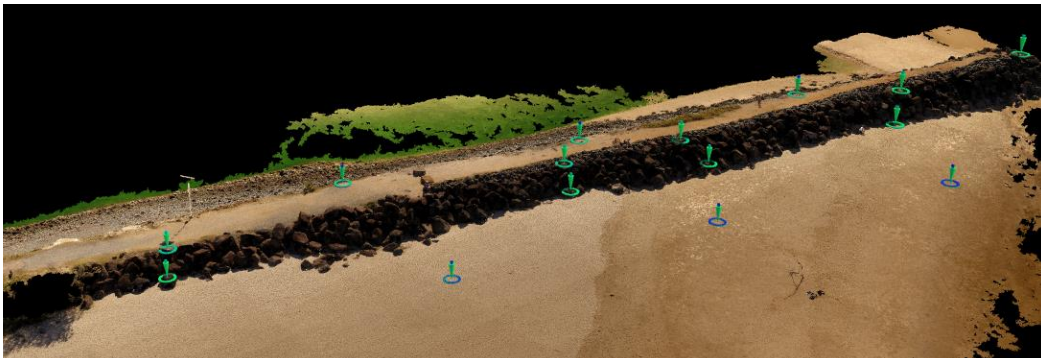
Figure 69, Pix4D RMSE & Pixel Size Results

Project	F1D1 F _ Final
Processed	2017-10-09 16:29:23
Camera Model Name(s)	FC330_3.6_4000x2250 (RGB)
Average Ground Sampling Distance (GSD)	1.88 cm / 0.74 in

Quality Check

Images	median of 27576 keypoints per image
Dataset	118 out of 118 images calibrated (100%), all images enabled
Camera Optimization	0.48% relative difference between initial and optimized internal camera parameters
Matching	median of 17597.6 matches per calibrated image
Georeferencing	yes, 15 GCPs (15 3D), mean RMS error = 0.016 m

Figure 70, Pix4D Day 1 Flight 1 Point Cloud



4.7.2 Day 1 Flight 2 3D Point Cloud Model Accuracies

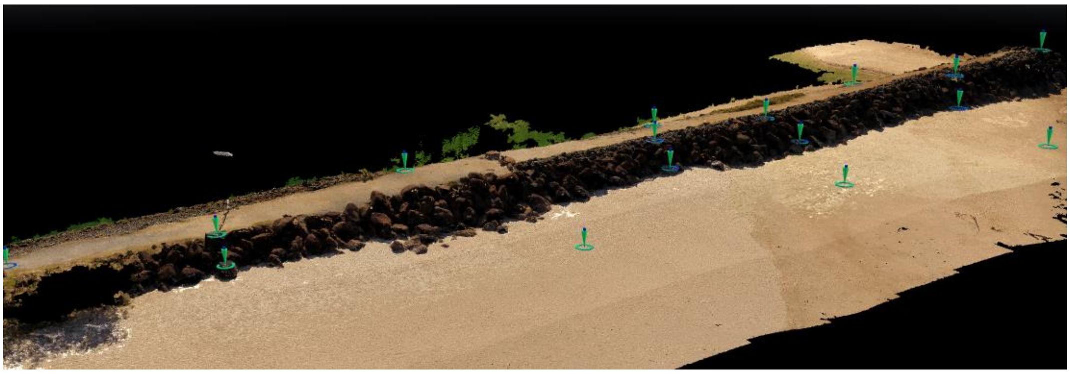
Figure 71, Pix4D RMSE & Pixel Size Results

Project	D1F2_Final
Processed	2017-10-09 16:31:00
Camera Model Name(s)	FC330_3.6_4000x2250 (RGB)
Average Ground Sampling Distance (GSD)	1.85 cm / 0.72 in

Quality Check

Images	median of 26256 keypoints per image
Dataset	82 out of 82 images calibrated (100%), all images enabled
Camera Optimization	1.18% relative difference between initial and optimized internal camera parameters
Matching	median of 13860.9 matches per calibrated image
Georeferencing	yes, 16 GCPs (16 3D), mean RMS error = 0.015 m

Figure 72, Pix4D Day 1 Flight 2 Point Cloud



4.7.3 Day 2 Flight 1 3D Point Cloud Model Accuracies

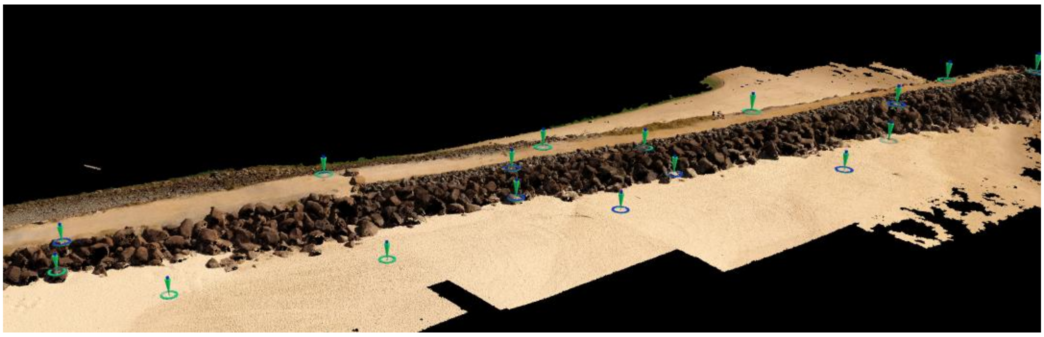
Figure 73, Pix4D RMSE & Pixel Size Results

Project	D2F1_Final
Processed	2017-10-09 16:32:42
Camera Model Name(s)	FC330_3.6_4000x2250 (RGB)
Average Ground Sampling Distance (GSD)	1.9 cm / 0.75 in

Quality Check

Images	median of 32581 keypoints per image
Dataset	37 out of 37 images calibrated (100%), all images enabled
Camera Optimization	0.75% relative difference between initial and optimized internal camera parameters
Matching	median of 13615.8 matches per calibrated image
Georeferencing	yes, 18 GCPs (18 3D), mean RMS error = 0.018 m

Figure 74, Pix4D Day 2 Flight 1 Point Cloud



4.7.4 Day 2 Flight 2 3D Point Cloud Model Accuracies

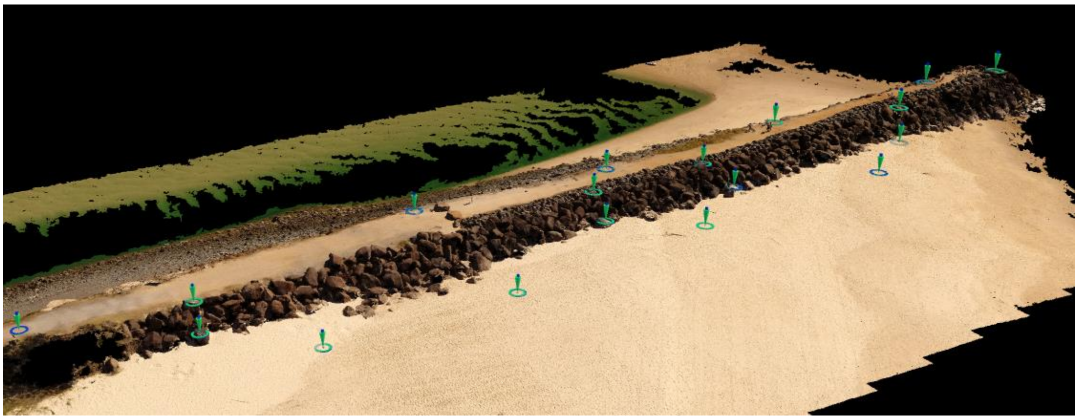
Figure 75, Pix4D RMSE & Pixel Size Results

Project	D2F2_Final
Processed	2017-10-09 16:33:55
Camera Model Name(s)	FC330_3.6_4000x2250 (RGB)
Average Ground Sampling Distance (GSD)	1.84 cm / 0.72 in

Quality Check

Images	median of 29081 keypoints per image
Dataset	66 out of 66 images calibrated (100%), all images enabled
Camera Optimization	1.53% relative difference between initial and optimized internal camera parameters
Matching	median of 15663.4 matches per calibrated image
Georeferencing	yes, 18 GCPs (18 3D), mean RMS error = 0.014 m

Figure 76, Pix4D Day 2 Flight 2 Point Cloud



4.7.5 Day 3 Flight 1 3D Point Cloud Model Accuracies

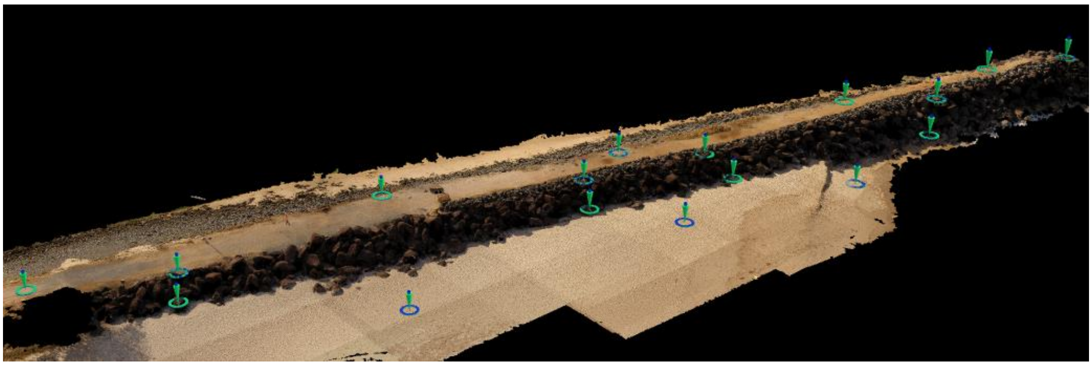
Figure 77, Pix4D RMSE & Pixel Size Results

Project	D3F1_Final
Processed	2017-10-09 16:34:57
Camera Model Name(s)	FC330_3.6_4000x2250 (RGB)
Average Ground Sampling Distance (GSD)	1.81 cm / 0.71 in

Quality Check

Images	median of 31904 keypoints per image
Dataset	36 out of 36 images calibrated (100%), all images enabled
Camera Optimization	1.27% relative difference between initial and optimized internal camera parameters
Matching	median of 16537.3 matches per calibrated image
Georeferencing	yes, 17 GCPs (17 3D), mean RMS error = 0.01 m

Figure 78, Pix4D Day 3 Flight 1 Point Cloud



4.7.6 Day 3 Flight 2 3D Point Cloud Model Accuracies

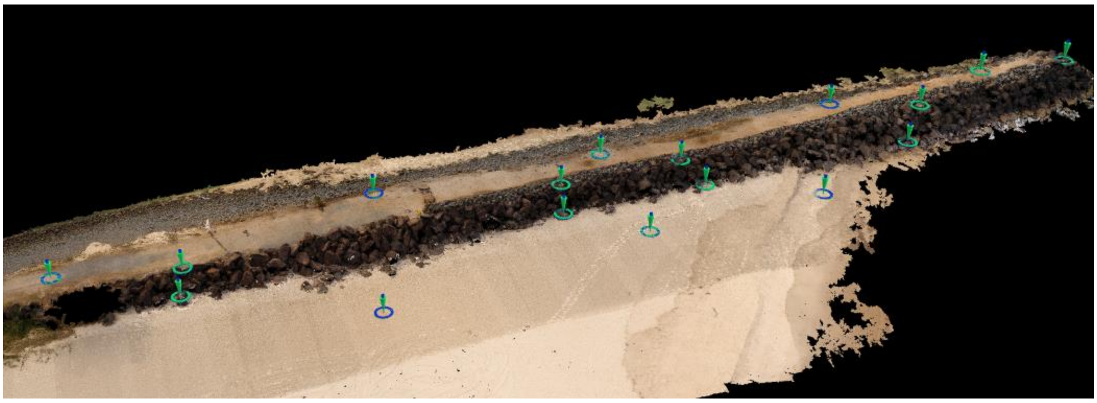
Figure 79, Pix4D RMSE & Pixel Size Results

Project	D3F2_Final 3
Processed	2017-10-09 16:36:13
Camera Model Name(s)	FC330_3.6_4000x2250 (RGB)
Average Ground Sampling Distance (GSD)	1.8 cm / 0.71 in

Quality Check

Images	median of 32498 keypoints per image
Dataset	66 out of 66 images calibrated (100%), all images enabled
Camera Optimization	1.74% relative difference between initial and optimized internal camera parameters
Matching	median of 10825.4 matches per calibrated image
Georeferencing	yes, 17 GCPs (17 3D), mean RMS error = 0.01 m

Figure 80, Pix4D Day 3 Flight 2 Point Cloud



4.8 Movement from Base Control to GPS GCP Data

Table 28, Sea Wall Base Control Points

Sea Wall TS Base Control Points				
Pt Number	**Easting**	**Northing**	**Elevation**	**Code**
9000	545277.725	6892072.889	5.657	SIC (9000)
9001	545364.746	6892244.477	5.349	SIR
9002	545351.713	6892206.669	5.921	SIR
9003	545329.262	6892161.387	5.903	SIR
9004	545319.004	6892141.566	6.11	SIR
9005	545291.263	6892086.512	6.297	SIR
9006	545353.277	6892199.788	1.67	SIR
9007	545334.395	6892161.563	2.891	SIR
9008	545322.337	6892138.11	3.521	SIR
9009	545294.648	6892083.351	4.551	SIR

Table 29, Sea Wall Day 2 GPS Control Points

Sea Wall Day 2 GPS Control Points				
Pt Number	**Easting**	**Northing**	**Elevation**	**Code**
1000	545277.724	6892072.89	5.655	SIC (9000)
20357	545364.756	6892244.466	5.324	SIR (9001)
20355	545351.728	6892206.665	5.913	SIR (9002)
20353	545329.308	6892161.382	5.905	SIR (9003)
20351	545319.009	6892141.564	6.11	SIR (9004)
20349	545291.266	6892086.514	6.302	SIR (9005)
20358	545353.289	6892199.79	1.668	SIR (9006)
20360	545334.4	6892161.566	2.891	SIR (9007)
20362	545322.347	6892138.102	3.504	SIR (9008)
20365	545294.672	6892083.339	4.533	SIR (9009)

Table 30, Sea Wall Day 3 GPS Control Points

Sea Wall Day 3 GPS Control Points				
Pt Number	**Easting**	**Northing**	**Elevation**	**Code**
5017	545277.725	6892072.889	5.657	SIC (9000)
5008	545364.732	6892244.45	5.339	SIR (9001)
5006	545351.693	6892206.652	5.936	SIR (9002)
5003	545329.27	6892161.367	5.929	SIR (9003)
5001	545318.995	6892141.538	6.128	SIR (9004)
5016	545291.273	6892086.516	6.313	SIR (9005)
5018	545353.251	6892199.74	1.673	SIR (9006)

5011	545334.383	6892161.543	2.9	SIR (9007)
5013	545322.325	6892138.074	3.524	SIR (9008)
5015	545294.66	6892083.334	4.555	SIR (9009)

4.8.1 Day 2 GPS GCPs to Base Line Movement

Table 31, Movement of Base Control to GPS Control Points Day 2

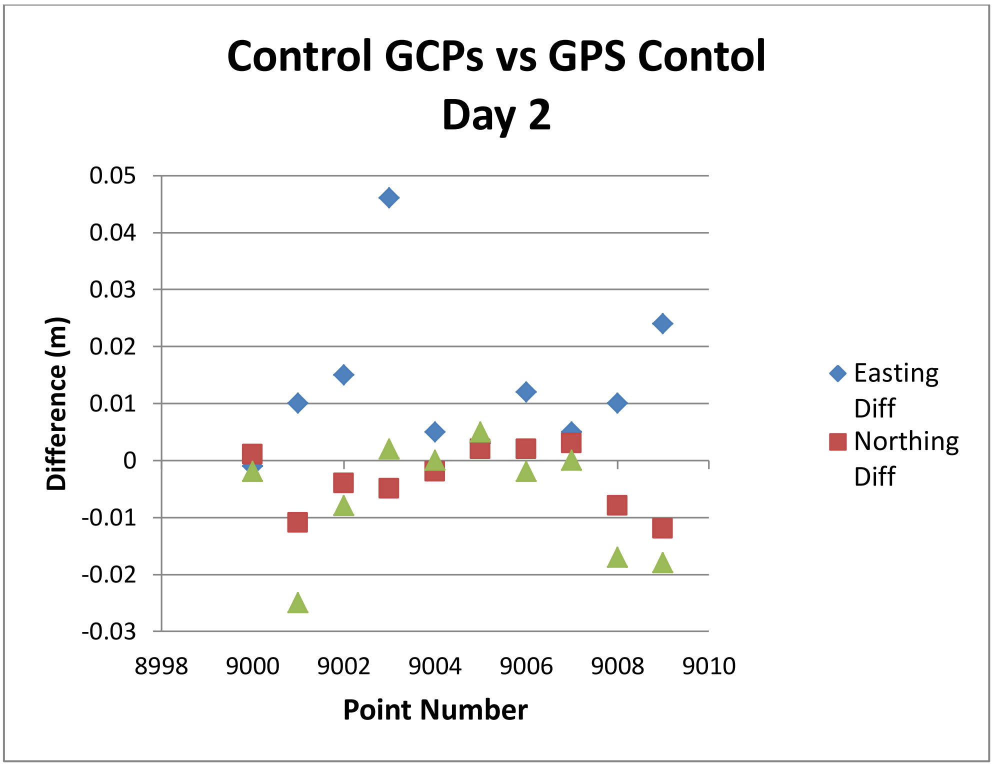
Hz Difference between Base Points and GPS Points Day 2			
Base Pt No	**Day 2 Points**	**Hz Difference (mm)**	
9000	9000	**1.414**	
9001	9001	**14.866**	
9002	9002	**15.524**	
9003	9003	**46.271**	
9004	9004	**5.385**	
9005	9005	**3.606**	
9006	9006	**12.166**	
9007	9007	**5.831**	
9008	9008	**12.806**	
9009	9009	**26.833**	
		Mean	**14.470**
		Median	12.486
		Max	46.271
		Min	1.414
		St Dev	12.725
		Variation	161.914

Table 32, Elevation movement between Base Control Points and GPS GCPs

GCP	CONTROL ELEVATION	PCP	UAV ELEVATIO N	POINT ID	Diff Elevatio n	Absolute Diff
9000	5.657	9000	5.655	9000	-0.002	0.002
9001	5.349	9001	5.324	9001	-0.025	0.025
9002	5.921	9002	5.913	9002	-0.008	0.008
9003	5.903	9003	5.905	9003	0.002	0.002
9004	6.11	9004	6.11	9004	0.000	0.000
9005	6.297	9005	6.302	9005	0.005	0.005
9006	1.67	9006	1.668	9006	-0.002	0.002
9007	2.891	9007	2.891	9007	0.000	0.000
9008	3.521	9008	3.504	9008	-0.017	0.017
9009	4.551	9009	4.533	9009	-0.018	0.018
				Mean	**-0.006**	**0.008**

Median	-0.002	0.004
Max	0.005	0.025
Min	-0.025	0.000
St Dev	0.010	0.008
Variation	0.000	0.000

Figure 81, Movement of Base Control to GPS Control Points Day 2



4.8.2 Day 3 GPS GCPs to Base Line Movement

Table 33, Movement of Base Control to GPS Control Points Day 3

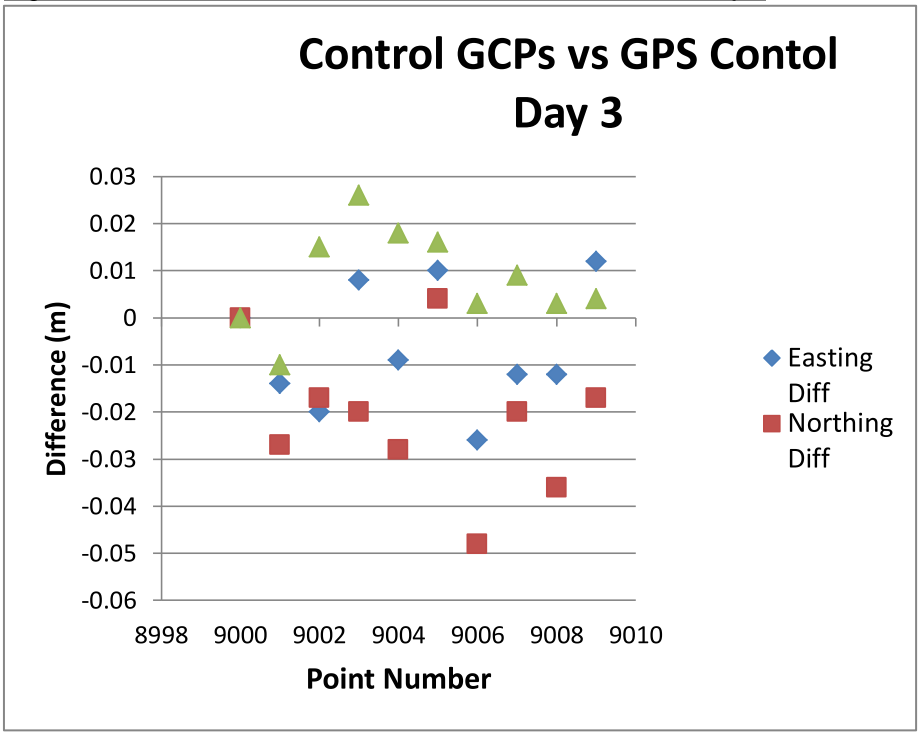
Hz Difference between Base Points and GPS Points Day 3		
Base Pt No	**Day 2 Points**	**Hz Difference (mm)**
9000	9000	**0.000**
9001	9001	**30.414**
9002	9002	**26.249**
9003	9003	**21.541**
9004	9004	**29.411**
9005	9005	**10.770**
9006	9006	**54.589**
9007	9007	**23.324**
9008	9008	**37.947**
9009	9009	**20.809**

	Mean	**25.505**
	Median	24.786
	Max	54.589
	Min	0.000
	St Dev	13.967
	Variation	195.076

<u>Table 34, Elevation movement between Base Control Points and GPS GCPs</u>

GCP	CONTROL ELEVATION	PCP	UAV ELEVATIO N	POINT ID	Diff Elevatio n	Absolute Diff
9000	5.657	9000	5.657	9000	0.000	0.000
9001	5.349	9001	5.339	9001	-0.010	0.010
9002	5.921	9002	5.936	9002	0.015	0.015
9003	5.903	9003	5.929	9003	0.026	0.026
9004	6.11	9004	6.128	9004	0.018	0.018
9005	6.297	9005	6.313	9005	0.016	0.016
9006	1.67	9006	1.673	9006	0.003	0.003
9007	2.891	9007	2.9	9007	0.009	0.009
9008	3.521	9008	3.524	9008	0.003	0.003
9009	4.551	9009	4.555	9009	0.004	0.004
				Mean	**0.008**	**0.010**
				Median	0.007	0.010
				Max	0.026	0.026
				Min	-0.010	0.000
				St Dev	0.010	0.008
				Variation	0.000	0.000

Figure 82, Movement of Base Control to GPS Control Points Day 3



4.8.3 Overall GPS GCPs to Base Line Movement

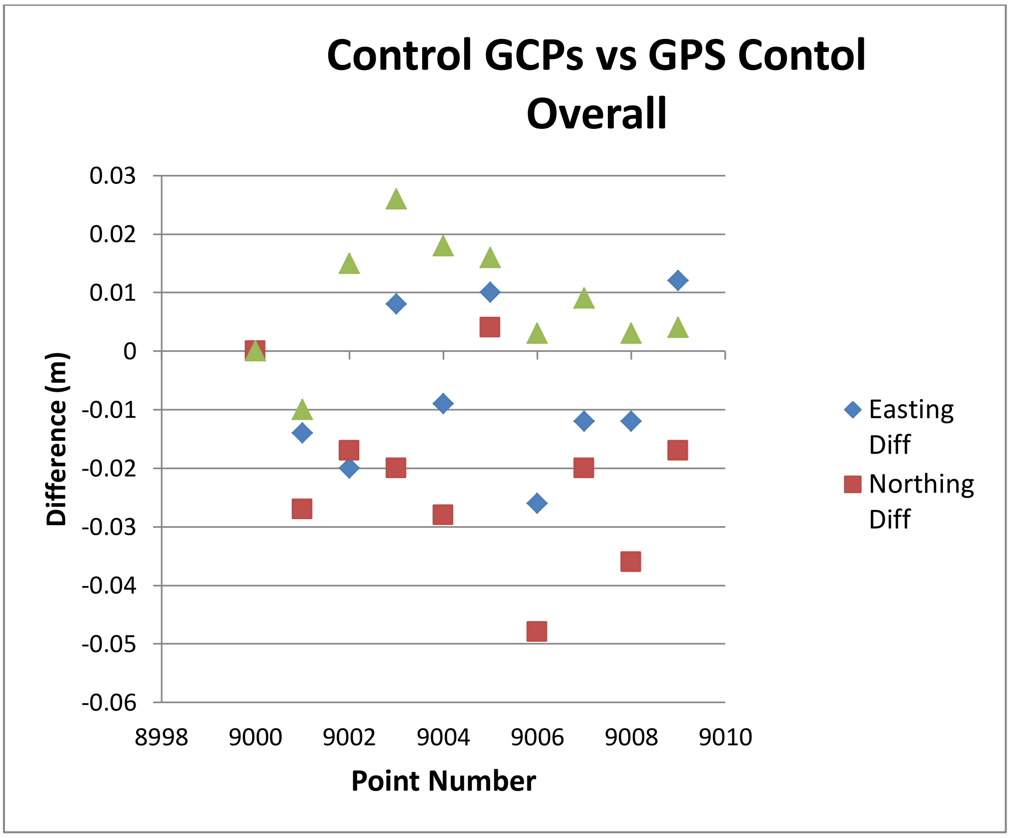
Table 35, Movement of Base Control to GPS Control Points Overall

Hz Difference between Base Points and Overall GPS Points		
Base Pt No	**Overall Points**	**Hz Difference (mm)**
9000	1000	**1.414**
9001	20357	**14.866**
9002	20355	**15.524**
9003	20353	**46.271**
9004	20351	**5.385**
9005	20349	**3.606**
9006	20358	**12.166**
9007	20360	**5.831**
9008	20362	**12.806**
9009	20365	**26.833**
9000	5017	**0.000**
9001	5008	**30.414**
9002	5006	**26.249**
9003	5003	**21.541**
9004	5001	**29.411**
9005	5016	**10.770**
9006	5018	**54.589**
9007	5011	**23.324**

9008	5013	**37.947**
9009	5015	**20.809**

Mean	**19.988**
Median	18.166
Max	54.589
Min	0.000
St Dev	14.455
Variation	208.939

Figure 83, Movement of Base Control to GPS Control Points Overall



4.9 Horizontal and Vertical Movement - GCPs vs UAV GCPs

4.9.1 Day 1 Flight 1 Photo GCP to Base Line Movement

Table 36, Hz Base Control GCPs vs Photogrammetry GCPs

GCP ID	EASTING	NORTHING	PCP ID	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.720	6892072.875
9001	545364.746	6892244.477	9001	545364.738	6892244.465
9002	545351.713	6892206.669	9002	545351.711	6892206.669
9003	545329.262	6892161.387	9003	545329.275	6892161.385

9004	545319.004	6892141.566	9004	545318.994	6892141.561
9005	545291.263	6892086.512	9005	545291.262	6892086.520
9006	545353.277	6892199.788	9006	545353.268	6892199.802
9007	545334.395	6892161.563	9007	545334.401	6892161.559
9008	545322.337	6892138.11	9008	545322.325	6892138.101
9009	545294.648	6892083.351	9009	545294.665	6892083.343

Table 37, Calculated Hz movement between Control GCPs and UAV GCPs

Hz Difference Base Points and UAV GCPs D1F1			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**14.866**	
9001	9001	**14.422**	
9002	9002	**2.000**	
9003	9003	**13.153**	
9004	9004	**11.180**	
9005	9005	**8.062**	
9006	9006	**16.643**	
9007	9007	**7.211**	
9008	9008	**15.000**	
9009	9009	**18.788**	
		Mean	**12.133**
		Median	13.788
		Max	18.788
		Min	2.000
		St Dev	4.806
		Variation	23.099

Table 38, Vertical Base Control GCPs vs Photogrammetry GCPs

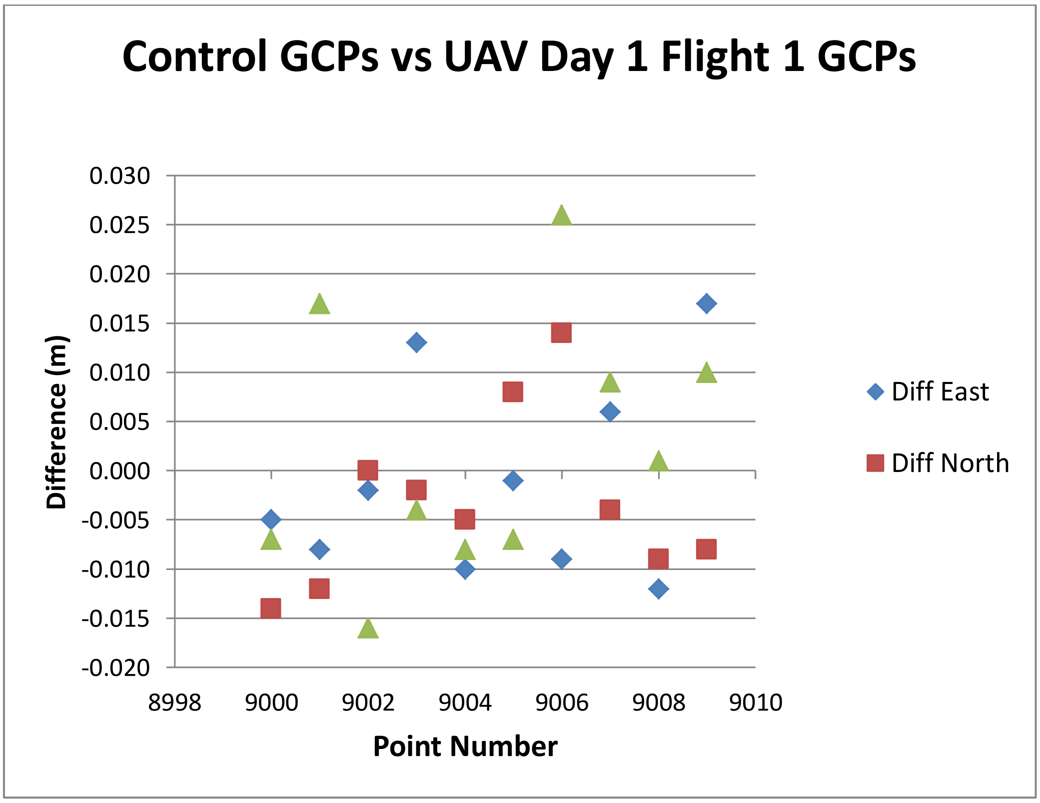
GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.650
9001	5.349	9001	5.366
9002	5.921	9002	5.905
9003	5.903	9003	5.899
9004	6.11	9004	6.102
9005	6.297	9005	6.290
9006	1.67	9006	1.696
9007	2.891	9007	2.900
9008	3.521	9008	3.522

9009	4.551	9009	4.561

Table 39, Calculated Vert movement between Control GCPs and UAV GCPs

Control GCPS vs D1F1 UAV GCPs			
GCP ID	Diff East	Diff North	Elevation Diff
9000	-0.005	-0.014	-0.007
9001	-0.008	-0.012	0.017
9002	-0.002	0.000	-0.016
9003	0.013	-0.002	-0.004
9004	-0.010	-0.005	-0.008
9005	-0.001	0.008	-0.007
9006	-0.009	0.014	0.026
9007	0.006	-0.004	0.009
9008	-0.012	-0.009	0.001
9009	0.017	-0.008	0.010

Figure 84, Overall Movement from Base GCP to UAV GCP Day 1 Flight 1



4.9.2 Day 1 Flight 2 Photo GCP to Base Line Movement

Table 40, Base Control GCPs vs Photogrammetry GCPs

GCP ID	EASTING	NORTHING	PCP ID	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.723	6892072.889
9001	545364.746	6892244.477	9001	545364.748	6892244.478
9002	545351.713	6892206.669	9002	545351.713	6892206.672
9003	545329.262	6892161.387	9003	545329.280	6892161.387
9004	545319.004	6892141.566	9004	545318.998	6892141.558
9005	545291.263	6892086.512	9005	545291.260	6892086.513
9006	545353.277	6892199.788	9006	545353.274	6892199.805
9007	545334.395	6892161.563	9007	545334.400	6892161.560
9008	545322.337	6892138.11	9008	545322.322	6892138.100
9009	545294.648	6892083.351	9009	545294.657	6892083.332

Table 41 , calculated movement between Control GCPs and UAV GCPs

Difference Base Points and UAV GCPs D1F2			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**2.000**	
9001	9001	**2.236**	
9002	9002	**3.000**	
9003	9003	**18.000**	
9004	9004	**10.000**	
9005	9005	**3.162**	
9006	9006	**17.263**	
9007	9007	**5.831**	
9008	9008	**18.028**	
9009	9009	**21.024**	
		Mean	**10.054**
		Median	7.915
		Max	21.024
		Min	2.000
		St Dev	7.349
		Variation	54.010

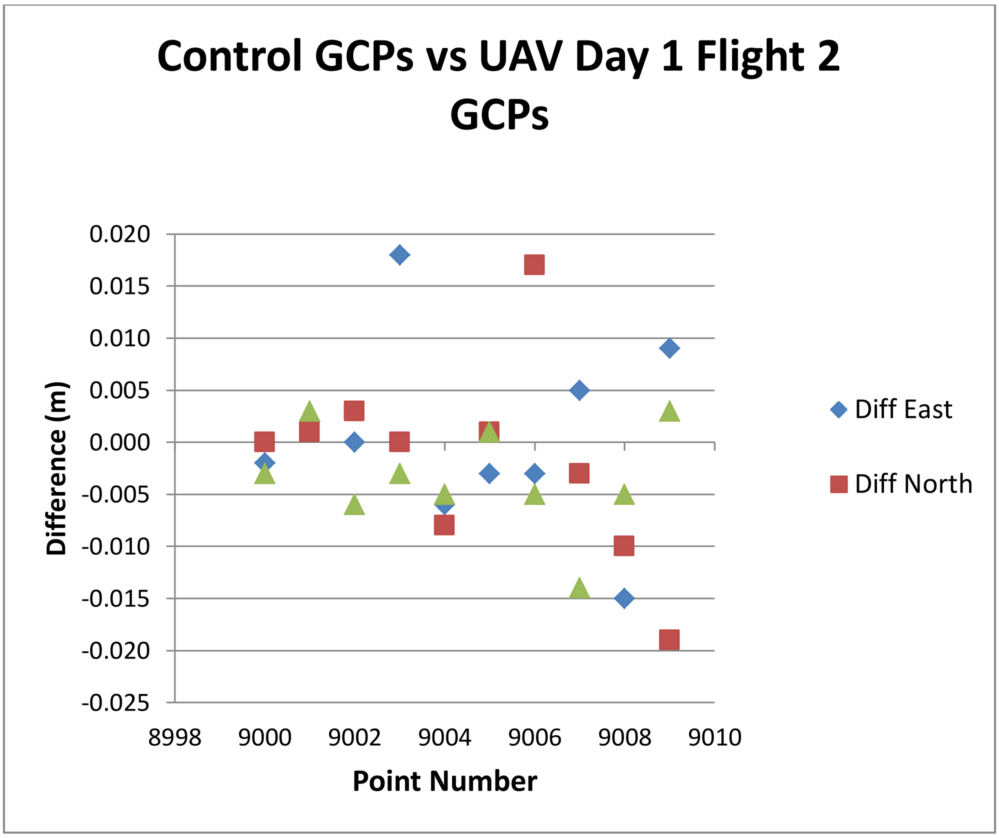
Table 42, Vertical Base Control GCPs vs Photogrammetry GCPs

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.654
9001	5.349	9001	5.352
9002	5.921	9002	5.915
9003	5.903	9003	5.900
9004	6.11	9004	6.105
9005	6.297	9005	6.298
9006	1.67	9006	1.665
9007	2.891	9007	2.877
9008	3.521	9008	3.516
9009	4.551	9009	4.554

Table 43, Calculated Vert movement between Control GCPs and UAV GCPs

Control GCPS vs D1F2 UAV GCPs			
GCP ID	Diff East	Diff North	Elevation Diff
9000	-0.002	0.000	-0.003
9001	0.002	0.001	0.003
9002	0.000	0.003	-0.006
9003	0.018	0.000	-0.003
9004	-0.006	-0.008	-0.005
9005	-0.003	0.001	0.001
9006	-0.003	0.017	-0.005
9007	0.005	-0.003	-0.014
9008	-0.015	-0.010	-0.005
9009	0.009	-0.019	0.003

Figure 85, Overall Movement from Base GCP to UAV GCP Day 1 Flight 2



4.9.3 Day 2 Flight 1 Photo GCP to Base Line Movement

Table 44, Hz Base Control GCPs vs Photogrammetry GCPs

GCP ID	EASTING	NORTHING	PCP ID	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.716	6892072.909
9001	545364.746	6892244.477	9001	545364.762	6892244.463
9002	545351.713	6892206.669	9002	545351.723	6892206.661
9003	545329.262	6892161.387	9003	545329.294	6892161.383
9004	545319.004	6892141.566	9004	545319.013	6892141.565
9005	545291.263	6892086.512	9005	545291.271	6892086.515
9006	545353.277	6892199.788	9006	545353.298	6892199.883
9007	545334.395	6892161.563	9007	545334.392	6892161.566
9008	545322.337	6892138.11	9008	545322.343	6892138.101
9009	545294.648	6892083.351	9009	545294.673	6892083.332

Table 45, Calculated Hz movement between Control GCPs and UAV GCPs

Difference Base Points and UAV GCPs D2F1			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**21.932**	
9001	9001	**21.260**	
9002	9002	**12.806**	
9003	9003	**32.249**	
9004	9004	**9.055**	
9005	9005	**8.544**	
9006	9006	**97.293**	
9007	9007	**4.243**	
9008	9008	**10.817**	
9009	9009	**31.401**	
		Mean	**24.960**
		Median	17.033
		Max	97.293
		Min	4.243
		St Dev	25.786
		Variation	664.899

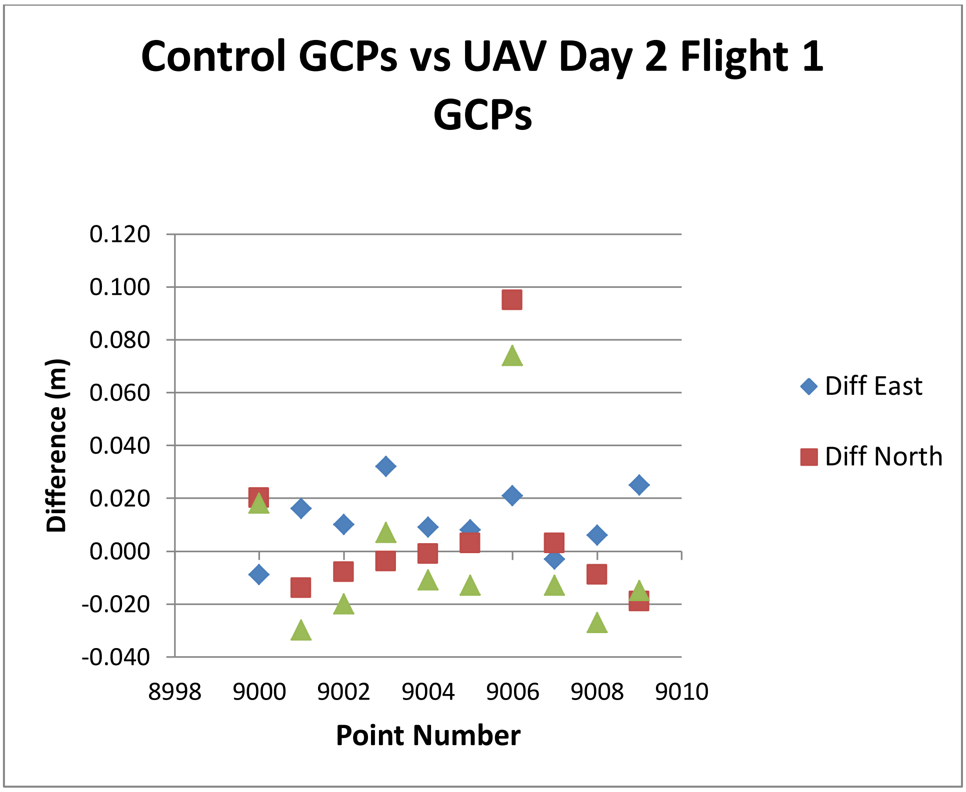
Table 46, Vertical Base Control GCPs vs Photogrammetry GCPs

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.675
9001	5.349	9001	5.319
9002	5.921	9002	5.901
9003	5.903	9003	5.910
9004	6.11	9004	6.099
9005	6.297	9005	6.284
9006	1.67	9006	1.744
9007	2.891	9007	2.878
9008	3.521	9008	3.494
9009	4.551	9009	4.536

Table 47, Calculated Vert movement between Control GCPs and UAV GCPs

Control GCPS vs D2F1 UAV GCPs			
GCP ID	Diff East	Diff North	Elevation Diff
9000	-0.009	0.020	0.018
9001	0.016	-0.014	-0.030
9002	0.010	-0.008	-0.020
9003	0.032	-0.004	0.007
9004	0.009	-0.001	-0.011
9005	0.008	0.003	-0.013
9006	0.021	0.095	0.074
9007	-0.003	0.003	-0.013
9008	0.006	-0.009	-0.027
9009	0.025	-0.019	-0.015

Figure 86, Overall Movement from Base GCP to UAV GCP Day 2 Flight 1



4.9.4 Day 2 Flight 2 Photo GCP to Base Line Movement

Table 48, Hz Base Control GCPs vs Photogrammetry GCPs

GCP ID	EASTING	NORTHING	PCP ID	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.738	6892072.881
9001	545364.746	6892244.477	9001	545364.764	6892244.457
9002	545351.713	6892206.669	9002	545351.717	6892206.665
9003	545329.262	6892161.387	9003	545329.287	6892161.390
9004	545319.004	6892141.566	9004	545319.011	6892141.567
9005	545291.263	6892086.512	9005	545291.273	6892086.515
9006	545353.277	6892199.788	9006	545353.301	6892199.865
9007	545334.395	6892161.563	9007	545334.401	6892161.567
9008	545322.337	6892138.11	9008	545322.333	6892138.105
9009	545294.648	6892083.351	9009	545294.664	6892083.336

Table 49, Calculated Hz movement between Control GCPs and UAV GCPs

Difference Base Points and UAV GCPs D2F2			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**15.264**	
9001	9001	**26.907**	
9002	9002	**5.657**	
9003	9003	**25.179**	
9004	9004	**7.071**	
9005	9005	**10.440**	
9006	9006	**80.654**	
9007	9007	**7.211**	
9008	9008	**6.403**	
9009	9009	**21.932**	
		Mean	**20.672**
		Median	12.852
		Max	80.654
		Min	5.657
		St Dev	21.419
		Variation	458.774

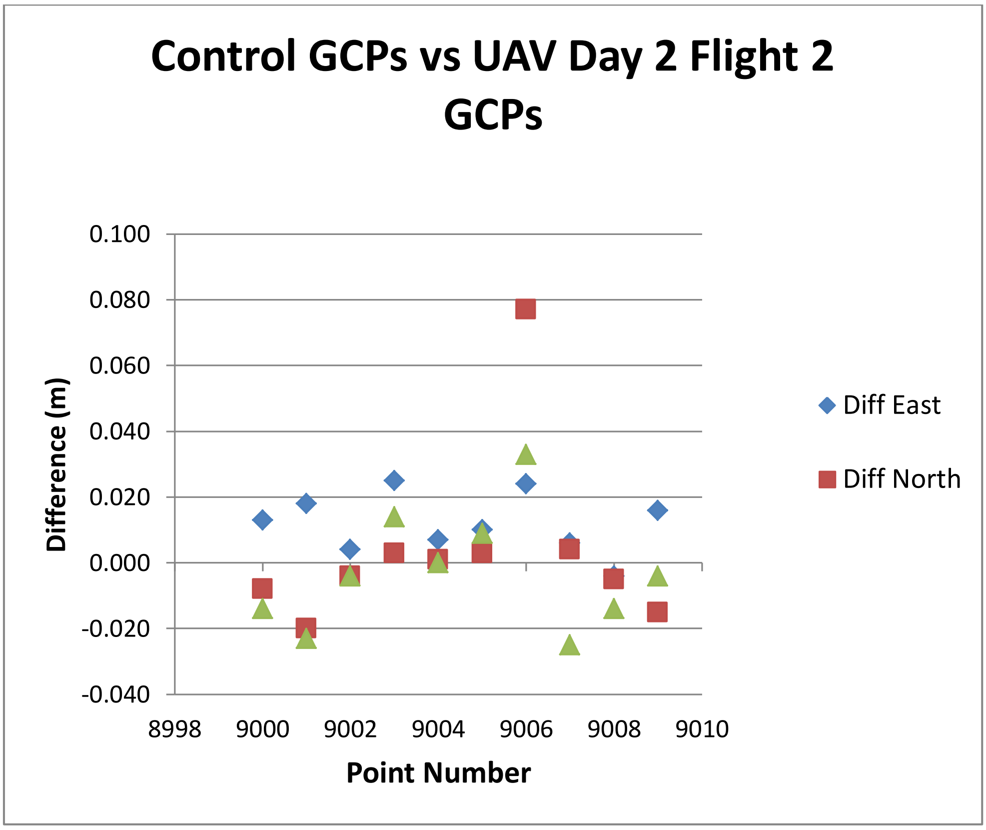
Table 50, Vertical Base Control GCPs vs Photogrammetry GCPs

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.643
9001	5.349	9001	5.326
9002	5.921	9002	5.917
9003	5.903	9003	5.917
9004	6.11	9004	6.110
9005	6.297	9005	6.306
9006	1.67	9006	1.703
9007	2.891	9007	2.866
9008	3.521	9008	3.507
9009	4.551	9009	4.547

Table 51, Calculated Vert movement between Control GCPs and UAV GCPs

Control GCPS vs D2F2 UAV GCPs			
GCP ID	Diff East	Diff North	Elevation Diff
9000	0.013	-0.008	-0.014
9001	0.018	-0.020	-0.023
9002	0.004	-0.004	-0.004
9003	0.025	0.003	0.014
9004	0.007	0.001	0.000
9005	0.010	0.003	0.009
9006	0.024	0.077	0.033
9007	0.006	0.004	-0.025
9008	-0.004	-0.005	-0.014
9009	0.016	-0.015	-0.004

Figure 87, Overall Movement from Base GCP to UAV GCP Day 2 Flight 2



4.9.5 Day 3 Flight 1 Photo GCP to Base Line Movement

Table 52, Hz Base Control GCPs vs Photogrammetry GCPs

GCP ID	EASTING	NORTHING	PCP ID	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.720	6892072.902
9001	545364.746	6892244.477	9001	545364.734	6892244.448
9002	545351.713	6892206.669	9002	545351.697	6892206.637
9003	545329.262	6892161.387	9003	545329.270	6892161.363
9004	545319.004	6892141.566	9004	545318.988	6892141.550
9005	545291.263	6892086.512	9005	545291.265	6892086.515
9006	545353.277	6892199.788	9006	545353.258	6892199.763
9007	545334.395	6892161.563	9007	545334.388	6892161.531
9008	545322.337	6892138.11	9008	545322.330	6892138.075
9009	545294.648	6892083.351	9009	545294.680	6892083.345

Table 53, Calculated Hz movement between Control GCPs and UAV GCPs

Hz Difference Base Points and UAV GCPs D3F1			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**13.928**	
9001	9001	**31.385**	
9002	9002	**35.777**	
9003	9003	**25.298**	
9004	9004	**22.627**	
9005	9005	**3.606**	
9006	9006	**31.401**	
9007	9007	**32.757**	
9008	9008	**35.693**	
9009	9009	**32.558**	
		Mean	**26.503**
		Median	31.393
		Max	35.777
		Min	3.606
		St Dev	9.965
		Variation	99.294

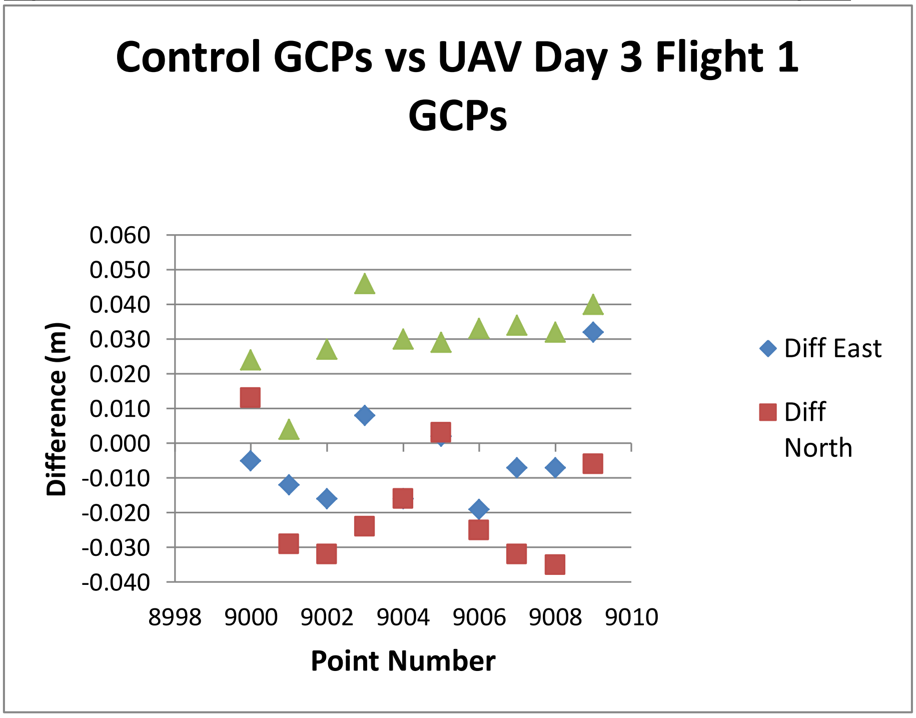
Table 54, Vertical Base Control GCPs vs Photogrammetry GCPs

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.681
9001	5.349	9001	5.353
9002	5.921	9002	5.948
9003	5.903	9003	5.949
9004	6.11	9004	6.140
9005	6.297	9005	6.326
9006	1.67	9006	1.703
9007	2.891	9007	2.925
9008	3.521	9008	3.553
9009	4.551	9009	4.591

Table 55, Calculated Vert movement between Control GCPs and UAV GCPs

Control GCPS vs D3F1 UAV GCPs			
GCP ID	Diff East	Diff North	Elevation Diff
9000	-0.005	0.013	0.024
9001	-0.012	-0.029	0.004
9002	-0.016	-0.032	0.027
9003	0.008	-0.024	0.046
9004	-0.016	-0.016	0.030
9005	0.002	0.003	0.029
9006	-0.019	-0.025	0.033
9007	-0.007	-0.032	0.034
9008	-0.007	-0.035	0.032
9009	0.032	-0.006	0.040

Figure 87, Overall Movement from Base GCP to UAV GCP Day 3 Flight 1



4.9.6 Day 3 Flight 2 Photo GCP to Base Line Movement

Table 56, Hz Base Control GCPs vs Photogrammetry GCPs

GCP ID	EASTING	NORTHING	PCP ID	EASTING	NORTHING
9000	545277.725	6892072.889	9000	545277.735	6892072.885
9001	545364.746	6892244.477	9001	545364.731	6892244.445
9002	545351.713	6892206.669	9002	545351.684	6892206.653
9003	545329.262	6892161.387	9003	545329.269	6892161.362
9004	545319.004	6892141.566	9004	545318.987	6892141.549
9005	545291.263	6892086.512	9005	545291.263	6892086.511
9006	545353.277	6892199.788	9006	545353.254	6892199.774
9007	545334.395	6892161.563	9007	545334.389	6892161.538
9008	545322.337	6892138.11	9008	545322.318	6892138.085
9009	545294.648	6892083.351	9009	545294.662	6892083.333

Table 57, Calculated Hz movement between Control GCPs and UAV GCPs

Difference Base Points and UAV GCPs D3F2			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**10.770**	
9001	9001	**35.341**	
9002	9002	**33.121**	
9003	9003	**25.962**	
9004	9004	**24.042**	
9005	9005	**1.000**	
9006	9006	**26.926**	
9007	9007	**25.710**	
9008	9008	**31.401**	
9009	9009	**22.804**	
		Mean	**23.708**
		Median	25.836
		Max	35.341
		Min	1.000
		St Dev	9.932
		Variation	98.652

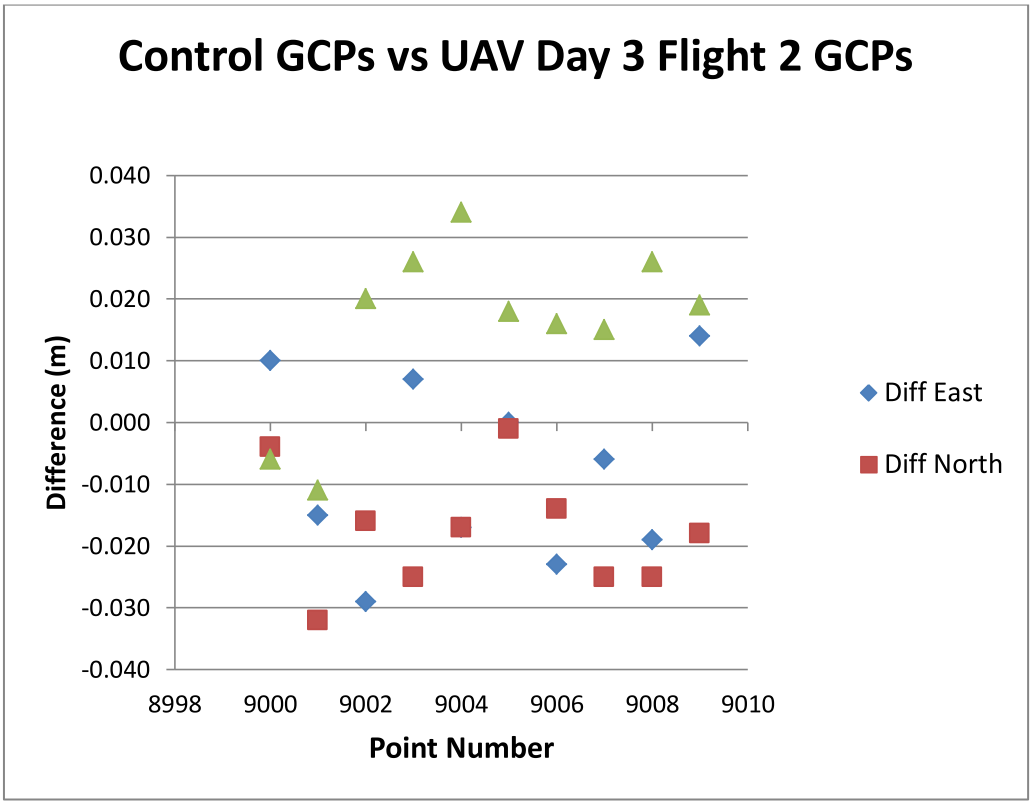
Table 58, Vertical Base Control GCPs vs Photogrammetry GCPs

GCP	CONTROL ELEVATION	PCP	UAV ELEVATION
9000	5.657	9000	5.651
9001	5.349	9001	5.338
9002	5.921	9002	5.941
9003	5.903	9003	5.929
9004	6.11	9004	6.144
9005	6.297	9005	6.315
9006	1.67	9006	1.686
9007	2.891	9007	2.906
9008	3.521	9008	3.547
9009	4.551	9009	4.570

Table 59, Calculated Vert movement between Control GCPs and UAV GCPs

Control GCPS vs D3F2 UAV GCPs			
GCP ID	Diff East	Diff North	Elevation Diff
9000	0.010	-0.004	-0.006
9001	-0.015	-0.032	-0.011
9002	-0.029	-0.016	0.020
9003	0.007	-0.025	0.026
9004	-0.017	-0.017	0.034
9005	0.000	-0.001	0.018
9006	-0.023	-0.014	0.016
9007	-0.006	-0.025	0.015
9008	-0.019	-0.025	0.026
9009	0.014	-0.018	0.019

Figure 88, Overall Movement from Base GCP to UAV GCP Day 3 Flight 2



4.10 Conclusion

From the above results, it can be clearly seen that there is some noted error between the GPS points and UA points established during the survey. It is also noted that there is some movement recorded between the base line points and the surveyed GPS Points and AV Points, however this will be discussed further in the following section, clarifying if this is noted movement or just resulted error between survey days.

A check on the accuracies achieved between the GPS and UAV Points was necessary to ensure the results would be sufficient, and to ensure the surveys were completed correctly.

Section 6 below will further discuss the results above.

5 Discussion

5.1 Introduction

The below section will outline the results achieved during the project and will outline the accuracies achieved and the movement noted during the surveys. It will go into further detail about the error between the GPS Points and UAV Points recorded, the GCP Movements between the Base Line Points, UAV and GPS and whether it is not just noise error, and will discuss the 3D Point clouds created and the accuracy of the data formed. This section will also discuss the benefits and negatives of both UAV Surveying and GPS Surveying and whether this data can be used accurately for the purpose of monitoring surveying on sea walls.

5.2 GCP Error – GPS & UAV

5.2.1 GPS GCP Data

For the purpose of the monitoring survey it was necessary to have base line control points established to compare the data to, for the comparison of accuracy as well as for movement of the sea wall structure.

These points were established into the rock surface as screws and were painted up White to ensure clear visibility in the UAV Photos.

Figure 88, GCP 9005, installed in Rock

With the base line control established it was necessary to survey these 10 specific points during each survey to check for movement within the sea wall. Therefor it is worth noting that the GPS used was based on a cors network RTK Solution which would allow for an accuracy of +/- 10mm horizontally and +/- 30mm vertically.

There are other noted factors that can contribute to in-accuracies with the data, however these normally limit to Base GPS range and coverage (trees etc.), however due to the location of the sea wall have large open spaces, with no coverage at all, it would be safe to say the GPS was working at optimal precision for that piece of equipment.

5.2.2 GPS GCP vs UAV GCP Data

In order to ensure all Ground Control Points (GCPs) were accurately captured, it was necessary to check all the accuracies between the UAV computed GCP and the actual surveyed GCP from the GPS during that flight. This process was completed for each flight (1 & 2) for each day (3 Days) to check the RMSEx, RMSEy and the Elevation. This is necessary to ensure the data is accurate for the monitoring survey.

In order to ensure the results are accurate, an error cut of zone will be used of +/- 20mm horizontally and +/- 20mm vertically, thus ensuring the results are of a higher standard.

5.2.2.1 Day 1 Flight 1& 2 UAV vs GPS

Flight 1

Section 4.6.1 of the results outlines the results and accuracies achieved from the survey.

From the results compiled it is clear to see that the mean difference of error between the two types of survey points would be at 8mm Easting and 8mm Northing, showing the largest error of 17mm noted in the easting of point 9009. This may indicate a discrepancy in the picture or may have been obstructed during the survey. However as there is no noted consistent error between the points, this would suggest the survey was completed accurately for horizontal measures.

Section 4.6.1 of the results also illustrates the accuracies between the UAV GCPs elevation in comparison to the GPS GCPs elevation. The average error is of 2mm accuracy which would propose the survey to be very accurate vertically, however there is a noted spike of 26mm for point 9006. As the 26mm is outside the 20mm +/- tolerance, it would be deemed too inaccurate to be able to use point 9006 for the purpose of the monitoring survey.

It is also worth noting that the 95% Confidence for the RMSE values are as follows;

- RMSEx - 95% confident results lie between 2mm & 15mm
- RMSEy - 95% confident results lie between 0mm & 15mm

With results ranging between 0 to 15mm accurate if this was too preformed over again, this clearly illustrates that the results would be accurate enough to be used and achieved consistently.

These results and errors can be seen clearly within the tables and graphs supplied in section 4.6.1.

Flight 2

Section 4.6.2 of the results outlines the results and accuracies achieved from the survey.

From the results compiled in section 4.6.2, it is clear to see the largest error found within the Easting and Northing is -19mm with the largest RMSE (distance) error being 21mm. However as the results are not all consistent and do not suggest any shift or swing in the data, this would possibly suggest the error is found within the photos and clarity of the data.

Section 4.6.2 of the results also illustrates the accuracies between the UAV GCPs elevation in comparison to the GPS GCPs elevation. The average error is of -3mm accuracy which would propose the survey to be very accurate vertically, however there is a noted small low of -14mm error for point 9007. This may suggest image clarity issues or could suggest the pixel sixe is too large to obtain a more accurate result. As all these results fall within the +/- 20mm tolerance, it would safe to assume these points are accurate enough to conduct a monitoring survey of the sea wall.

It is also worth noting that the 95% Confidence for the RMSE values are as follows;

- RMSEx - 95% confident results lie between -1mm & 13mm
- RMSEy - 95% confident results lie between -1mm & 13mm

With results ranging between -1 to 13mm accurate if this was too preformed over again, this clearly illustrates that the results would be accurate enough to be used and achieved consistently.

These results and errors can be seen clearly within the tables and graphs supplied in section 4.6.2.

5.2.2.2 Day 2 Flight 1 & 2 UAV vs GPS

Flight 1

Section 4.6.3 of the results outlines the results and accuracies achieved from the survey. From the results compiled it can be clearly seen that the accuracies of all the marks are within tolerance of =/- 20mm except for point 9006, with an Northing error of 93mm with the next closest point being 19mm out. This would suggest there is an error in the UAV Data and would suggest that this point either needs to be checked or the images used need to be rectified.

Section 4.6.3 of the results also illustrates the accuracies between the UAV GCPs elevation in comparison to the GPS GCPs elevation. The mean error for the elevations of Flight 2 is 3mm with the largest error being 76mm. Again this is found to be consistent with point 9006, and again would suggest and confirm that there is an issue with point 9006 within the photogrammetric data.

It is also worth noting that the 95% Confidence for the RMSE values are as follows;

- RMSEx - 95% confident results lie between -1mm & 14mm
- RMSEy - 95% confident results lie between 9mm & 17mm

The results for the RMSEx are significantly lower than the RMSEy and this is caused due to the error found with point 9006. It is safe to say the data would be of a sound standard; however point 9006 would need to be checked and rectified prior to commencing further.

These results and errors can be seen clearly within the tables and graphs supplied in section 4.6.3.

Flight 2

Section 4.6.4 of the results outlines the results and accuracies achieved from the survey.

As discussed in section 6.2.2.2 Flight 1, there was a large error noted within point 9006. This again can be clearly illustrated within table 2 of section 4.6.4 showing a Northing error of 75mm. This is 55mm over the tolerance zone for the control and cannot be used. This error can also be noted again within the elevation. It is however slightly less, but does not correspond with the remainder of the data, further proving this mark needs to be reviewed.

Point 9006 has consistent errors between both flight 1 and flight 2 suggesting that there is a program error, photo issue or discrepancy. This point would need further review before commencing further.

However for the purpose of this report, point 9006 of day 2 will not be used to review the movement of the control points.

These results and errors can be seen clearly within the tables and graphs supplied in section 4.6.4.

5.2.2.3 Day 3 Flight 1 & 2 UAV vs GPS

Flight 1

Section 4.6.5 of the results outlines the results and accuracies achieved from the survey.

The results compiled in section 4.6.5, clearly illustrate the accuracies between the UAV flight and the GPS survey. Table 2 in section 4.6.5 shows the largest error found within the Easting and Northing is 23mm with the largest RMSE (distance) error being 24mm. However as the results are not all consistent this does not suggest any shift or swing in the data, this would possibly suggest the error is found within the photos and clarity of the data or even the location of the mark.

Section 4.6.5 of the results also illustrates the accuracies between the UAV GCPs elevation in comparison to the GPS GCPs elevation. The average error is of 21mm accuracy which would propose the survey to be sound vertically. As a few of the results are outside the +/- 20mm tolerance, it would suggest that there is a discrepancy with the data used. This may be cause from the GPS Unit that day, supplying an incorrect datum height.

It is also worth noting that the 95% Confidence for the RMSE values are as follows;

- RMSEx - 95% confident results lie between -1mm & 14mm
- RMSEy - 95% confident results lie between 3mm & 16mm

With results ranging between -1 to 16mm accurate if this was too preformed over again, it would suggest that the data is of sound standard and could be reviewed further.

These results and errors can be seen clearly within the tables and graphs supplied in section 4.6.5.

Flight 2

Section 4.6.6 of the results outlines the results and accuracies achieved from the survey.

As previously discussed, there seems to be a consistency error with point 9006, thus having another large Northing error of 34mm thus failing the tolerance zone. However as the other marks are of a higher accuracy it would be safe to assume this again is just point specific.

The elevations are of a sound standard with a mean error of 7mm and the largest being 23mm, point 9008.

It is also worth noting that the 95% Confidence for the RMSE values are as follows;

- RMSEx - 95% confident results lie between -2mm & 14mm
- RMSEy - 95% confident results lie between 2mm & 13mm

With results ranging between -2 to 14mm accurate if this was too preformed over again, this clearly illustrates that the results would be accurate enough to be used and achieved consistently.

These results and errors can be seen clearly within the tables and graphs supplied in section 4.6.6.

5.2.2 GPS GCP vs UAV GCP Findings

From the results compiled it has been proved there is an accurate result between the GPS GCPs and the UAV GCPs and that the data could be used as a comparison platform. However there was a noted error within the information of point 9006. As point 9006 seems to consistently be the point of issue, it would seem as though the program may not be able to process thoroughly and accurately the location of mark 9006.

As detailed below in figure 89, the point 9006 is located quite low on the sea wall surrounded by larger stones and is positioned quite low and on a point of an uneven surface. This would be a contributing factor to the error associated with the point RMSE between the GPS and the UAV.

Figure 89, Point 9006 Location .

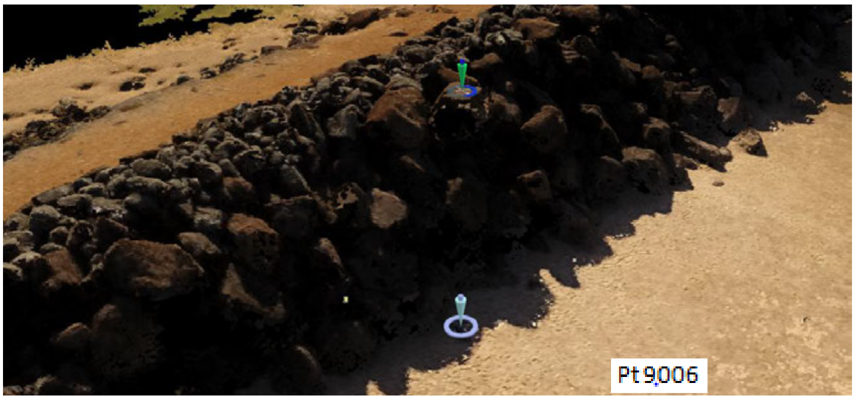


Figure 90, Point 9006 Location on Rock

Other than this noted error, the rest of the results are of sound accuracy and the 95% confidence for the RMSEx & RMSEy illustrate that if this was to be performed again similar results would be achieved. Thus being said it would be ideal to find a new location for point 9006, as it will not provide a result accurate enough for the test of movement.

5.3 Monitoring Points Movement

5.3.1 GPS vs Base Point GCPs Movement

5.3.1.1 Base Points vs GPS Day 2

Section 4.8.1 of the results outlines the total movement noticed between the GPS GCP points and the base line points.

As point 9006 has had noticed errors within section 6.2, point 9006 will not be reviewed for movement as it is deemed too inaccurate for the report.

During flight day 2, the GPS points were recorded using a Trimble S6 receiver hooked up with a cors network RTK system. This allows for horizontal accuracy of +/- 10mm and vertical accuracy of +/- 30mm. This being said, this does not mean it will not accurately show minor movement, however it will be less accurate in comparison to a total station.

On day 2 of the monitoring survey it was noted that the maximum amount of movement achieved horizontally was 46mm demonstrated by point 9003, with the average amount of movement being 14.5mm with larger results of 46mm & 27mm I would feel confident in saying that the location of these marks would have shifted horizontally accordingly.

Vertically however, the marks have not shifted significantly with a maximum movement of -25mm and average of -6.5mm. As the GPS is only accurate to 30mm +/- I would not feel confident enough in saying the rocks have shifted vertically.

5.3.1.2 Base Points vs GPS Day 3

Section 4.8.2 of the results outlines the total movement noticed between the GPS GCP points and the base line points.

As point 9006 has had noticed errors within section 6.2, point 9006 will not be reviewed for movement as it is deemed too inaccurate for the report.

During flight day 3, the GPS points were recorded using a Trimble S6 receiver hooked up with a cors network RTK system. This allows for horizontal accuracy of +/- 10mm and vertical accuracy of +/- 30mm. This being said, this does not mean it will not accurately show minor movement, however it will be less accurate in comparison to a total station.

On day 3 of the monitoring survey it was noted that the maximum amount of movement achieved horizontally was 38mm and average was 22mm, disregarding the 55mm noted at point 9006 due to inaccurate results. The vertical movement maximum was a rise of 26mm and an average of 8.4mm.

As the average distance of 22mm was noted between the survey points and the GPS points on day 3, I would feel confident in saying the rock locations move accordingly, however as the GPS vertical locations did not move significantly, I would not feel confident in the small movements, as the GPS is only tolerant to +/- 30mm.

5.3.2 GPS vs Monitoring Points Movement Findings

After reviewing the points thoroughly and noting the error found in point 9006, I believe it is possible to monitor a sea wall using a GPS based on a cors network. However, as the GPS is of not the highest standards with accuracies, it would be of best interest to use a total station if more accurate results are required.

5.3.3 UAV vs Base Point GCPs Movement

5.3.2.1 Base Points vs UAV GCPs Day 1

Table 60 below illustrates the total amount of movement noted between the UAV Points on Day 1 in comparison to the GPS Base points. As day one was the initial date the points were established, therefor there should be noted very little movement between the points both horizontally and vertically.

Table 60, Overall movement results of Day 1

Difference Base Points and UAV GCPs Day 1		
Base Pt No	**UAV GCP Pts**	**Difference (mm)**
9000	9000	**14.866**
9001	9001	**14.422**
9002	9002	**2.000**

9003	9003	**13.153**
9004	9004	**11.180**
9005	9005	**8.062**
9006	9006	
9007	9007	**7.211**
9008	9008	**15.000**
9009	9009	**18.788**
9000	9000	**2.000**
9001	9001	**2.236**
9002	9002	**3.000**
9003	9003	**18.000**
9004	9004	**10.000**
9005	9005	**3.162**
9006	9006	
9007	9007	**5.831**
9008	9008	**18.028**
9009	9009	**21.024**
	Mean	**10.442**
	Median	10.590
	Max	21.024
	Min	2.000
	St Dev	6.308
	Variation	39.789

From the above table, it is noted that the largest amount of movement found in comparing the base control points with the UAV points to be 21mm and the average to be 10.5mm. This being said, there should be very minimal movement noted between the two, as the base control was established that day, therefor, since the pixel size achieved that day was 1.88cm and 1.85cm (section 4.7.1 & 4.7.2) this would then back the argument that the points had not shifted during that flight.

Just as the GPS is limited by accuracy so are the Drone/UAV and the results they can produce, therefor the results are limited by the pixel size and RMSE error that the program can fix. Therefor it will be necessary to check the pixel sixe and make the judgement based upon that.

Table 61 below illustrates the amount of movement noted on Day 1 of the survey, however just like the horizontal movement, this should be noted to be very minimal if none, which can be seen below.

Table 61, Vertical Movement UAV vs Control Day 1

Control GCPS vs Day 1 UAV GCPs	
GCP ID	Elevation Diff (m)
9000	-0.007
9001	0.017
9002	-0.016
9003	-0.004
9004	-0.008
9005	-0.007
9006	
9007	0.009
9008	0.001
9009	0.010
9000	-0.003
9001	0.003
9002	-0.006
9003	-0.003
9004	-0.005
9005	0.001
9006	
9007	-0.014
9008	-0.005
9009	0.003
Mean	**-0.002**
Median	-0.003
Max	0.017
Min	-0.014
St Dev	0.008
Variation	0.000

5.3.2.2 Base Points vs UAV GCPs Day 2

Table 62 below illustrates the total amount of movement noted between the UAV Points on Day 2 in comparison to the GPS Base points. As it was the first day that had duration between surveys, there may be some noticed movement, similar to that found in section 6.3.1.1 above.

Table 62, Overall movement results of Day 2

Difference Base Points and UAV GCPs Day 2			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**21.932**	
9001	9001	**21.260**	
9002	9002	**12.806**	
9003	9003	**32.249**	
9004	9004	**9.055**	
9005	9005	**8.544**	
9006	9006		
9007	9007	**4.243**	
9008	9008	**10.817**	
9009	9009	**31.401**	
9000	9000	**15.264**	
9001	9001	**26.907**	
9002	9002	**5.657**	
9003	9003	**25.179**	
9004	9004	**7.071**	
9005	9005	**10.440**	
9006	9006		
9007	9007	**7.211**	
9008	9008	**6.403**	
9009	9009	**21.932**	
		Mean	**15.465**
		Median	11.811
		Max	32.249
		Min	4.243
		St Dev	9.018
		Variation	81.331

As previously discussed in section 6.3.1.1, the average amount of movement experienced between points was 14.5mm and the largest amount of movement was experience by point 9003 of 46mm. This is very similar results seen in the above table illustrating the average amount of movement achieved was 15.5mm and the maximum of 32mm by point 9003. This would support the argument that it's possible to accurately monitor a sea wall using a drone.

Table 63 below illustrates the amount of movement noted on Day 2 of the survey, which shows an average of -9mm similar to the -6.5mm noted by the GPS and a maximum of -25mm identical to the GPS Survey, thus further proving the similarities between the GPS Survey and Drone survey.

Table 63, Vertical Movement UAV vs Control Day 2

Control GCPS vs Day 2 UAV GCPs	
GCP ID	Elevation Diff (m)
9000	0.018
9001	-0.030
9002	-0.020
9003	0.007
9004	-0.011
9005	-0.013
9006	
9007	-0.013
9008	-0.027
9009	-0.015
9000	-0.014
9001	-0.023
9002	-0.004
9003	0.014
9004	0.000
9005	0.009
9006	
9007	-0.025
9008	-0.014
9009	-0.004
Mean	**-0.009**
Median	-0.013
Max	0.018
Min	-0.025
St Dev	0.014
Variation	0.000

5.3.2.3 Base Points vs UAV GCPs Day 3

Table 64 below illustrates the total amount of movement noted between the UAV Points on Day 3 in comparison to the GPS Base points. This was the second day the survey was completed, thus meaning further movement should be achieve, similar to that of section 6.3.1.2 above.

Table 64, Overall movement results of Day 3

Difference Base Points and UAV GCPs Day 3			
Base Pt No	**UAV GCP Pts**	**Difference (mm)**	
9000	9000	**13.928**	
9001	9001	**31.385**	
9002	9002	**35.777**	
9003	9003	**25.298**	
9004	9004	**22.627**	
9005	9005	**3.606**	
9006	9006		
9007	9007	**32.757**	
9008	9008	**35.693**	
9009	9009	**32.558**	
9000	9000	**10.770**	
9001	9001	**35.341**	
9002	9002	**33.121**	
9003	9003	**25.962**	
9004	9004	**24.042**	
9005	9005	**1.000**	
9006	9006		
9007	9007	**25.710**	
9008	9008	**31.401**	
9009	9009	**22.804**	
		Mean	**24.654**
		Median	25.836
		Max	35.777
		Min	1.000
		St Dev	10.467
		Variation	109.551

As previously discussed in section 6.3.1.2, the average amount of movement experienced between points was 26mm and the largest amount of movement was experience by point 9008 of 38mm. This is very similar results seen in the above table illustrating the average amount of movement achieved was 25mm and the maximum of 36mm by point 9003. As this is not the same point, however the results of the mean value and the fact that all the other values are showing high results of movement helps prove that the drone is an accurate source of surveying.

Table 65 below illustrates the amount of movement noted on Day 3 of the survey, which shows an average of 23mm a maximum of 26mm noted by point 9003. However this is not similar to the result achieved by the GPS and is most probably related to the Pixel Size achieved of 1.81 and 1.8cm per pixel, giving this survey an approximate accurate results of approximately 20mm

Table 65, Vertical Movement UAV vs Control Day 3

Control GCPS vs Day 3 UAV GCPs	
GCP ID	Elevation Diff (m)
9000	0.024
9001	0.004
9002	0.027
9003	0.046
9004	0.030
9005	0.029
9006	
9007	0.034
9008	0.032
9009	0.040
9000	-0.006
9001	-0.011
9002	0.020
9003	0.026
9004	0.034
9005	0.018
9006	
9007	0.015
9008	0.026
9009	0.019
Mean	**0.023**
Median	0.026
Max	0.046
Min	-0.011
St Dev	0.014
Variation	0.000

5.3.4 UAV vs Monitoring Points Movement Findings

From the information compiled and tested between both the GPS and the UAV data, it is obvious that these methods both have certain aspects that are stronger than the other. As the GPS is more accurate overall, it is expected to have a more accurate result, however there was very similar results found in the data supporting both the GPS found movements and the Drone. However as discussed before, if the result is one that needs higher accuracy, it is going to be a better result using either the GPS or other methods, but for a quick and easy solution, the drone will supply a result similar to the GPS by +/- 20mm x,y and z.

5.4 3D Point Cloud vs GPS Survey

5.4.1 Benefits

GPS	3D Point Cloud
Easy to use- quick setup with instant results	Quick flight time – short distances
Not weather specific – not limited by wind	Easy to fly – fully autonomous flight
Not public specific – can be used around public	Creates large 3D model – not just point specific
Accurate – accurate to 10mm hz and 30mm vert	Creates large DSM – can be used for multiple applications not just one
Light weight and durable – more robust	
Significantly less processing – 20min office work	

5.4.1 Negatives

GPS	3D Point Cloud
Point specific – only picks up nominated points, much less work area	Not plug and play – a lot of ground work required
No 3D image created – no 3D model or ability to create DSM	More survey control – GPS or total station required for extra control
	Long processing time – significantly longer time processing 2-3hrs
	Not as clear as anticipated – due to in house camera and flight height
	Whether dependant – cannot be used in less than average weather conditions
	Limited use – can't be used around public or public air spaces.

5.5 Conclusion

The two methods of surveying used are of a sound standard when capturing data and have their own specific negatives and benefits suited to the task. As the Drone creates a much larger product at the end it is substantially longer and more complex to use with large hours spent in the office creating the data. However the information supplied at the end of the work model, is significantly more than the GPS which is only specific to the points recorded.

For the purpose of this report it was required to check the accuracies between the UAS GCPs and the GPS GCPs which has been clearly illustrated to have similar traits and accuracies, however the UAS is not as accurate and had noted errors with one of the control marks. There are also larger restrictions on the use of the drone in public areas and licensing required.

Some alternative method worth using would be to fly the drone closer to the ground; this would help to provide a smaller pixel size of 1.8cm, creating a much more accurate data set, giving the user further confidence in the work they are preforming.

Overall, the GPS is going to be quicker and more accurate, but if a large scale survey or DSM is to be used and created, the UAS would be a more ideal platform.

6 Conclusion

6.1 Review of Project Objectives

The objectives of this project were to compare the accuracy achievable between two methods of surveying, Conventional GPS Surveying (Figure 91) and UAS Photogrammetry Surveying (figure 92) in respect to monitoring sea walls.

In order to complete this task it was necessary to complete a large literature review on the methods and materials sea walls are built from, methods previous and currently used to survey and monitor sea walls, GPS and drone benefits and negatives thus ensuring the most accurate results are achieve and a review on the Casa standards of flight ensuring all personnel and public are kept safe.

In order to test the results it was also necessary to create a nominated flight path specific to the task, choose a site for the test (Tallebudgera Creek Sea Wall) and engage in a monitoring survey using both a GPS and UAS Platform. These systems were used to capture data, more specifically 10 monitoring points that were used as base line data to test for accuracy between the GPS and UAV and to test for any movement between the nominated base line controls.

This information was then compiled and tested for accuracies and movement through the use of Pix4d and other Cad based systems and office programs such as excel.

6.2 Results

The aim of this project was to determine the accuracy of the UAS (DJI Phantom 4) against the Cors Network RTK GPS unit in respect to a monitoring survey performed on the Tallebudgera sea wall, this was achieved with promising results.

As illustrated in the results section there is an accurate relationship between the GPS and Drone survey points with accurate results and common traits noticed between the GPS points and the UAV GCPs. This is then further proved with similar results shown in the movement between Base Line control, GPS and Drone GCPs.

The data sets were compared against a base line control survey completed on the first flight day using a S6 Trimble Total, thus ensuring a more accurate solution was achieved to compare against.

The positions of the control points established and the GCPs used to monitor the survey points were generally expressed as coordinates such as x, y & z values. Therefor it was necessary to check the accuracies between the two types of points surveyed, that being the GPS and UAV points in respect to the day in which they were captured. This was expressed as RMSEx, RMSEy and Elevation which helped to delineate the accuracy between the data sets captured on their respected day.

As the aim of this report was to test accuracies between the two survey systems it was also necessary to test for movement between days of survey for the sole purpose of monitoring the sea wall, therefor it was necessary to test for the overall movement in the values of Easting, Northing and Elevation, generally expressed as E, N, El. An overall mean, median, min, max, standard deviation and variation were computed to help understand the total amount of movement achieved between the points and to assist with checking for similarities between data sets.

6.3 Key Outcomes

Some of the key outcomes from this report are;

- Accurate results between GPS survey points and Drone GCP
- Accurate RMSEx, RMSEy and RMSExy results achieved and correspond to the data sets
- Movement in sea wall captured between GPS monitoring points and UAV Monitoring points in respect to each other.
- A more simplified way of surveying large surface area of rocks using Photogrammetry survey
- GPS is an easy and more cost effective and time effective approach to survey, but produces less information

6.4 Future Research

For future works in may be of best interest to see the representation between GPS Survey and Total Station survey, relating back to a nominated datum point with an established height. This would give a true representation into the quickest and most accurate way of monitoring the sea wall. It would also be of benefit to analyse the results further using the UAV but flown at a lower height of 20m. This would create smaller pixel size than the 1.8cm achieved. This would help to provide a more accurate result in the data, creating a more true representation of the sea wall during the flight.

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Appendix A

ENG4111/4112 Research Project

Project Specification

For: Luke David Bartlett

Title: Accuracy comparison between GPS Surveying and UAV Surveying on Seawall monitoring

Major: Surveying

Supervisors: Xiaoye Liu

Julian Armstrong, North Group Surveys Pty Ltd

Enrolment: ENG4111 – EXT S1, 2017.

ENG4112 – EXT S2, 2017.

Project Aim: To compare the accuracy differences between commercial based drones, such as the DJI 4, mounted with a suitable camera and the Trimble GPS in respect to seawall monitoring. The survey will be taken over monitoring sites previously established from council sources and used to compare the time and accuracy differences between conventional GPS surveying and UAV.

Programme: Revision A, 15th March 2017

1. Research the background information relating to Seawall Monitoring Sites and Monitoring requirements. Source information from Local Governments.
2. Research the specifications and accuracies of both UAVs (commercial drones) and conventional GPS Surveying equipment.
3. Review most suitable programs to process captured data such as Pixel4D.
4. Design the most suitable flight path and surveying techniques for the chosen site to achieve the most accurate results. Include a site risk assessment.
5. Monitor and compare results of chosen site for the nominated period of time and visits. E.g. 6 visit over 4 months.
6. Compare, Analyse and Present results from both survey methods (UAV & Conventional).
7. Demonstrate which survey method is more accurate and why and which method is quicker with higher accuracy and why.

If time permits;

8. Compare point designs between conventional CAD programs and Point Cloud based programs such as Pixel4D
9. Overlap both CAD Drawings to assess differences and coverage.

Appendix B

Resources

Project Supervisors

Julian Armstrong Photogrammetry Manager & High Rise Manager, North Group

Xiaoye Liu USQ Lecturer, University of Southern Queensland

Software

Terra Model will be used to adjust the control network from the Corse Network and will be used to create the Base Line of both the Monitoring Control Points (MP) and Photogrammetry Control Points (PP).

Pix4D, Photomodeler will be used for the registration and processing of the photogrammetric data.

Magnet Office may be used to assist with the creation of the Digital Terrain Model from the GPS Survey Data.

GPS Equipment

Trimble R8 GPS Receiver connected through the Cors Network with a Trimble TSC3 Controller

Figure 91: Trimble R8 Receiver and TSC3 Controller (Trimble, 2017)

UAV – DJI Phantom

The UAV chosen for this project is a DJI Phantom 4 Drone (Figure 92). This particular drone was used as the research is looking at whether an off the shelf model UAV targeted at your average hobby seeking Joe can achieve industry standard data.

Figure 92: DJI Phantom 4 Drone (JB Hi-Fi, 2017)

Table 66, DJI Phantom 4 Specifications

(*http://www.dji.com/phantom-4/info#specs, 2017)*

Max Tilt Angle	S-mode: 42° A-mode: 35° P-mode: 15°
Max Angular Speed	S-mode: 200°/s A-mode: 150°/s
Max Service Ceiling Above Sea Level	19685 feet (6000 m)
Max Wind Speed Resistance	10 m/s
Max Flight Time	Approx. 28 minutes
Operating Temperature Range	32° to 104°F (0° to 40°C)
Satellite Positioning Systems	GPS/GLONASS
Hover Accuracy Range	Vertical: ±0.1 m (with Vision Positioning) ±0.5 m (with GPS Positioning) Horizontal: ±0.3 m (with Vision Positioning) ±1.5 m (with GPS Positioning)

VISION SYSTEM

Vision System	Forward Vision System Downward Vision System
Velocity Range	≤10 m/s (2 m above ground)
Altitude Range	0 - 33 feet (0 - 10 m)
Operating Range	0 - 33 feet (0 - 10 m)
Obstacle Sensory Range	2 - 49 feet (0.7 - 15 m)
FOV	Forward: 60°(Horizontal), ±27°(Vertical) Downward: 70°(Front and Rear), 50°(Left and Right)
Measuring Frequency	Forward: 10 Hz Downward: 20 Hz
Operating Environment	Surface with clear pattern and adequate lighting (lux>15)

CAMERA

Sensor	1/2.3" CMOS Effective pixels: 12.4 M
Lens	FOV 94° 20 mm (35 mm format equivalent) f/2.8 focus at ∞
ISO Range	• 100-3200 (video) • 100-1600 (photo)
Electronic Shutter Speed	8 - 1/8000 s
Image Size	4000×3000
Still Photography Modes	Single shot Burst shooting: 3/5/7 frames Auto Exposure Bracketing (AEB): 3/5 bracketed frames at 0.7 EV Bias Timelapse HDR
Video Recording Modes	UHD: 4096×2160 (4K) 24 / 25p 3840×2160 (4K) 24 / 25 / 30p 2704×1520 (2.7K) 24 / 25 / 30p FHD: 1920×1080 24 / 25 / 30 / 48 / 50 / 60 / 120p HD: 1280×720 24 / 25 / 30 / 48 / 50 / 60p
Max Video Bitrate	60 Mbps
Supported File Systems	FAT32 (≤32 GB); exFAT (>32 GB)
Photo	JPEG, DNG (RAW)
Video	MP4, MOV (MPEG-4 AVC/H.264)
Supported SD Cards	Micro SD Max capacity: 64 GB Class 10 or UHS-1 rating required
Operating Temperature Range	32° to 104°F (0° to 40°C)

CHARGER

Appendix C

Planning

Gantt chart 1 – Method Phases

Table 67: Project Phases & Time frames

Task	Start Date	End Date	Duration
1. Data Storage Phase	15-May-17	21-May-17	7
1.a Check All memory Cards and Formats	12-Jun-17	18-Jun-17	7
2. Drone & GPS Testing Phase	22-May-17	25-Jun-17	42
2.a Calibration	22-May-17	28-May-17	7
2.b Trial Run of Test Site	29-May-17	04-Jun-17	7
2.c Flight Path Creation	22-May-17	28-May-17	7
2.d Setup Site & Control	22-May-17	25-Jun-17	42
Review 1 - Sample Data	26-Jun-17	02-Jul-17	7
3. Data Collection Phase	26-Jun-17	20-Aug-17	56
3.a Test Run of Test Site	26-Jun-17	02-Jul-17	7
3.b Drone Flights over chosen site	03-Jul-17	20-Aug-17	49
3.c GPS Surveying over chosen site	03-Jul-17	20-Aug-17	49
3.d Collect & Reduce Data	15-May-17	20-Aug-17	98
Review 2 - Data	21-Aug-17	27-Aug-17	7
4. Data Analysis Phase	29-May-17	12-Oct-17	136
4.a Compile all Flight & GPS Data	03-Jul-17	20-Aug-17	49
4.b Review & Analysis Data Sets	03-Jul-17	03-Sep-17	63
4.c Compare Data Sets & Accuracies	04-Sep-17	24-Sep-17	21
4.d Prepare Distertaion	15-May-17	12-Oct-17	150

Table 68: Project Task Descriptions

Phase 1	**Data Storage Phase**
1A	**Check all memory cards –** ensure all devices have the correct storage cards with sufficient space & have been calibrated to the correct format required.
Phase 2	**Drone & GPS Testing Phase**
2A	**Calibration –** Calibrate all GPS equipment to correct zone or area, ensure all systems are functional. Calibrate Drone to correct speed, height, angle and shutter speed and ensure the drone is fully functional
2B	**Test Flight –** Test flight over a nominated area. Check speeds, angles, camera shutter speed, and height. This can be used to check picture size and pixel count.
2C	**Flight Path Creation –** Create a nominated flight path over the chosen site, ensuring adequate overlap is achieved from the test flight previously taken
2D	**Setup Control –** Check site for known PSMs and establish site datum using RTK or Conventional Survey methods. This will be used and adopted during each flight.
Phase 3	**Data Collection Phase**
3A	**Trial Run of Test Site –** Initial flight over chosen site to test flight path location

	and camera angles and distances.
3B	**Drone flights over site** – Create flight path suited to site (achieved in phase 2.C). Fly drone over chosen site at an allocated height and speed. Collect Photogrammetry Data.
3C	**GPS Surveying Over Site –** Conducted RTK GPS Survey over chosen site, based on the requirements outlined in the Seawall Monitoring Assessment Criteria outlined in the literature review, Appendix A.
3D	**Collect & Reduce Data** - Collect all date over the period of time allocated, briefly consolidate the information and begin basic reductions to check the accuracy and clarity of all data collected.
Phase 4	**Data Analysis Phase**
4A	**Compile all Flight Data & GPS Data** – Compile all data into their required work areas and ensure all data has been captured over the entire work area/flight path chosen. Check for any overlap issues or any result discrepancies and assess whether more information is required.
4B	**Review & Analyse Data Sets –** Review all information that has been compiled. Review all imagery and RTK GPS Points. Review the DTMs created and the accuracies of the information. Analyse the information for any errors or issues prior to comparison.
4C	**Compare Data Sets & Accuracies –** Compare all the information captured. Compare each point cloud captured during each flight day and compare the result, accuracies, differences and time frames. Compare the amount of information captured from each survey method and to determine the most effective, efficient and productive method.

Appendix D

Risk and Communication Assessment

The risk assessment is necessary for this project. It will analyse the risk involved for the person/s undertaking the work within the Sea Wall (Project Area) and related areas which may have potentially live surfaces or interaction with plant or people.

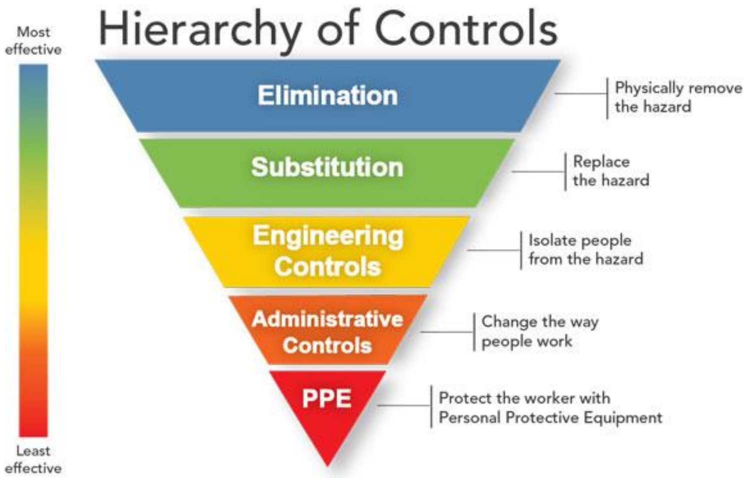
The first assessment adapted from NVETC (2014) are outlined in Tables ??. This assessment will consider all the potential hazards identified before commencing and whilst commencing the project. These hazards listed below, were identified by the Student and Drone Operator prior to commencing the flight. These personal safety considerations mainly apply to the drone Flight in the sea wall. The assessment identifies hazards, evaluates the level of associated risk (based on the likelihood-consequence matrix, Table 69) and proposes measures to reduce the risk. The second assessment, provided in Table ??, considers aspects that may pose a risk to timely completion of the project. A simpler risk profile is employed; low, medium and high. These project-related 'hazards' is managed by introducing contingency plans, triggered if critical resources become unavailable'. The hierarchy of Control goes onto further mention that Elimination is the best mean of controlling a hazard, as illustrated below;

1. Elimination – removes the cause of danger completely.
2. Substitution – controls the hazard by replacing it with a less risky way to achieve the same outcome.
3. Isolation – separates the hazard from the people at risk by isolating it.
4. Engineering – using engineering controls, i.e. making physical changes, to lessen any remaining risk, e.g. redesign a machine by adding safeguards.
5. Administration – use administrative controls to lessen the risk, e.g. install signs, and rotate jobs.

Personal Protective Equipment (PPE) – require your employees to wear PPE, e.g. provide gloves, earplugs, goggles, iridescent vests *(Heathandsafetyhandbook.com (PorterPress 2017)*

Note: The use of PPE to control hazards should always be the last resort.

<u>Figure 93- Hierarchy of Control,</u> *(PorterPress, 2017)*



This hierarchy of control will be implemented during the project exercise with all intentions to eliminate any risk prior to commencing any works.

<u>Table 69: Personal Risk – Likelihood and Consequence Matrix</u>

		Consequence			
		A Minor First aid or some medical attention	B Moderate Increased medical attention	C Major Severe health outcome or injury	D Extreme Intensive care or death
Likelihood of Occurrence	1 Rare	A1	B1	C1	D1
	2 Unlikely	A2	B2	C2	D2
	3 Likely	A3	B3	C3	D3
	4 Almost Certain	A4	B4	C4	D4
	Legend	Low Risk	Medium Risk	High Risk	

<u>Table 70: Personal Risk Assessment</u>

Task	Hazard	Risk	Mitigation
2A	Injury by being hit by Drone	B1	1. Keep clear of Drone during takeoff and

	during flight		landing 2. Adhere to relevant safety advice from professional UAV/Drone technician 3. keep flight zone clear of personnel 4. Follow CASR rules and regulations
2A	Accident due to other airborne traffic	B1	1. Ensure evasive measures are in place prior to commencing project. 2. Clear communication with other personal in area
2A	Exposure to sun	B3	1. Avoid skin exposure to the sun for prolonged periods of time. 2. Use of sunscreen and correct PPE.
2A	Injury caused by driving	C2	1. Avoid driving more than 2 hrs. 2. switch drivers when tired 3. Avoid driving at night times 4. Avoid high traffic areas during peak times

Table 71: Project Risk Assessment

Task	Hazard	Risk	Mitigation
2A	No Data samples as weather prevents Drone Flight	High Risk	1. Prepare an alternative date and ensure a contingency plan if all else fails. 2. Contact employer to organize another date, and notify supervisor/s
3A	Photography not clear or images are blurred	Medium Risk	1.Select most clear and contrast images 2. assess if project can commence 3. if unable to commence, conduct another flight within a week
3B	Insufficient control & Overlap	Medium Risk	1. ensure there is sufficient control in the area 2. Check all images for overlapping imagery and control (50-60%)

Communication Plan

The communication plan was established early into the project and is outlined below in Table 72. This plan was established early into the project, as there is a clear understanding that the Student and the Supervisors all have prior work commitments and requires ample time to respond. It also accounts for the situation that Luke Bartlett is a part time student working within Gold Coast Area for a company that has access to RTK GPS survey equipment, and easy access to a Drone, in particular the DJI Phantom 4.

Table 72 Communication Plan

Communication Link	Description
1	Meetings organised fortnightly to liaise with the supervisor to gather feedback. Due to significance distance between supervisors and student, communications will be limited to email, skype, face time or any other web based service.
2	Email trail of all equipment issues and access issues to site.
3	Notification of any equipment failures that have been resolved
4	Weekly updates to supervisor of progress and any other related issues