PIEneering
Parallel Image Engineering

Aspects of Accuracy in UAS Photogrammetry

White Paper

Version 1.0.4

THE GROUND TRUTH

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Abstract

Strict processing principles are familiar to all professional photogrammetrists, who have traditionally focused on accuracy aspects and controlling the error propagation in the entire data processing workflow. However, these principles may sometimes be unfamiliar to Unmanned Aerial System (UAS) mapping operators coming from the GIS sector and there exists some uncertainty about the important quality factors and correct data handling procedures of mapping projects.

This paper gives essential views of photogrammetric accuracy and data quality aspects applicable in UAS mapping, along with highlights of RapidStation, the advanced photogrammetric software suite from PIEneering Ltd.

Introduction

Large format digital metric cameras equipped with stabilized mounts have dominated the photogrammetric field until recent years. A wide variety of software based production systems are available on the market for digital mapping and automatic data extraction from the digital imagery. Image matching has meanwhile experienced a strong revival and is now, in addition to LIDAR systems, commonly used for extracting dense point clouds from digital imagery for generating interesting further derivatives, like 3D city models.

Rapid advances in unmanned aerial vehicle (UAS) technology have brought miniature aircraft carrying non-metric small format cameras into everyday use and they are successfully utilized in various types of photogrammetric projects and GIS applications.

Compact size UAS's are rather unstable imaging platforms as they are easily exposed to local turbulences during the flight. As a result, the image blocks often consist of a mix of oblique and near-vertical images that may be of inadequate radiometric quality. Automatic matching algorithms designed for standard near-vertical aerial photogrammetry are less optimal for processing UAS imagery and may even completely fail in that task.

However, despite the challenges regarding data processing, UASs have proven to be a most flexible and cost efficient way to acquire 2D/3D data for a wide variety of applications areas. At PIEneering, we've addressed the data processing challenges with an elegant solution by combining the best image engineering algorithms of photogrammetry and machine vision.

Our RapidStation photogrammetric software suite covers the entire workflow of processing aerial mapping data, from on-site flight quality control to fully automatic aerial triangulation solutions as well as generating colour balanced true-ortho mosaics and detailed DSM's/DTM's. Besides using state-of-the-art algorithms for data processing, we have paid special attention to an extended quality assurance, through thorough statistical testing of the results.

All modules of the RapidStation suite make use of modern Graphic Processing Unit (GPU) technology. One GPU boost up the processing speed by a factor of 50, usage of several GPUs increasing the speed respectively.

Data Processing Workflow

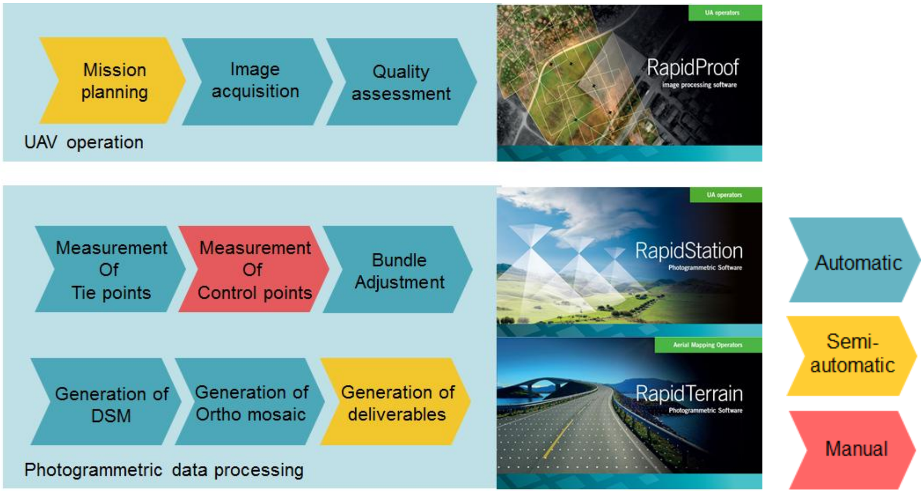
The typical workflow of a UAS mission can be split up into two major tasks: mission planning along with the flight itself and post processing of the acquired data.

UAS vendors provide dedicated solutions for mission planning & flight related tasks, including

- setting of general project parameters
- photogrammetric mission planning
- autonomous / manually assisted flight

Software vendors offer solutions for post processing the acquired image blocks, consisting of:

- on site quality assessment of the acquired data
- block reconstruction, i.e. automatic aerial triangulation with bundle block adjustment
- DTM/DSM generation
- ortho / true ortho mosaic computation
- quality check and generation of the deliverables



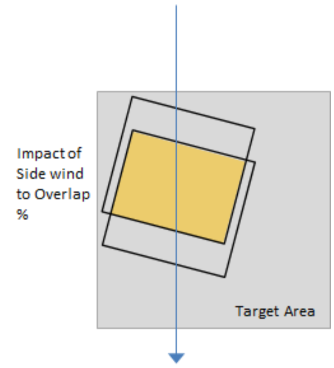
Photogrammetric processing workflow.

Mission Planning

Image Overlaps

Mission planning is an important part of the UAS process, as good planning defines a successful project result.

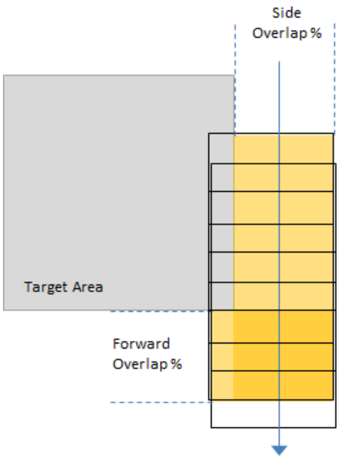
It's fundamentally important to use 75% - 85% forward and side overlaps in UAS projects to create geometrically strong image blocks. As mentioned above, compact size UAS's are rather unstable imaging platforms as they are easily exposed to local turbulences during the flight. As a result, the image blocks often consist of a mix of oblique and near-vertical images that may be of inadequate radiometric quality. This has a direct influence on the overlaps, as very often the preset overlaps do not materialize during the flight. If a block rips because of inadequate or nonexistent overlaps, the only possible remedies are to stitch the block with manual tie point measurements, fly a patch flight or in the most severe cases, redo the mission.



In windy conditions, the UAS aircraft may advance on its flight path with a significant crab angle, even up to 45°. In such cases, the preset 75% - 85% overlaps may vary significantly. This can be avoided by paying attention to the wind direction over the target area and using as high overlaps as the UAS system allows.

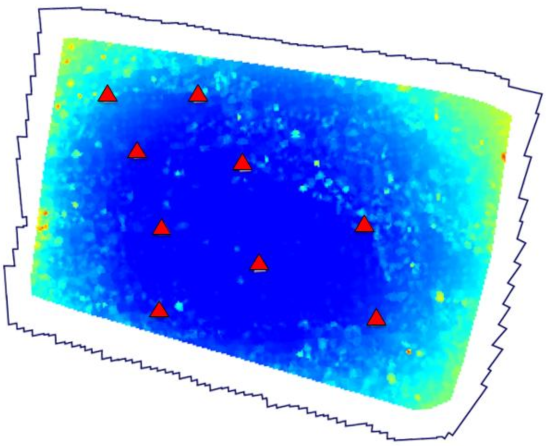
Flying with high overlaps doesn't add any significant extra costs to UAS projects. Instead, high overlaps do compensate the trajectory anomalies and image obliqueness, preserving overlaps high enough for successful automatic data processing. Moreover, high overlaps reduce occlusion areas to a minimum and are a prerequisite for advanced 3D DSM modeling.

For achieving an homogenous block and consistent quality over the entire target area, the edges of the block deserves special attention - full stereo coverage must be achieved over the whole target area. The block should be extended over the borders with a distance corresponding to the overlap percentage used.



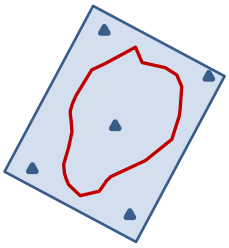
Mountainous areas or areas with large elevation differences create special challenges because of the varying image scale. In order to keep the image scale constant over the entire block, the flying altitude should remain the same relative to the ground. This means the target area should be divided into multiple blocks to be flown from different altitudes enabling control over the planned overlaps.Ground Control Points

A number of 3D ground control points (GCPs) are needed for achieving accurate, centimetre level georeferencing. The GCP's need to be located around the target area; some points are also required inside the area. The GCP's must effectively cover the entire target area to keep error propagation under control. It helps in achieving uniform accuracy throughout the entire project area, as can be seen from the picture below. The accuracy is well controlled inside the closed boundary around the GCPs.



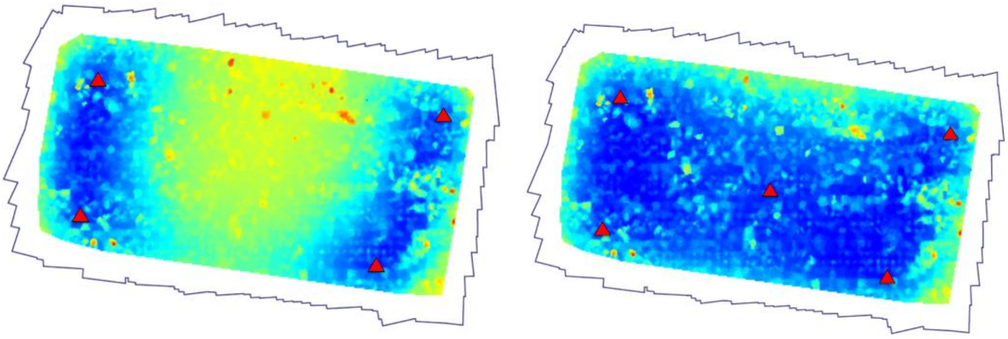
Visualization of the planimetric precision

The GCP's on the block edges should be located in the multi-image overlap area. The number of GCP's depends on the shape of the image block and in a rectangular area five GCP's is a minimum number.

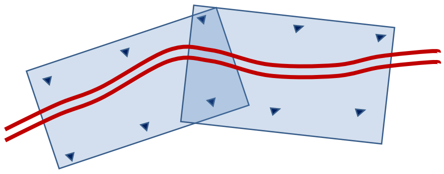


However, in more complicated projects, consisting of several flights or in corridor type projects (roads, power lines etc.) more GCP's are required (see images below) to avoid unfavourable error propagation.

The following images represent a comparison of achievable height precision when four and five GCP's were used for absolute orientation of a 1 km² UAS block. Without GCP control in the middle of the left hand side image, unfavorable error propagation does occur.



In case a project consists of two or more sub-blocks, there must be good overlap between them in order to create strong geometrical connections throughout the entire block.



Targets

The GCPs must be visualized for the aerial photography. The size, shape and contrast of the targets, along with the image quality, define the visibility of them on the images. This is a very important issue, as it has a direct influence on the georeferencing accuracy of the image block.

Round targets are recommended, but square or cross shaped targets can also be used. Round targets preserve their shape better (pictures below).

The targets must be carefully centered to the GCP's in order not to create any additional errors in georeferencing. The material of the targets is usually white matte painted hard-board or canvas; the signals can be also painted on the surface. An optimal painted target is shown in the picture on the left.

A ground sampling distance (GSD) of ≤ 5 cm can be typically achieved with standard digital consumer cameras, depending on the flying altitude. As a consequence, the signal width must be at least 15 to 25 pixels in order make sure signals will be clearly visible on the images. A non-reflecting contrast zone around a target is highly recommended for creating a high enough contrast between the target and the surrounding terrain.

It is advisable not to place any targets in potential occlusion areas. The targets should be visible on as many images as possible and should be even observable from wide viewing angles from the sky. The use of natural targets, such as details of man-made structures (fence corners, eaves corners, painted lines on tarmac etc.) is not recommended. Due to missing contrast zones, varying viewing angles and image motion, they are more difficult to identify on images than properly prepared targets on a flat ground.

Camera settings

It's an obvious aim of any UAS mission to acquire sharp images with good radiometry. Digital cameras equipped with high quality CMOS sensors and advanced exposure control systems deliver by experience the best images: low noise and high radiometric resolution or bit depth. However, the extremely small pixel size of consumer cameras gives a small GSD but the drawback is quite a high noise level on images. Furthermore, the Bayer pattern of CMOS for colour registration brings an additional quality degradation factor.

The camera should be focused to infinity. Aperture and shutter speed settings can be manually set or they can be set automatically using the cameras pre-set programs. With fixed exposure settings the camera will maintain constant parameters for the entire block and is not sensitive to the changes in luminosity in the target area. The brightness of the images may vary, but usually the image sharpness is better maintained than with automatic exposure control.

Setting of optimal exposure control, i.e. defining optimal aperture and shutter speed, is quite a challenging task and requires extensive experience. It is not always easy to estimate the effects of the atmosphere and changes in the illumination during the flight.

By experience, it's recommended to use as short a shutter speed as possible and adjust the aperture value to get maximum image sharpness. For compact cameras, the ISO value should be set to minimum, as image noise tends to increase rapidly, especially in shadow areas. This additional noise may lead to random matching errors and result in incorrect random elevations that weaken the quality of measured DSMs.

An uncompressed 12 to 14 bit image format is optimal for all automatic matching processes as there are usually many more measurable details on the images. It's recommended to always capture raw images, if the data storage speed of the camera is high enough.

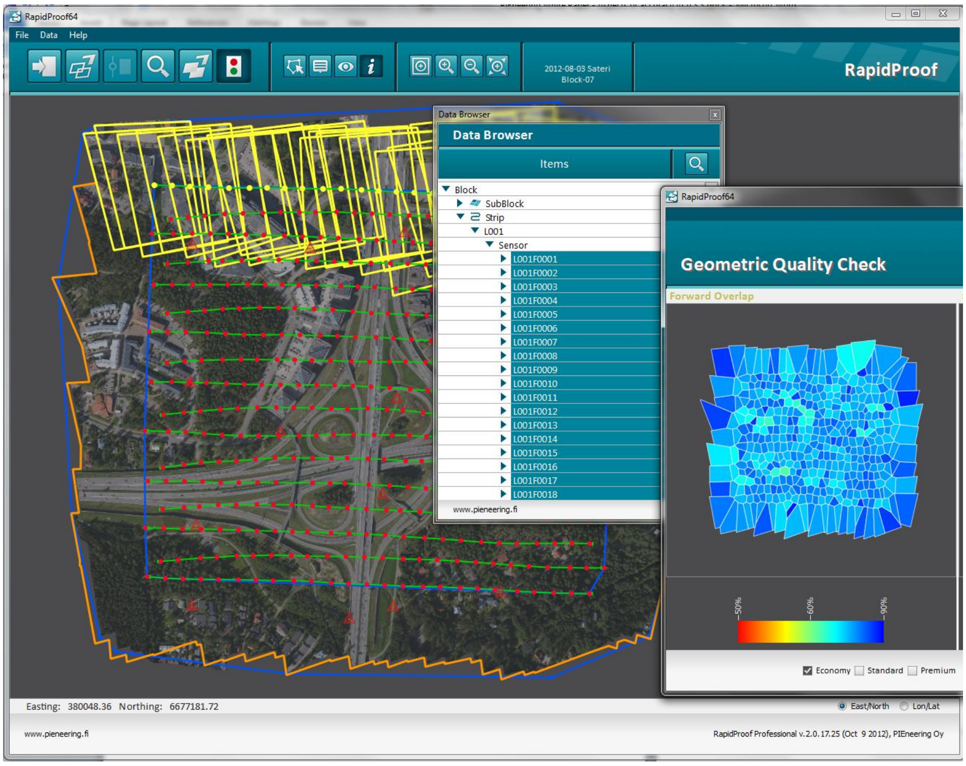
The risk of getting blurred images gets higher along with faster cruising speeds. High speed fixed- wing UAS's offer excellent performance as they can fly larger areas, however, the risk of compromising image quality is higher compared to lower speed fixed-wing or rotating-wing UAS's.

Quality Assessment in the Field

On-site quality checks, i.e. data monitoring immediately after the photo flight is essential to make sure the mission has been fully accomplished before leaving the project site. Visual monitoring reveals the data flaws, like missing images, corrupted log files, deviations from planned overlaps, variations in image exposures and GPS-to-image synchronizing problems, for example. Should the on-site checking be neglected, it is costly to revisit the mission site to fix the flaws.

PIEneering's RapidProof software is a powerful tool for aerial mapping quality management. With RapidProof,aerial mapping operators are able to confirm whether the mapping mission is successful at the immediate conclusion of the flight and prepare the data for further processing.

RapidProof has been integrated with all major UAS vendors' autopilot data formats, including C-Astral Bramor, Mavinci Sirius, Gatewing X100, SenseFly Swinglet CAM, Microdrones, CropCam and Pteryx.



Flights strips shown on a quick mosaic & overlap analysis generated with RapidProof.

Camera Calibration

Reliable camera calibration is mandatory in most precise photogrammetric projects. Traditionally, the interior orientation (IO) elements of a metric camera - principle point, principle distance (x_0, y_0, c) and image distortions - are defined in a laboratory calibration process.

A physical distortion model is commonly used for digital cameras with parameters for radial distortion, asymmetric distortion and in-plane distortion. Between the laboratory calibrations the status of the interior orientation can be monitored by applying self-calibration (on-the-job-calibration) in the photogrammetric aerial triangulation. However, self-calibration procedures cannot fully substitute laboratory calibration, as is pointed out later in this chapter.

Besides machine vision, consumer-grade digital cameras are also widely used in UAS based photogrammetric systems. Compared to professional metric cameras, they come with less stable, non-metric lens systems that can produce very large distortions on images. This is a fact that makes their proper calibration even more important than with metric cameras.

In serious UAS photogrammetry, digital cameras are handled as a precise measuring device with known and reliable calibration parameters, which are used for error-free image reconstruction for most accurate intersections in the object space block-wide.

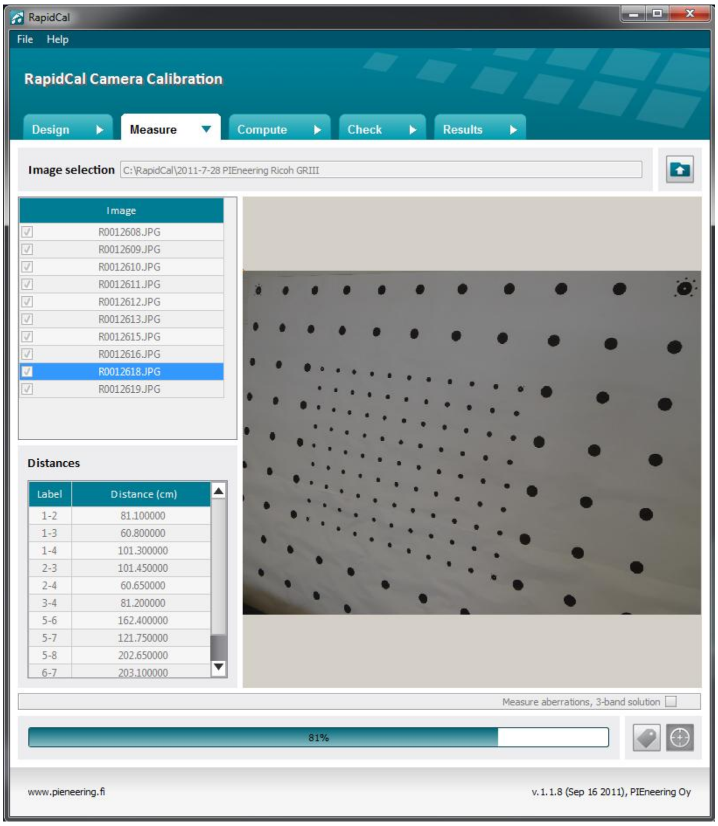
Bundle block software is based on linearized collinearity equations and this model can be extended with user selectable sets of additional parameters. They can be used for defining all the parameters of interior orientation (IO) in the bundle adjustment along with their precision and reliability estimates.

However, the use of additional parameters should always be accompanied by effective statistical testing. The determinability of the additional parameters and mathematical correlations between the IO and exterior orientation (EO) parameters must be carefully monitored in order to avoid over-parameterized adjustment. In such cases and especially in weak image blocks, the block adjustment may become instable, and deliver less optimal overall results.

When applying self-calibration, an image block with strong geometry is mandatory. A successful computation requires image scale variations, i.e. relatively large terrain height variations compared with flying altitude, varying flight altitudes and/or highly convergent images. Setting objective limits for these prerequisites is difficult. Because of this, post-triangulation reliability analysis of self-calibration is needed, for each computed block.

In conclusion, strict photogrammetric processing principles must be applied throughout all serious photogrammetric UAS projects. Special focus has to put on the camera calibration, because it is a genuine quality factor in any UAS mapping project.

RapidCal is an easy to use and powerful software tool for camera calibration. The fundamental design principle of RapidCal aims at stabile camera calibration of non-metric consumer cameras.



Automatic calibration measurement with RapidCal.

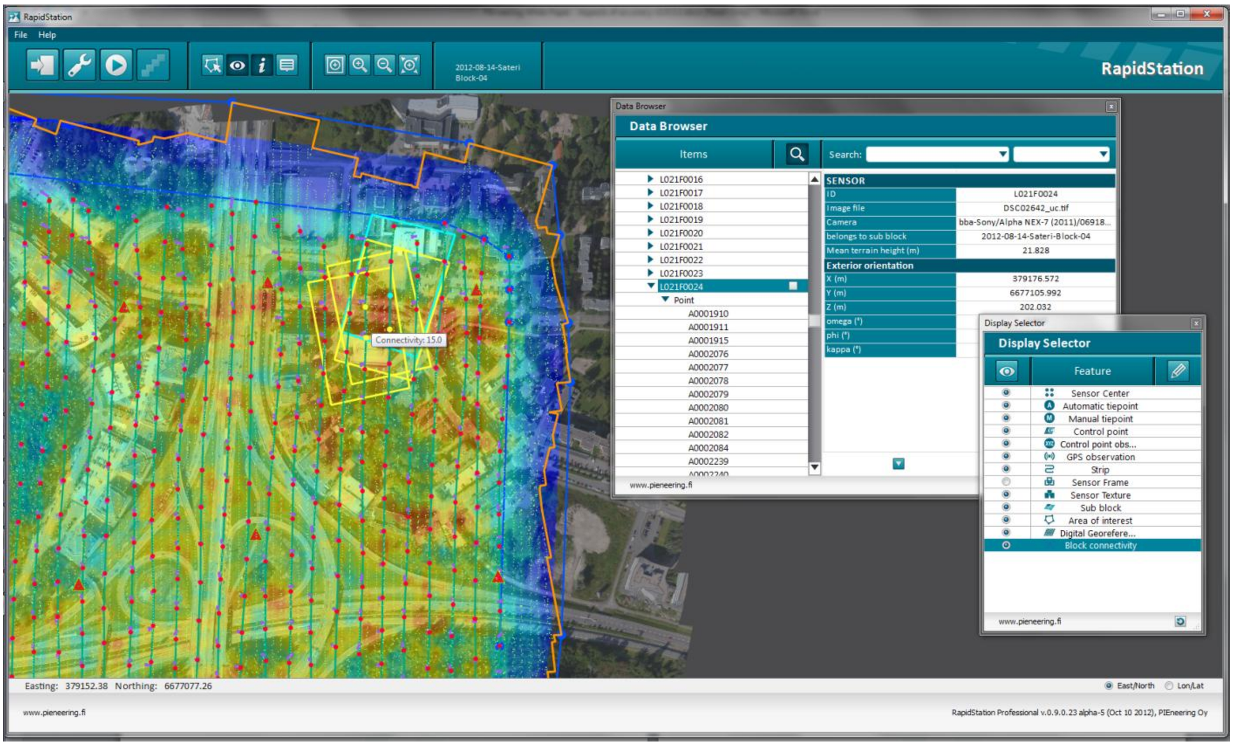
Block reconstruction

From a quality point of view, aerial triangulation is the most critical part of the photo-grammetric workflow and it is also the most challenging part to be fully automatized. The overall quality of all the subsequent processing steps, like DTM/DSM generation and ortho/true-ortho computation, fully depends on the precision and reliability of the exterior image orientations (EO) computed by the block reconstruction.

The RapidStation block reconstruction (Automatic Aerial Triangulation, AAT) module is one-click application that runs with minimum human intervention. Special attention has been paid to robust and fully automatic handling of challenges in image blocks consisting of a blend of vertical and oblique aerial images.

Special challenges for the automation are caused mainly by platform instability, high relative height differences and consumer grade cameras, along with wide angle lenses and small frame sizes. As a result of these factors, the following problems have to be solved:

- processing highly oblique views
- processing images with very large scale differences
- processing images with very low texture content
- acquiring adequate approximate values for all the parameters of non-linear processes



RapidStation offers comprehensive tools for block analysis and reporting.

The advanced matching algorithms, based on intelligently selected multi-scale image feature representation, enable successful image matching even under the most demanding circumstances. The algorithms work perfectly in blocks with strong variations in image scales, different lighting conditions and different perspectives due to often large image rotations.

To resolve the approximate values of exterior orientation and object point coordinates, closed form solutions are used throughout the matching process and in the bundle block adjustment.

The AAT module has an integrated state-of-the-art bundle block adjustment along with sophisticated mathematical models including advanced blunder detection routines and a variety of user selectable commonly used additional parameter sets for self-calibration. A comprehensive reliability and sensitivity analysis of the image block information delivers a full picture of the total quality achieved in a project.

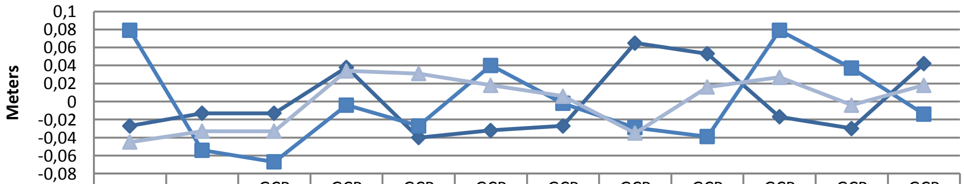
A Case Study

The target was a build-up area covering some 1.2 km^2 area. The area was covered with 19 flight strips in a single block of 893 images. Image overlaps were set to 85/85 percent and a total of 12 ground control points were measured.

Ortho mosaic of the project area

The aerial triangulation was performed with RapidStation automatically, with manual GCP measurements in monoscopic view. The statistics of bundle block adjustment is presented in Appendix 1.

Control Point Residuals



	GCP 1	GCP 4	GCP 101	GCP 102	GCP 103	GCP 105	GCP 106	GCP 107	GCP 108	GCP 109	GCP 111	GCP 112
X	-0,027	-0,013	-0,013	0,038	-0,04	-0,032	-0,027	0,065	0,053	-0,017	-0,03	0,042
Y	0,079	-0,054	-0,067	-0,004	-0,027	0,04	-0,002	-0,029	-0,039	0,079	0,037	-0,014
Z	-0,045	-0,033	-0,033	0,034	0,031	0,018	0,006	-0,035	0,016	0,027	-0,004	0,018

Ground control point residuals in the case study. With careful planning and realisation of a project centimeter level accuracy can be reached.

DTM/DSM generation

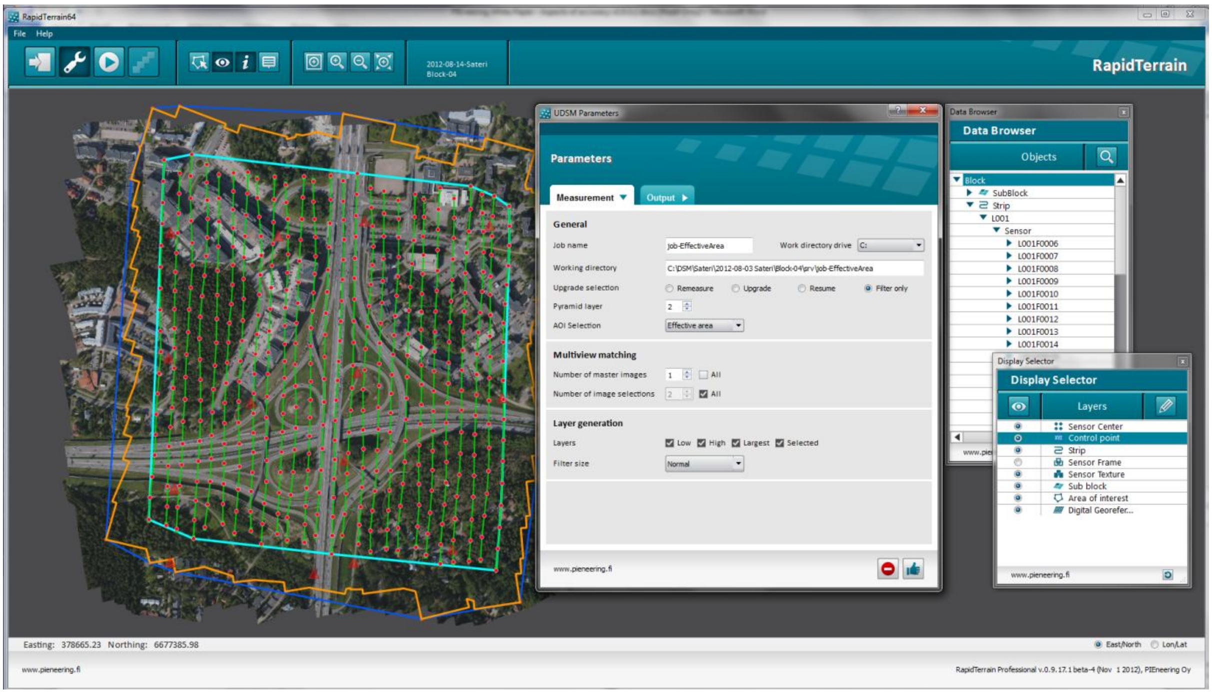
The total quality of high density DSM's/DTM's depends on the quality of the images and camera calibration data, accuracy of the EO parameters and the intelligence of the matching algorithms. Furthermore, overlap definitions in flight planning and the quality of the GCP's will have a significant influence on the final results.

A high performance level, along with very good success ratios in matching, excellent penetration in 3D objects as well as high accuracy are reached by using large image overlaps and multi-image matching on each input pixel. Standard, traditional photogrammetric overlaps - 60% forward and 30% side overlap - create a number of occlusion areas and give weak redundancy for automatic image matching. Higher overlaps - 75% / 75% or more - give much better redundancy along with high penetration in forest regions and urban environments, for example.

Block configuration of typical UAS projects is based on very high overlaps. This setup leads to a block geometry where a point is measurable on up to twenty overlapping images and a vast number of image combinations are available for point matching.

RapidTerrain utilizes multi-image matching using variations of dense stereo-matching procedures with advanced probabilistic optimization. Very detailed high-density pixel-level DSM's/DTM's are generated in a selected set of overlapping images, which results in a highly redundant elevation stack for each output pixel.

In the stack there are multiple independently measured elevations on the very same spatial location. The "raw" elevation information consists of different surfaces representing true ground (bottom surface), canopy structure and man-made objects (top surface) and objects between them (intermediate surface).



RapidTerrain offers superior software intelligence with a simple yet powerful user interface.

Advanced statistical filtering procedures are applied in creating final output surfaces out of the stacked raw elevation data. Very high redundancy allows for comprehensive local filtering operations and thorough statistical analyzing of the elevation data. Fine-tuned algorithms are used for eliminating matching blunders, for finding correct separation between the output surfaces and for best-fit spline surface reconstruction along with precision estimates and other statistical information. Continuous colour-coded precision maps are generated for each output surface for giving information on the achieved accuracy at a glance.

A visualization of a UAS point cloud (GSD 10 cm).

A 3D point cloud generated by RapidTerrain, called below microDSM or µDSM, is well suited to true-ortho production, building extraction and highly accurate DSM production as well as for more demanding derivatives like hybrid 3D models, for example.

RapidTerrain vs. LIDAR

In principle, µDSMs are equal to 3D point clouds generated by LIDAR systems. However, the very high redundancy of the image matching process offers superior quality control possibilities over the LIDAR process and allows for verifying the accuracy and reliability, i.e. the true quality of the point cloud. Image matching is a genuine cost and quality effective alternative to any LIDAR process.

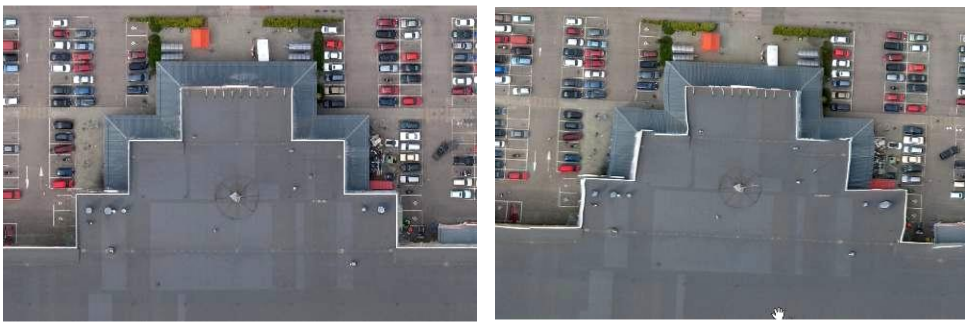
Due to limited controllability of the measurements, LIDAR process is statistically less reliable than multi-image matching. Virtually all LIDAR measurements, including the orientation information from direct GNSS & IMU georeferencing, are "single shots". There are no additional independent measurements that would allow effective internal quality controls of the point cloud and it is practically impossible to evaluate whether a single LIDAR measurement is correct or not. Furthermore, compared to highly redundant multi-image matching, the LIDAR process is more sensitive to gross errors / blunders.

However, both technologies have their advantages and drawbacks and most optimal results will be achieved by integrating them into the same rigorous mathematical model. Implementing this new model is one of the most important tasks in the upcoming developments of the RapidStation photogrammetric software suite.

Ortho mosaic generation

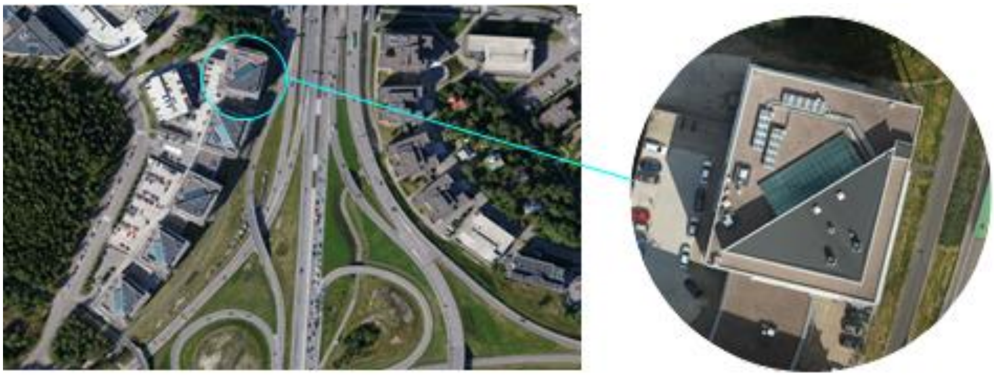
The final quality of an orthophoto depends on the quality of the input data: digital images and DTM/DSM as well as parameters of exterior orientation and camera calibration.

There are two types of ortho photos or ortho mosaics: ordinary ortho mosaics and true-ortho mosaics. Processing of true-ortho mosaics requires a DSM that contains all man-made 3D objects (e.g. buildings and bridges) and also the canopy surface in forest areas, which are usually not included in a DTM. All the DSM objects are presented on true ortho mosaics in their true locations and there are no disturbing relief displacements that are always present on standard ortho mosaics based on an ordinary DSM derived from aerial triangulation tie points.



Comparison of ortho mosaic details when µDSM and an ordinary DSM are being used.

RapidStation µDSM generates a detailed and accurate DSM that is a complete digital representation of local terrain. It is ready-to-use optimal data for computing true-ortho mosaics of the finest quality. The break lines on rooftops and other man-made structures are crisp and precisely described in the pixel-level µDSM. There is no need for any additional vectorisation process at extra costs that are often mandatory with lower resolution LIDAR data.



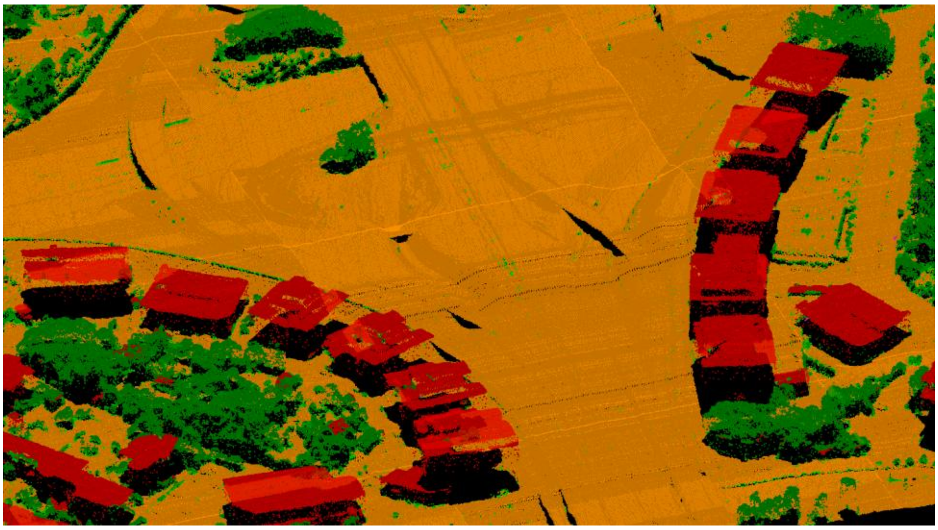
True-ortho image generated with µDSM. Eight-storey buildings need no manual seam line treatment.

Generation of deliverables

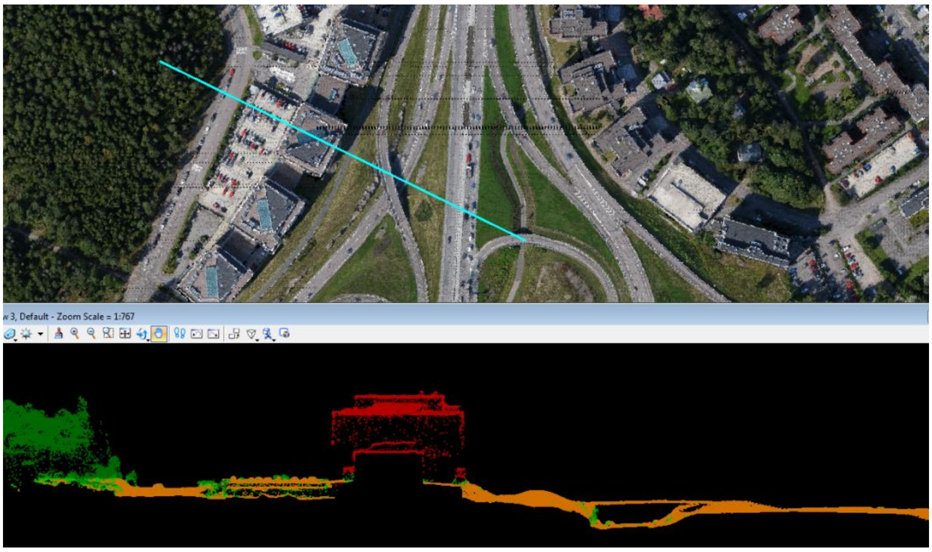
UAS technology is versatile and well suited to a wide range of applications, many of which are new ones outside the traditional photogrammetric field. A statement saying that 'only imagination sets the limits for utilization of UAS technology', is quite right, and currently documented application areas, to mention a few, are as follows: archeology, architecture, cultural heritage, cadastre, change detection, geology, large and very large scale local mapping, city planning, 3D city modeling, forestry and agriculture, flood control and landscapes studies, open pit mining and landfill analyses, hazard and environmental monitoring, crisis management, traffic arteries, accident recording and more.

In some applications, the ortho mosaics especially can be used as they are, as accurate and up-to-date reference data for planning, inventory or situation awareness purposes. Moreover, the orientation parameters (EO) from aerial triangulation can be used in stereo plotters for 3D digitizing in a normal way. A big plus is that a UAS block delivers a large number of stereo models due to high overlaps used. This gives a number of choices for a stereo operator to choose from, leaving less occlusion areas in mapping.

However, often the data is being used in engineering or planning applications, where there are more specific needs, such as a need to extract ground surface from the data, create vector building polygons or create draped images, a combination of DSM and ortho mosaic. This can be done with special software built for effective 3D point cloud processing. From experience, we recommend Terrascan from Terrasolid, the world leading LIDAR data processing software vendor.



Classification and visualization of 3D point cloud with Terrasolid's Terrascan.



Cross sections with Terrasolid's Terrascan.

Conclusions

Rapid advances in UAS technology have brought miniature aircraft carrying non-metric small format cameras into everyday use and they are successfully utilized in various types of photogrammetric projects and GIS applications.

Proper mission planning, camera calibration, good block geometry and an appropriate ground control point setup is of pivotal importance. When superior accuracy is required, systematic error propagation control is obligatory during the entire data acquisition and photogrammetric data processing workflow.

Block reconstruction (AAT) and extraction of DSM/DTM require advanced computing algorithms and elegant software solutions for achieving high levels of automation and accuracy. GPU support is essential in all steps of the production workflow for fast data throughput and real productivity.

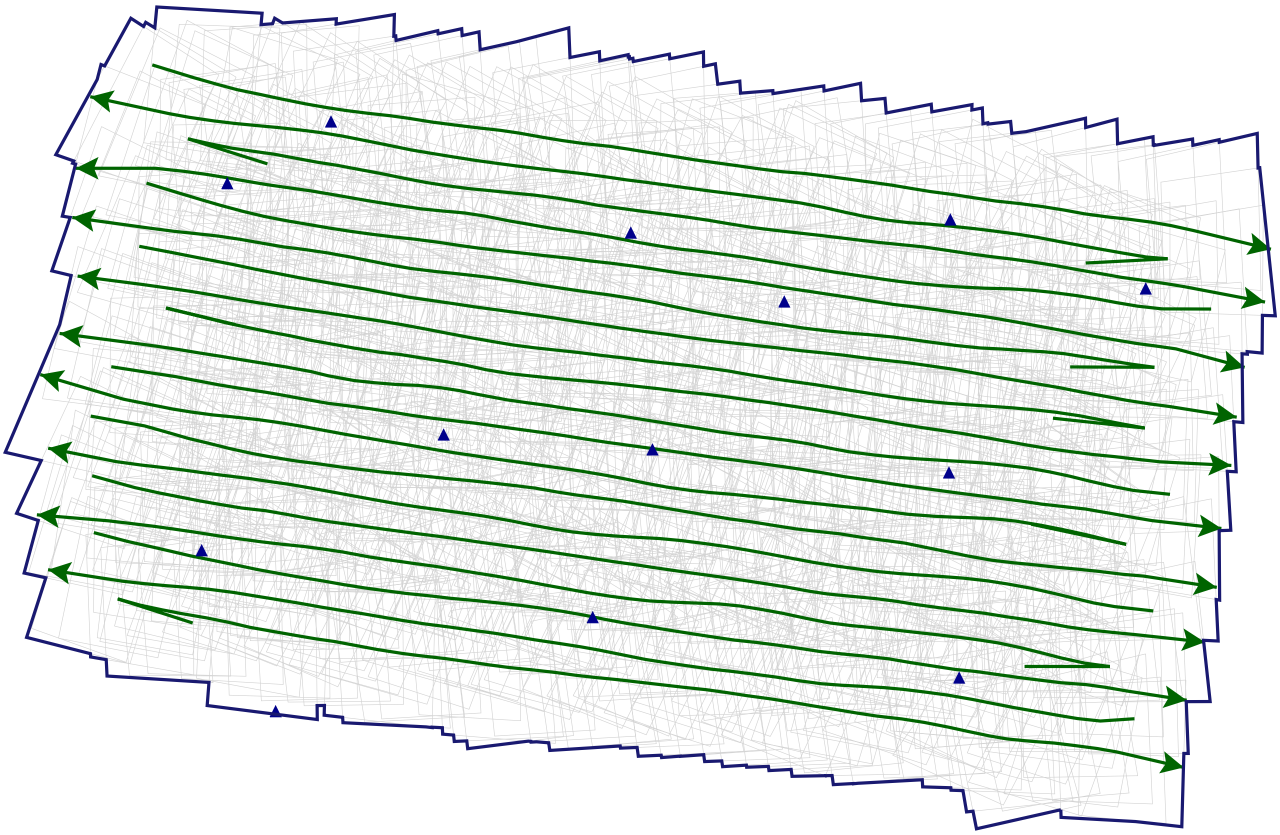
All the computational results and deliverables are created through heavy image processing. In the final end image quality quite much defines the total quality of an UAS project, so it makes sense to pay special attention to the camera selection. Strongly recommended are state-of-the-art digital consumer cameras for their excellent image quality along with advanced exposure controls and image formats.

With PIEneering's RapidStation photogrammetric software suite, a UAS operator can achieve results fully comparable with those achieved with traditional imaging and LIDAR scanning platforms, and with superb quality to price ratio.

Appendix 1 : Case study statistics

Block Quality Report

Project:	Mitta Oy, Ylivieskan kaupunki 1.8.2011
Project file:	2011-8-1 Ylivieska-Block-01
Project acreage:	121 hectare
Acquisition Time:	29.07 15:02:29 GMT +3 2011 - 29.07 15:37:39 GMT +3 2011
Target Products:	Premium-Orto and Premium-Dsm
Subblocks:	all
Printing Date:	10.05 15:46:30 GMT +3 2012
File:	white_paper_only.pdf



The print was produced by
RapidCluster v. 0.9.12 (5.6.2011)
PIEneering Oy, Finland
www.pieneering.fi

Block Quality Report

Part 1 : Residual Analysis

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Variance Components

	a'prior	a'posterior	no	redundancy	var. comp.
Observations, total					
	1.00	0.69	357706	0.87	
Image Observations, automatic tie-points [pixel]					
column coordinate	1.00	0.64	175890	0.87	0.64
row coordinate	1.00	0.74	175890	0.88	0.74
Image Observations, control-points [pixel]					
column coordinate	1.00	0.47	266	0.90	0.47
row coordinate	1.00	0.45	266	0.91	0.45
Gps Observations [m]					
Easting	5.00	4.33	893	0.98	0.87
Northing	2.00	1.01	893	1.00	0.51
Altitude	2.00	1.16	893	1.00	0.58
Attitude Observations [deg:min]					
Roll	7:00	3:08	893	1.00	0.45
Pitch	7:00	4:54	893	1.00	0.70
Yaw	40:00	16:07	893	1.00	0.40
Control Point Coordinates Class 2 [m]					
Easting	0.05	0.04	12	0.72	0.86
Northing	0.05	0.06	12	0.72	1.10
Height	0.05	0.03	12	0.72	0.65

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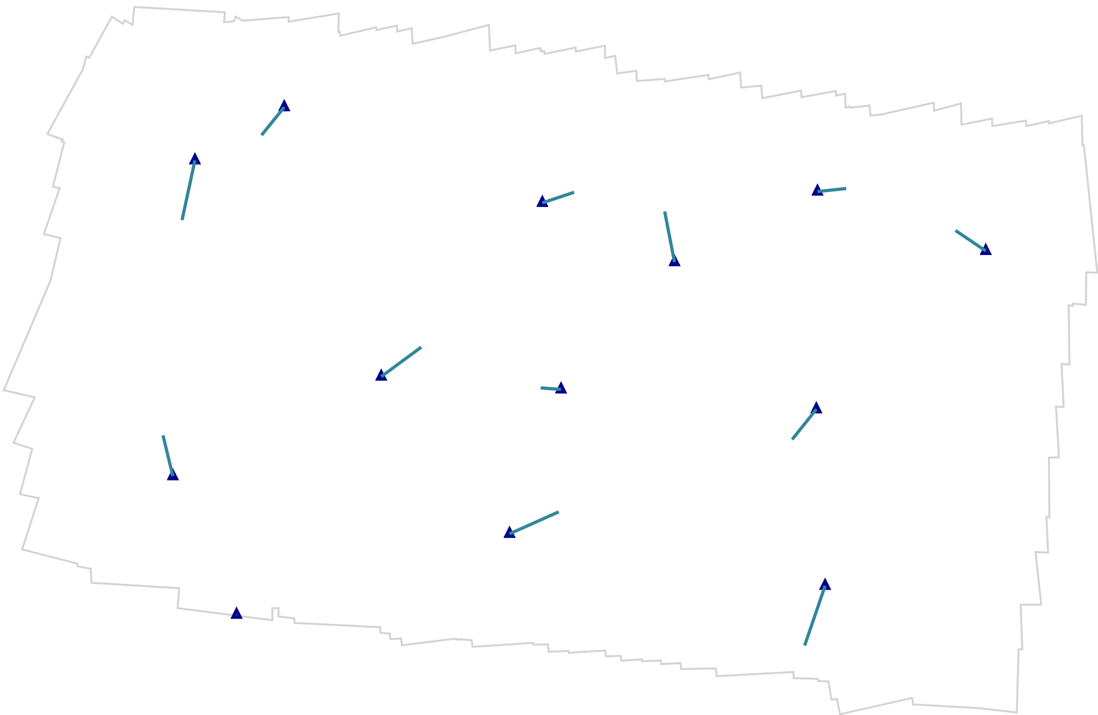
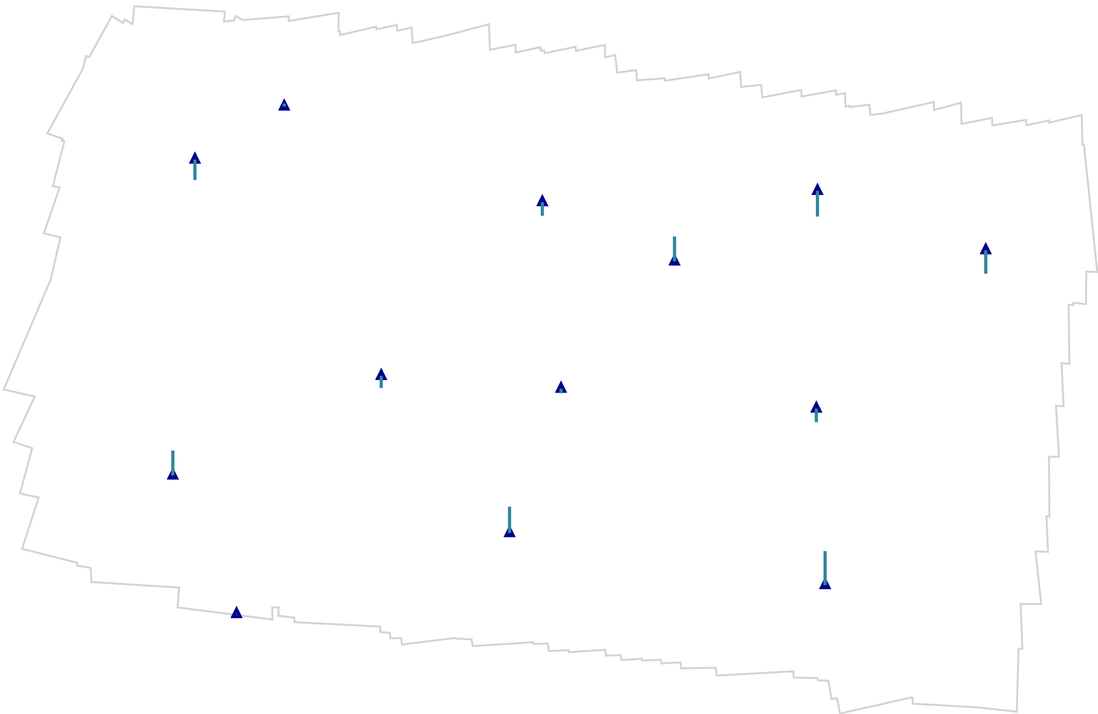
Control point residuals
Planimetry



Height



	no	redundancy	bias	rmse	max
Easting	12	0.72	-0.0 cm	4.3 cm	6.5 cm
Northing	12	0.72	-0.0 cm	5.5 cm	7.9 cm
Height	12	0.72	0.0 cm	3.3 cm	4.5 cm

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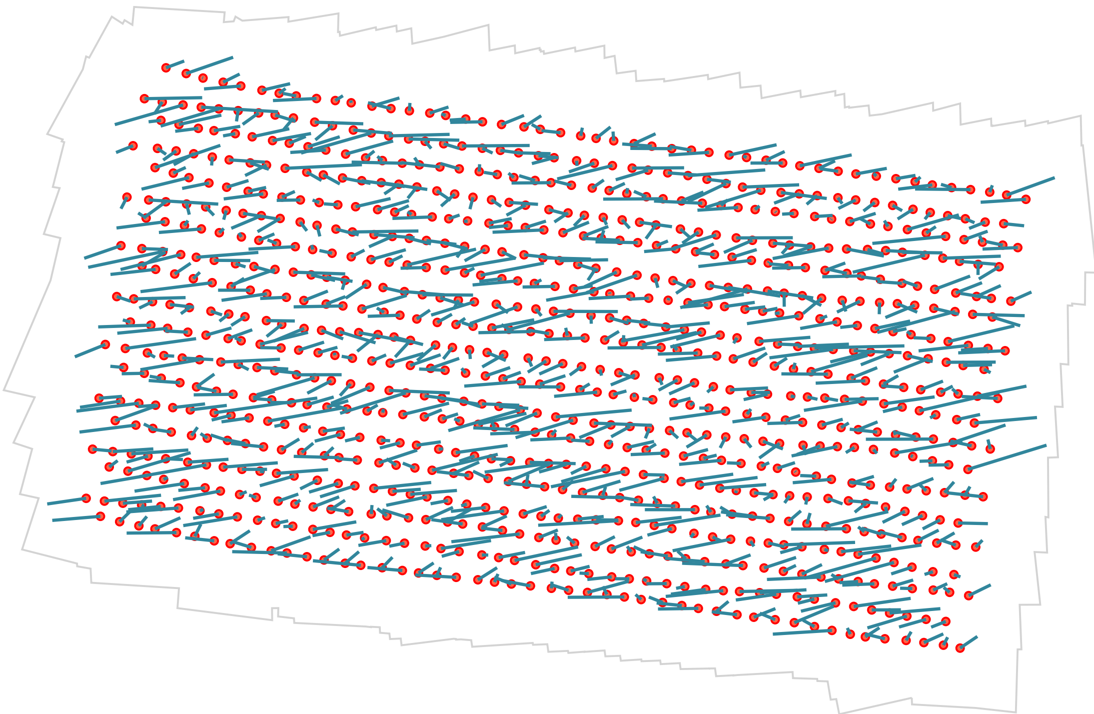
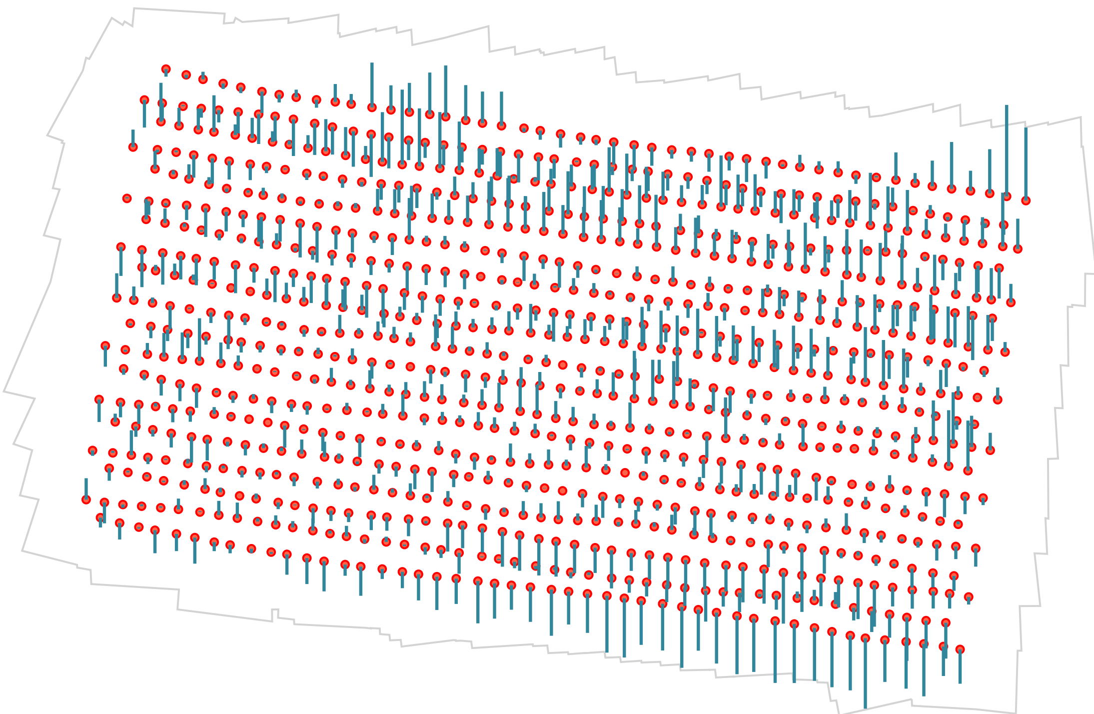
Residuals of GPS observations
Planimetry



Height



	no	redundancy	bias	rmse	max
Easting	893	0.98	-0.0 m	4.3 m	13.6 m
Northing	893	1.00	0.0 m	1.0 m	3.2 m
Height	893	1.00	-0.0 m	1.2 m	4.8 m

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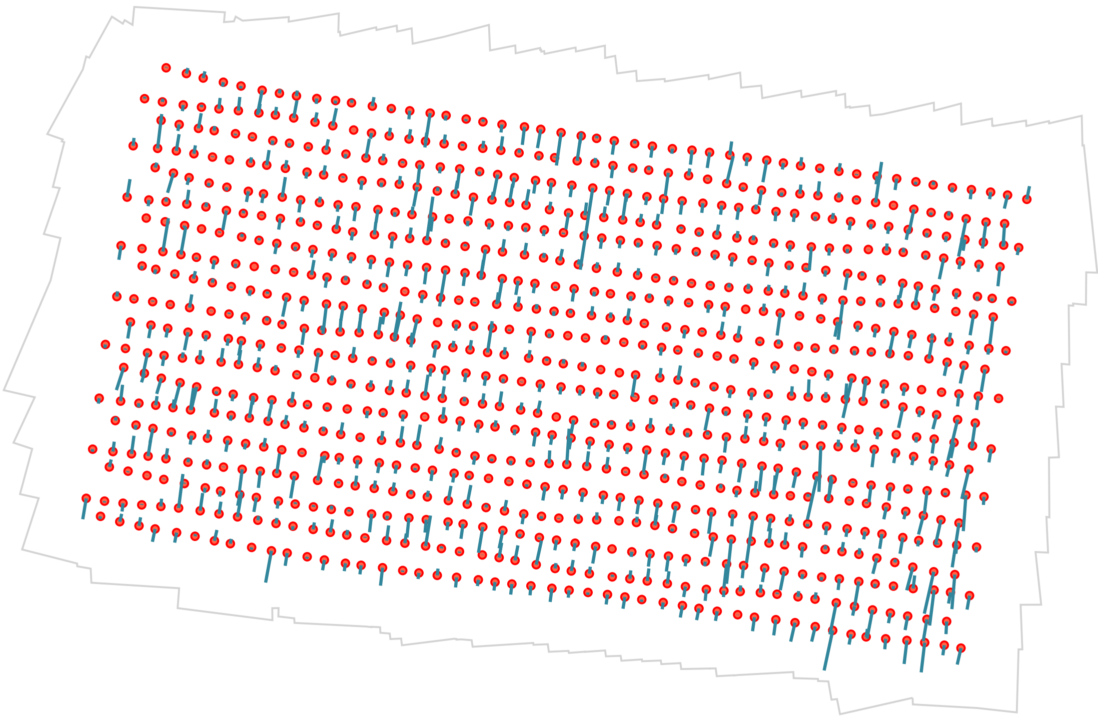
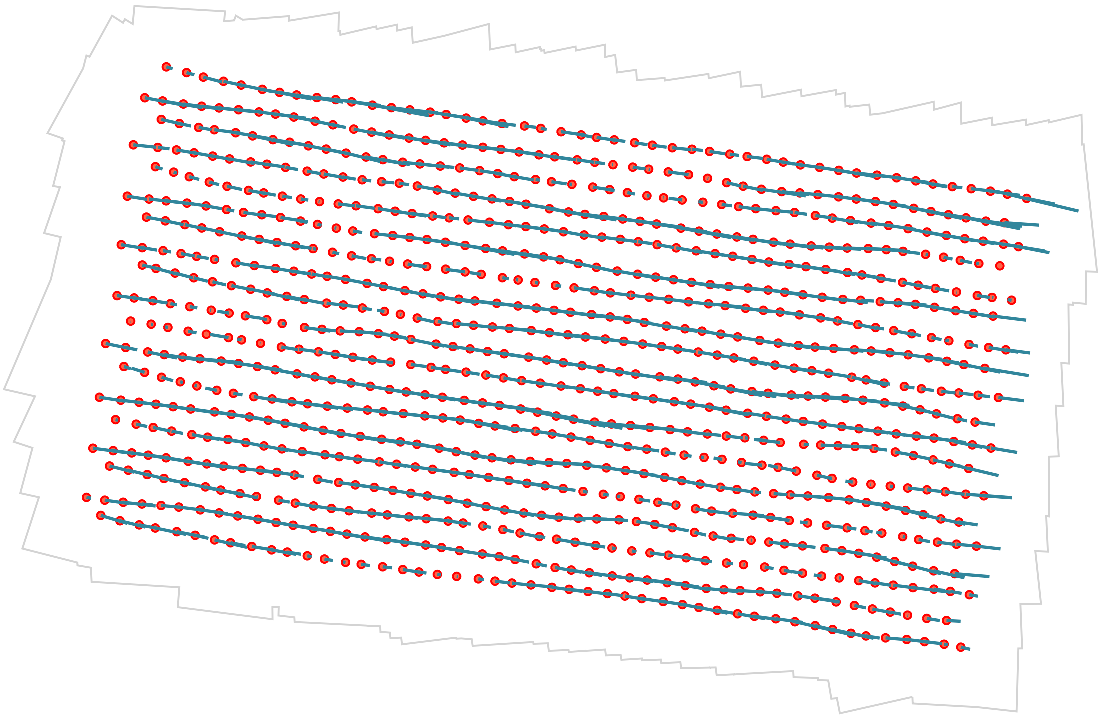
Residuals of Attitude observations
Roll angle



Pitch angle



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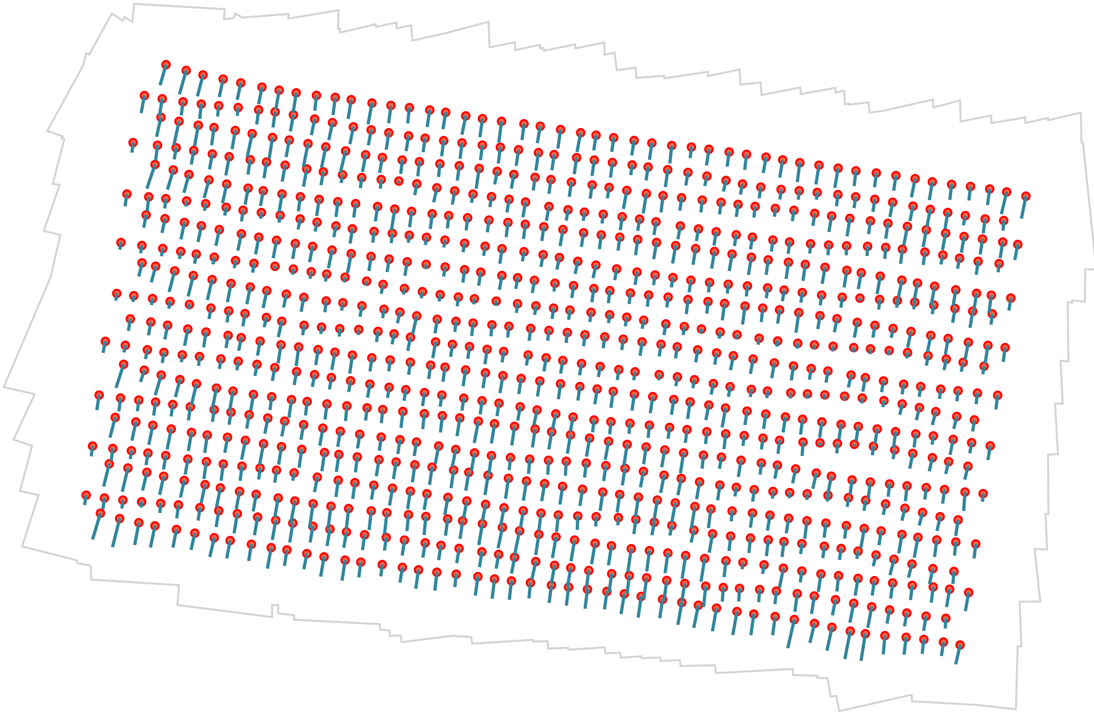
Yaw angle



	no	redundancy	bias	rmse	max
Roll	893	1.00	-1.2 deg	3.1 deg	15.7 deg
Pitch	893	1.00	-4.0 deg	4.9 deg	11.7 deg
Yaw	893	1.00	-3.2 deg	16.1 deg	31.2 deg

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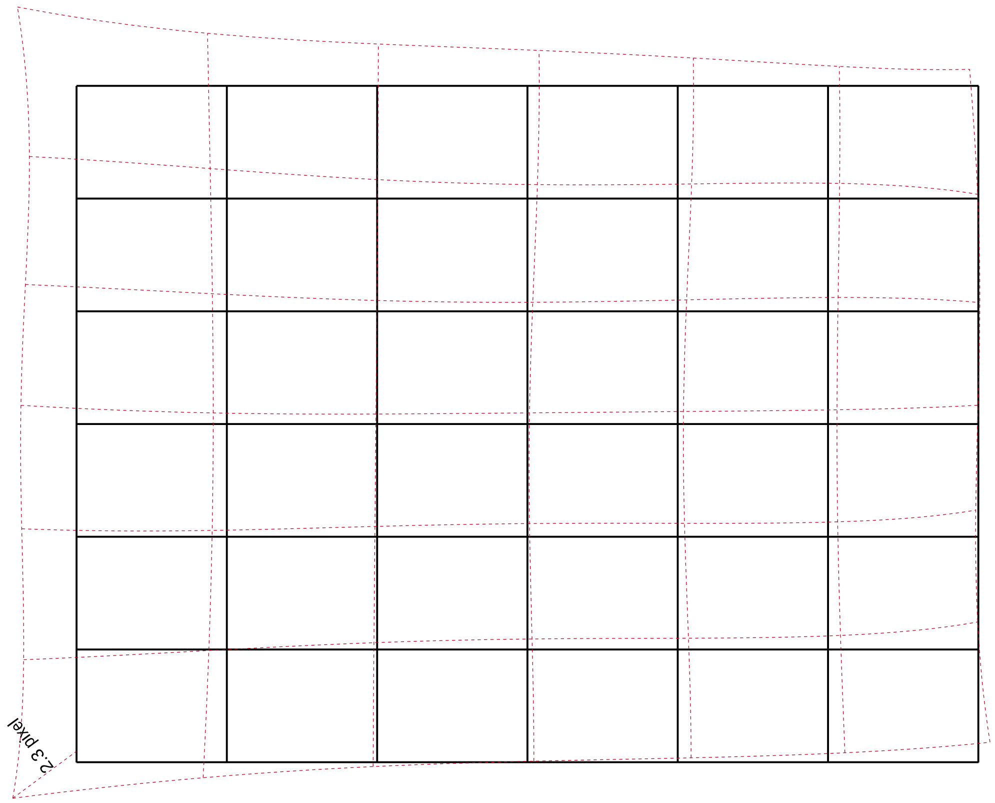
Estimated Image Deformation



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Part 2 : Precision Analysis

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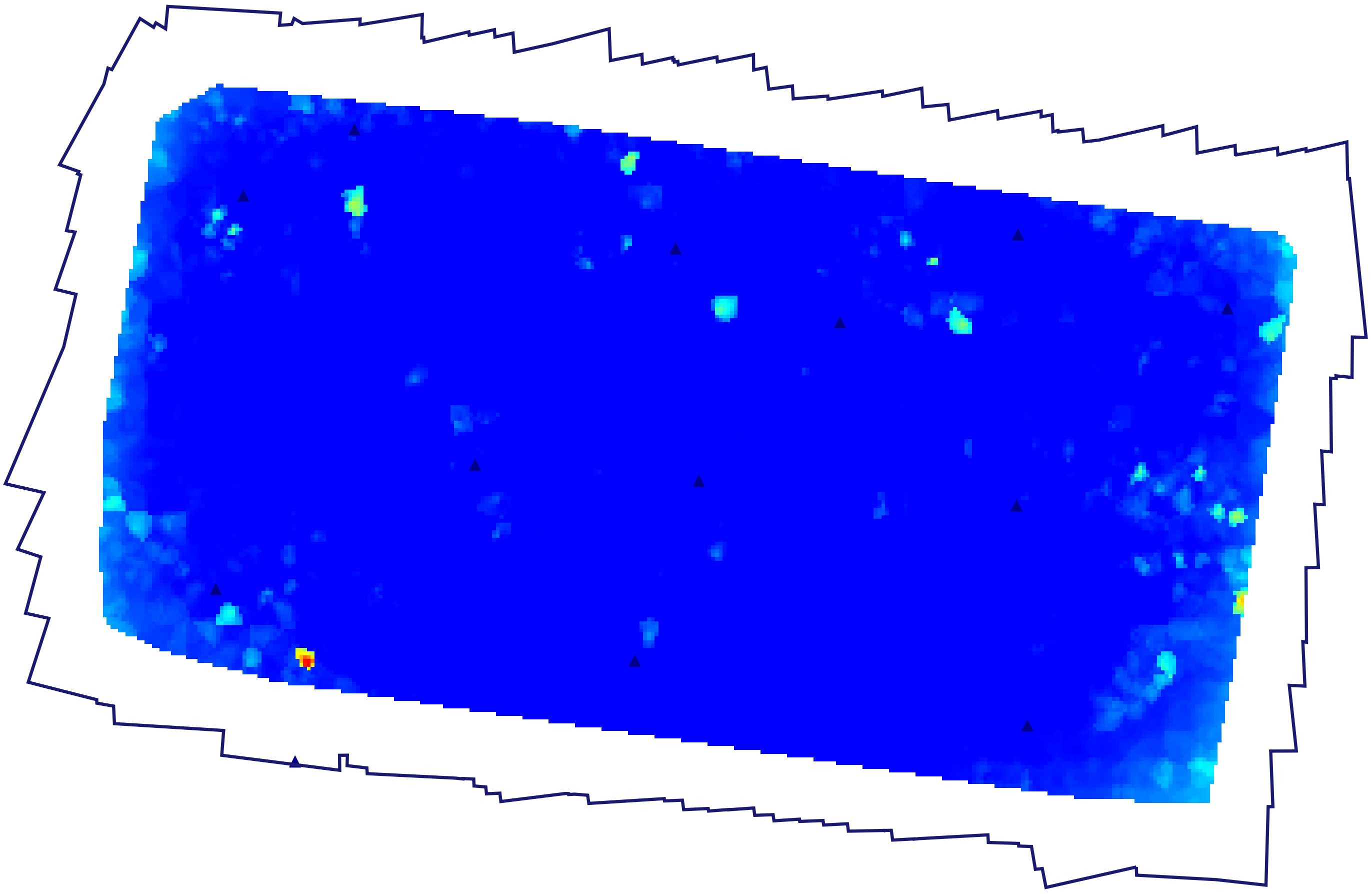
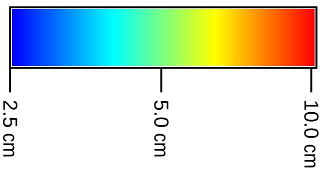
Precision in planimetry

Target Product : Premium [in planimetry 5.0 cm]





	mean	median	min	max
Easting	2.1 cm	2.0 cm	1.4 cm	28.1 cm
Northing	2.1 cm	2.0 cm	1.4 cm	13.1 cm

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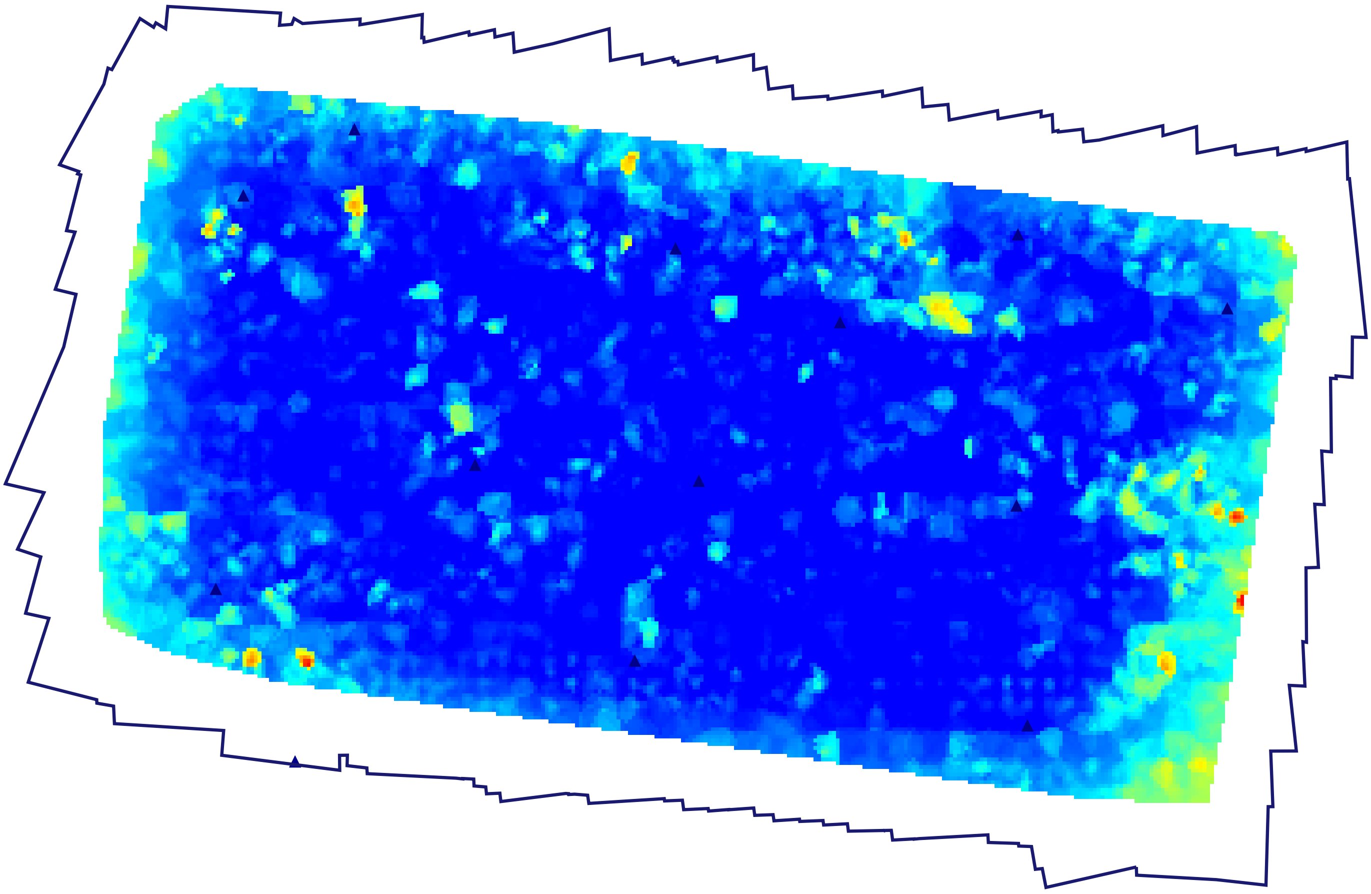
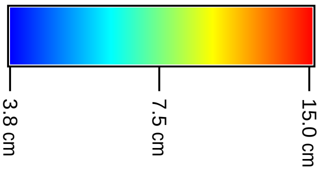
Precision in height

Target Product : Premium [in height 7.5 cm]





	mean	median	min	max
Height	4.4 cm	4.0 cm	2.3 cm	34.4 cm

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Part 3 : Reliability Analysis

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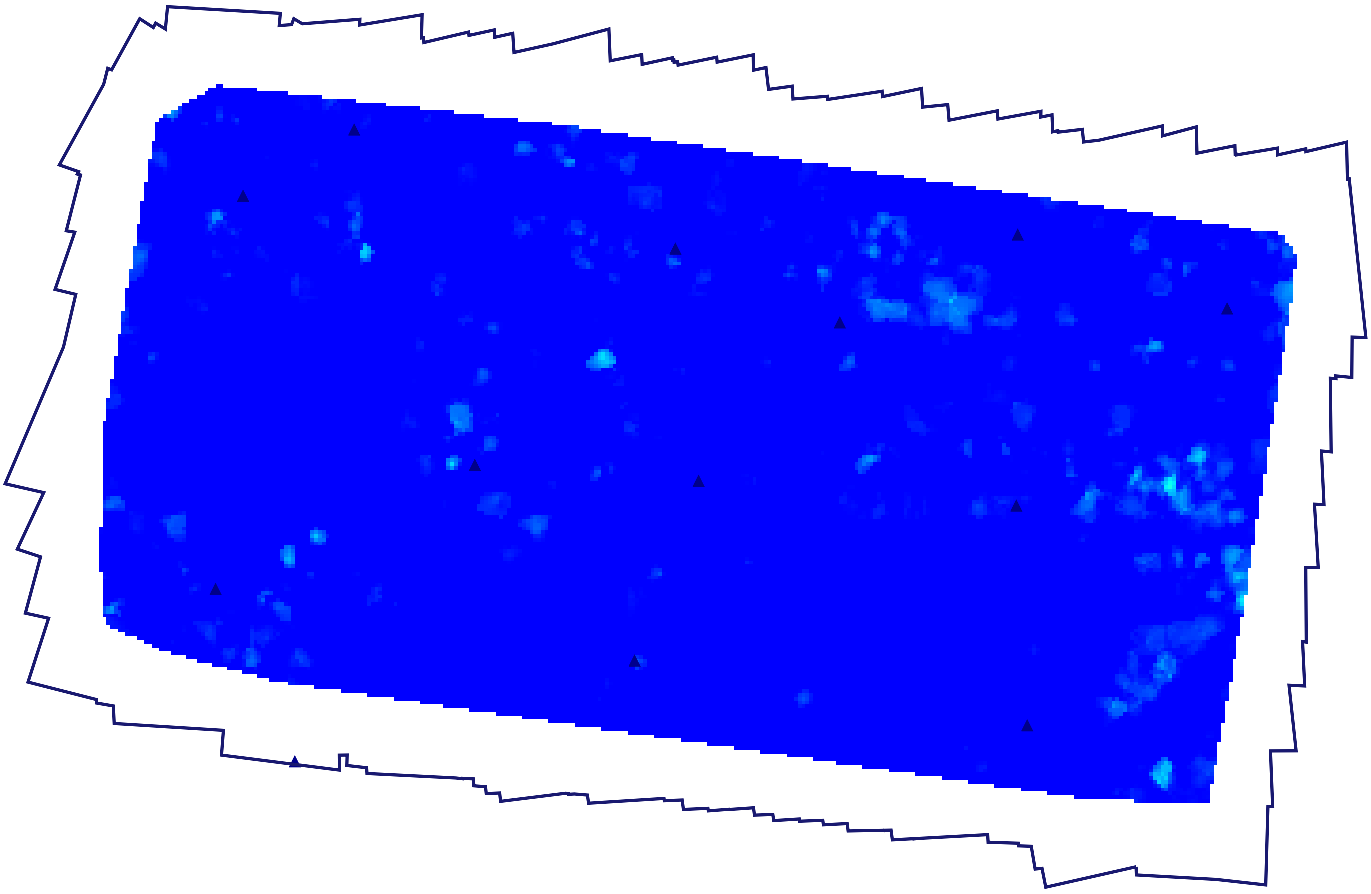
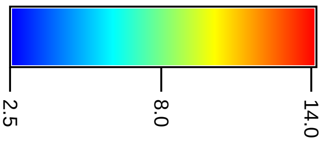
Reliability





	mean	median	min	max
Sensitivity	1.8	1.5	1.0	12.9

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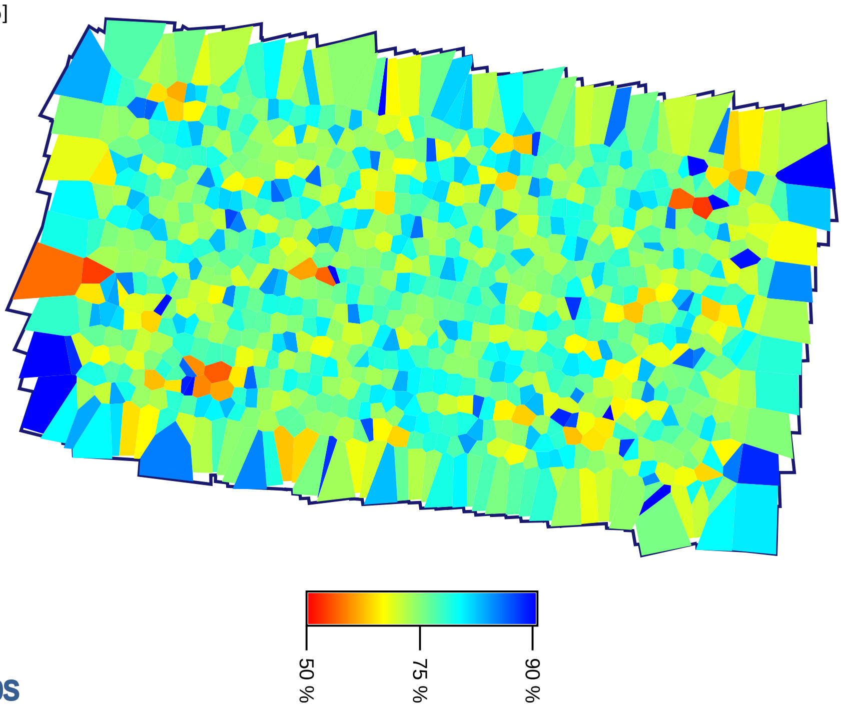
Part 4 : Flight Geometry Analysis

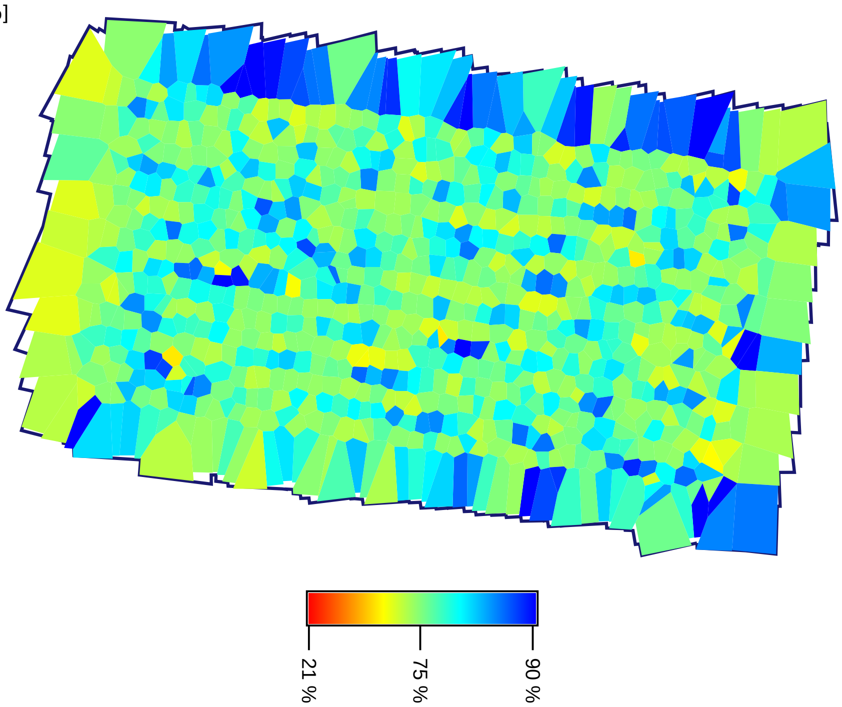
Flight Quality
Forward Overlaps

Target Product : Premium [75 %]



Sideward Overlaps

Target Product : Premium [75 %]



	Nominal Overlap			Actual Overlap			Coverage		
	Minimum	Median	Maximum	Minimum	Median	Maximum	Minimum	Median	Maximum
Forward Overlaps	70.3%	77.0%	83.9%	53.5%	75.9%	95.7%	47.3%	70.3%	90.9%
Sideward Overlaps	69.6%	76.6%	86.8%	53.4%	75.6%	98.7%	34.1%	69.6%	95.1%

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