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Surveying with Remote Piloted Aircraft Systems (RPAS)

System Capability & Preliminary Results Overview

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Table of Contents

List of Figures

1 Project Overview

The use of aerial photogrammetry for:

- Scaled 3D reconstruction of terrains and buildings
- Extracted volume- and distance calculations from reconstructed terrains
- Aerial terrain maps (Orthomosaic)
- Contour line maps
- Digital elevation maps (DEMs)
- Geo-referenced aerial imagery (current-> RGB, future-> NIR, IR, multi-spectral)

2 RPA System Overview

System development has been undertaken for photogrammetry purposes such as 3D object reconstruction and high accuracy terrain aerial surveying.

Note: The Aircraft referenced for this report for illustrative purposes may be interchanged to suite application endurance requirements.

Preliminary system details:

Y6 – multirotor RPA frame	Increased stability
○ Rated 2kg lift / motor ○ 15” rotary props	
12 – 15 min flight time / battery set	2 x 8000 mAh LiPo
○ Based on hover tests & preliminary grid flight tests	
2-5 cm positioning accuracy (X,Y,Z)	RTK GPS Positioning
○ <= 10Hz raw position calculation resolution ○ > 10Hz positioning resolution via interpolation & IMU integration ○ Position accuracy calculation via RTK standard deviations	

RF shielding	Increased RFI ruggedizing
- Shielding tape - Ferrite cores & common mode chokes - Altered wiring schemes	
Flight path generation & auto flights	Auto-pilot
- Automated Grid, POI, spiral flight path generation - Additional custom flight path generation & import capability - Navigation via EKF (extended Kalman Filter) GPS & IMU data integration - Extended system and navigation data logging and representation capability	
Camera stabilisation & auto control	Gimbal & stabilisation controller
- PID calibrated stabilisation via controller board - Integration and control from auto-pilot - Static and follow-me (from initial lock point) functionality	
Aerial imaging specs	Camera sensor
- Sensor Type: CMOS - Sensor Manufacturer: Sony - Effective Megapixels: 20.1 - Sensor Format: APS-C - Sensor size: 357.28 mm2 (23.20mm x 15.40mm) - Approximate Pixel Pitch: 4.25 micron	
Auto image triggering and geo-ref	Geo-tagging or post-processing
- Image triggering via flight plan waypoints and distance limits - In-flight or post-flight geo-referencing dependent on requirements	
Long-range wireless telemetry links	Duel wireless links
- Antenna diversity & dual polarization 20dB low-noise amplifier & FEC (forward error correction) - Frequency hopping & changeable data modulation schemes	

Figure 1: Current Y-6 multirotor frame with all interfaced hardware

3 System Implementation – Example, Horizontal Survey Grids

3.1 Flight Planning

Flight path planning is a relationship between the following:

- Image resolution -> ground sampling distance (GSD), cm/pxl
- Data quantity -> image overlap (side & frontal overlap), %
- Flight altitude -> terrain resolution <-> flight time
- Flight speed -> flight time <-> Cam triggering & geo-coding speed
- Area coverage -> flight altitude <-> flight speed

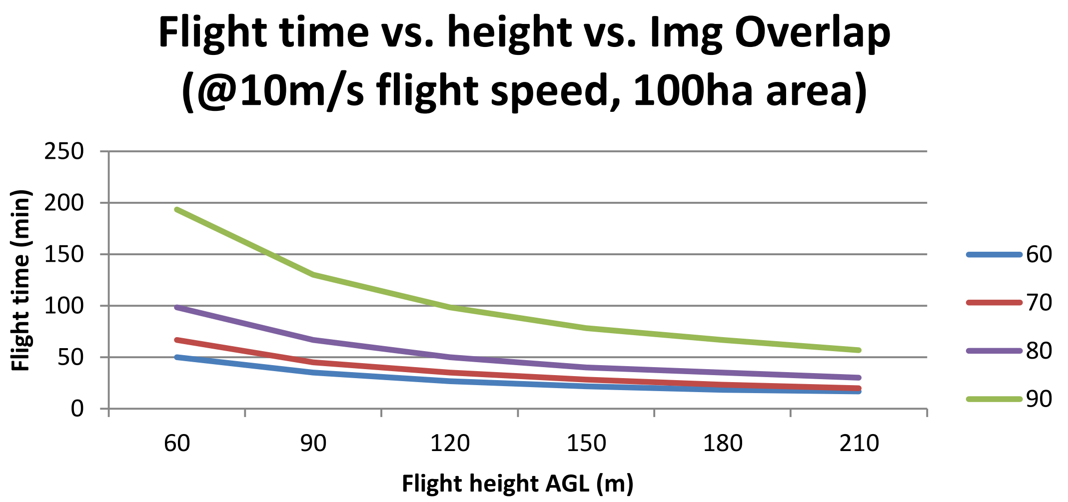


Figure 2: Relationship between flight altitude (m), image overlap (%) and flight time (min)

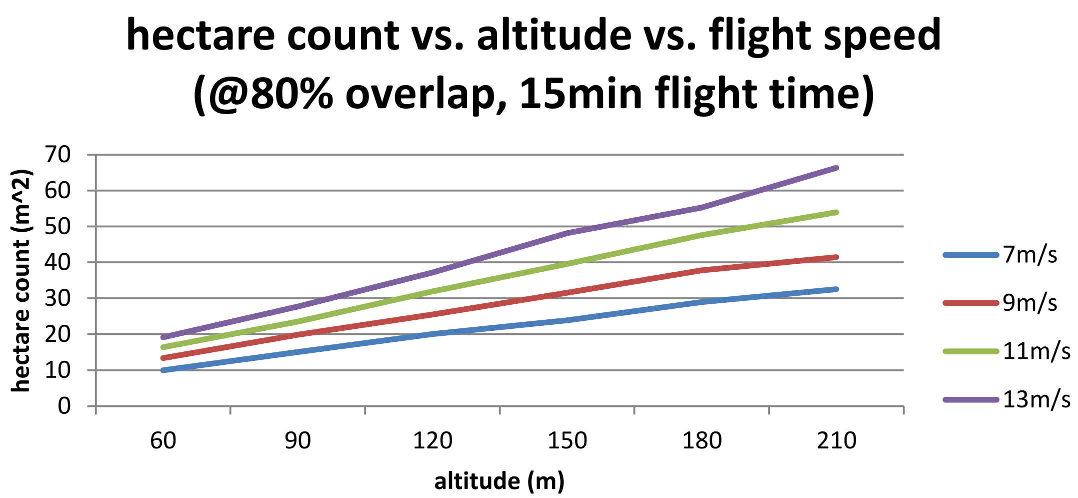


Figure 3: Relationship between area covered (hectare m^2), flight altitude (m) and flight speed (m/s)

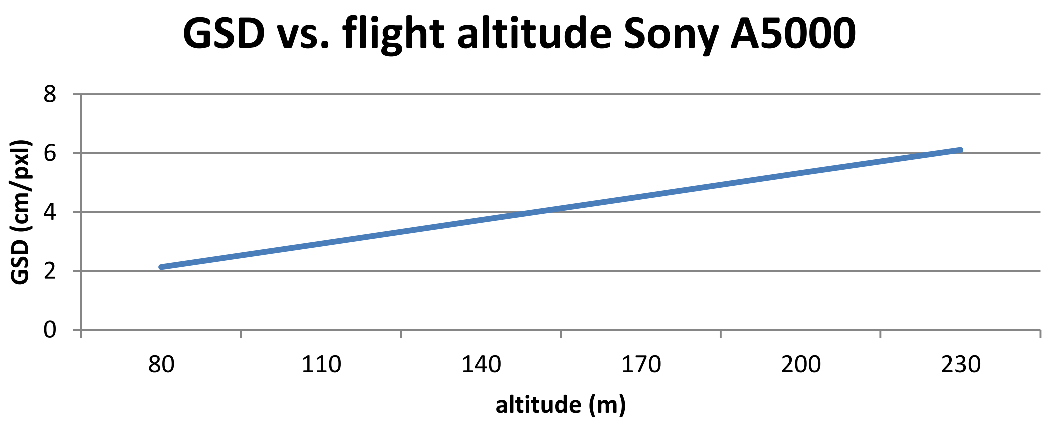


Figure 4: Relationship between terrain resolution (cm/pxl) and altitude (m) – camera specific

Figure 5: Screenshot of automatic flight plan generation in software tool

3.2 Flight Path Validation

Capability to display combination of system- and flight parameters from captured log files. Current telemetry data that is of importance:

- **Attitude:** RPA orientation specifics in terms of roll, pitch and yaw.
- **Baro altitude:** Altitude data from barometer sensor data.
- **Global positioning:** RPA positioning specifics based on EKF integrated GPS and IMU data.
- **GPS raw:** RPA positioning specifics based on RTK GPS data inputs alone.
- **Movement:** RPA movement speeds (air- & ground speed) and climb rates.
- **Mission data:** Identification of respective flight plan waypoints in log files.
- **Auto-pilot parameters:** Identification of all auto-pilot settings / parameters in log file.
- **Radio status:** Indicated signal strength, noise and transmission loss levels of wireless links.
- **Terrain report:** Terrain heights returned from referencing mapping data.
- **Camera trigger:** Specification of camera triggering commands.
- **System status:** Auto-pilot and battery status readings via system control sensors.

Developed interactive interface to display flight path logs and measurement data (currently images) in Google Earth environment:

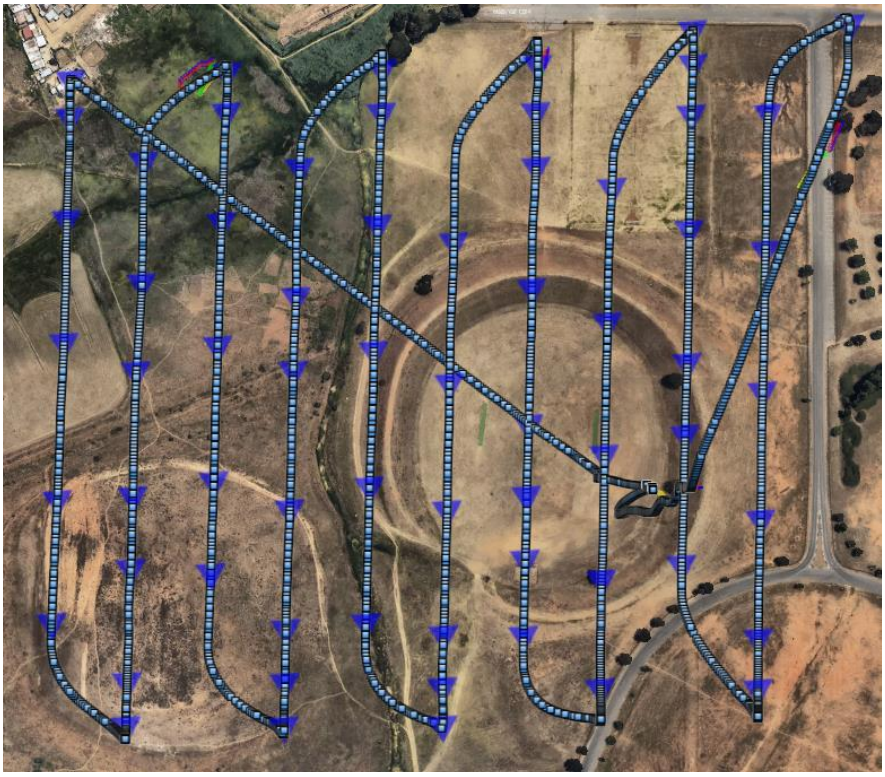


Figure 6: Top-view display of implemented single-grid flight, in Google Earth.

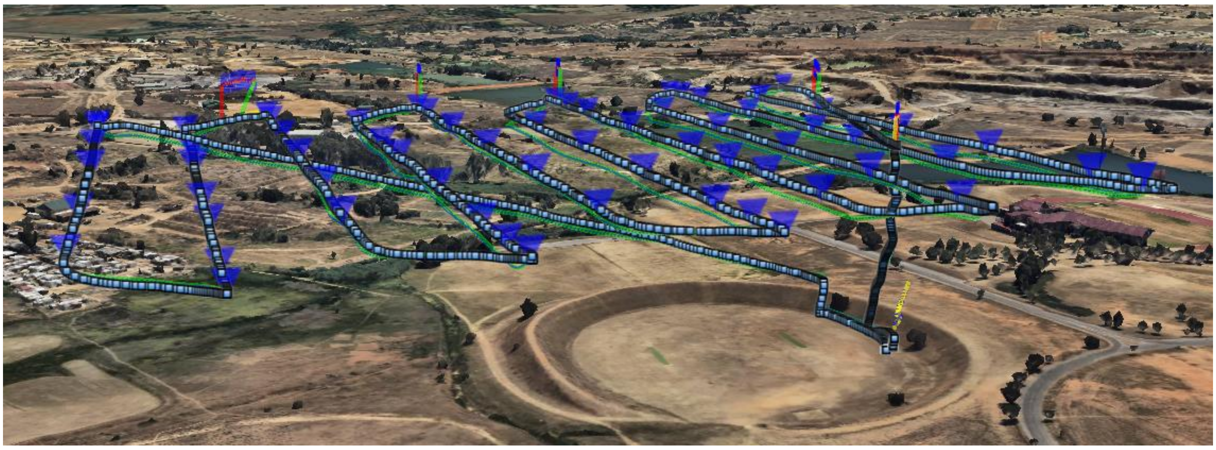


Figure 7: Slanted side-view display of implemented single-grid flight, in Google Earth

Figure 8: Flight and measurement data (currently geo-referenced images) displayed in Google Earth environment by clicking on respective objects in projected flight path.

3.3 Measurement Data Validation

The quality of the measurement data needs to be validated for result generation purposes. For small-area surveying and 3D terrain / object reconstruction these processes include the following:

- Validation of image overlap.
- Identification of average number of keypoints detected between images.
- Relative geo-referencing / repositioning of images via identified keypoints between images.
- Absolute geo-referencing and scaling of image dataset according to ground control points.

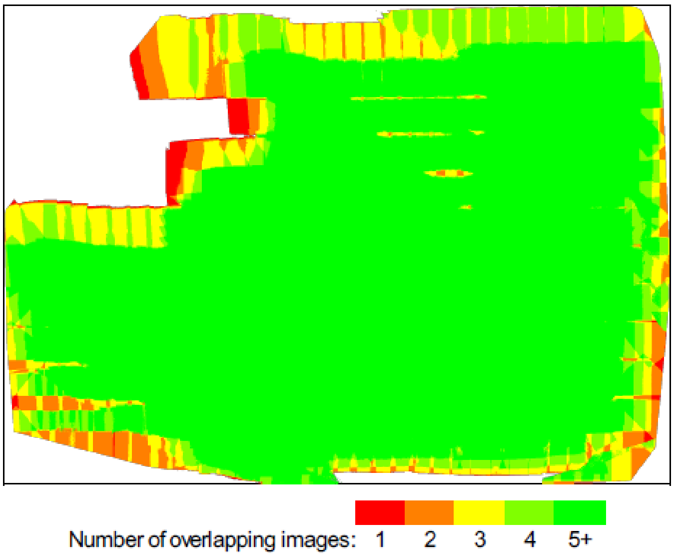


Figure 9: Identification of image overlapping detected in dataset

	Number of 2D Keypoints per Image	Number of Matched 2D Keypoints per Image
Median	35751	11754
Min	20089	333
Max	54981	30486
Mean	36350	11973

Figure 10: Example of number of matching keypoint / tie-points identified between images in dataset

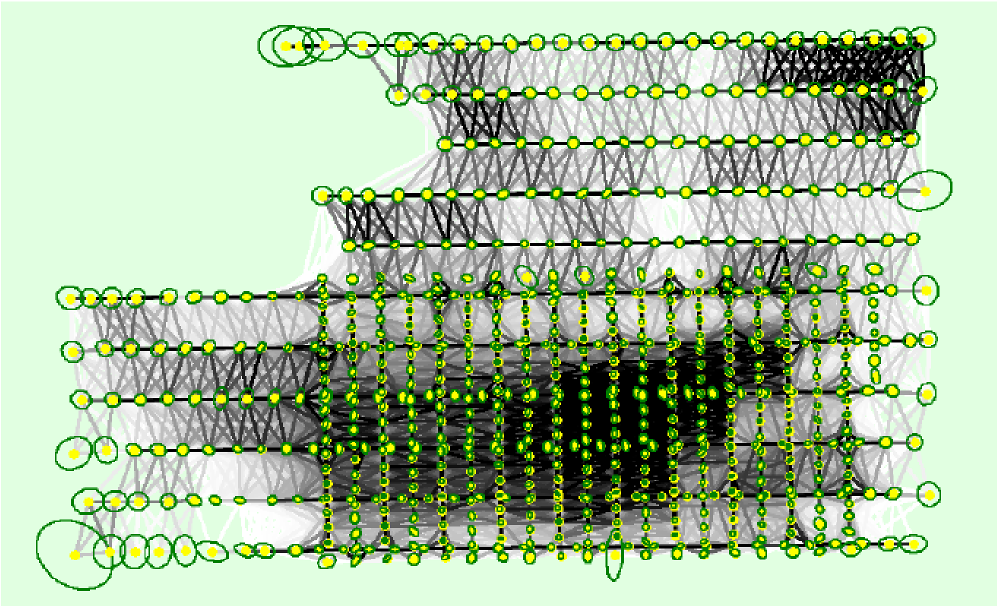


Figure 11: Relative geo-referencing of images, based on number of keypoint matches between neighbouring images in dataset, also showing image placement uncertainty with green circles.

GCP Name	Accuracy XY/Z [m]	Error X [m]	Error Y [m]	Error Z [m]	Projection Error [pixel]	Verified/Marked
P4_final (3D)	0.020/ 0.020	-0.042	0.004	-0.053	1.988	16 / 16
P1_final (3D)	0.020/ 0.020	0.015	-0.029	-0.028	0.694	16 / 16
P6_final (3D)	0.020/ 0.020	0.021	-0.012	-0.004	1.322	9 / 9
P8_final (3D)	0.020/ 0.020	0.015	0.031	0.015	1.017	22 / 22
P9_final (3D)	0.020/ 0.020	-0.002	-0.002	0.025	0.866	22 / 22
P10_final (3D)	0.020/ 0.020	-0.011	-0.060	0.075	0.700	28 / 28
P7_final (3D)	0.020/ 0.020	-0.003	0.052	0.004	1.072	22 / 22
Mean [m]		-0.000835	-0.002123	0.004740		
Sigma [m]		0.019907	0.034248	0.037609		
RMS Error [m]		0.019924	0.034314	0.037907		

Figure 12: Example, absolute geo-referencing and scaling of matching data between images via RTK-based ground control points.

4 Processing Deliverables

Deliverables are currently based on the use of an RGB camera. Deliverables may be diversified to other applications, for example agriculture, powerline surveys, high-accuracy model reconstruction by use of additional equipment.

4.1 Intermediate Workflow Processes

Scaled terrain / model reconstruction can be broken up into a number of processes to achieve a final model for surveying purposes. It is graphically displayed by the following figures.

- Import datasets and terrain ground control points (GCPs)

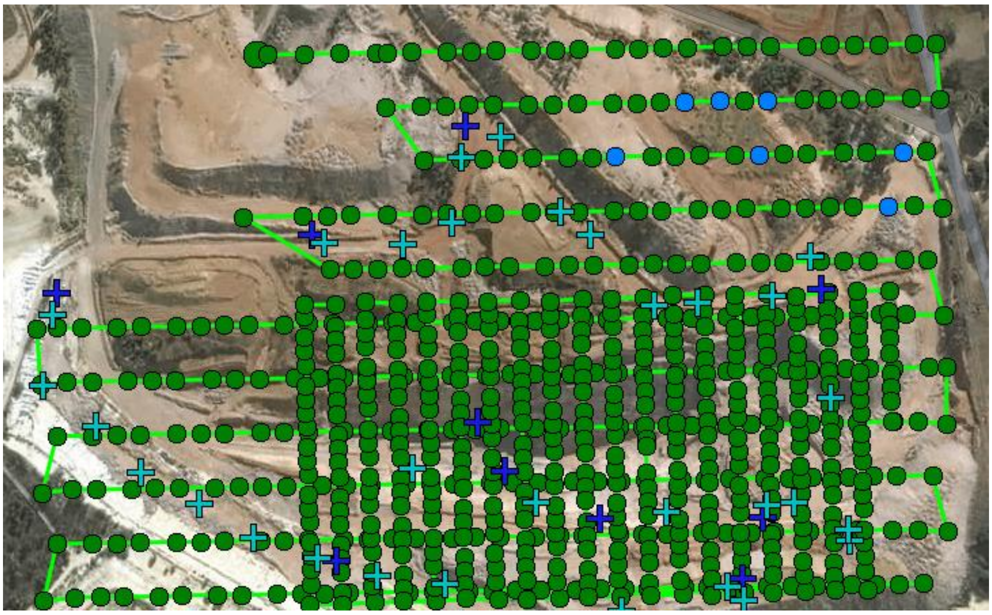


Figure 13: Project creation with different datasets

- Matching points determined between images to produce a sparse 3D terrain / model representation (point cloud)

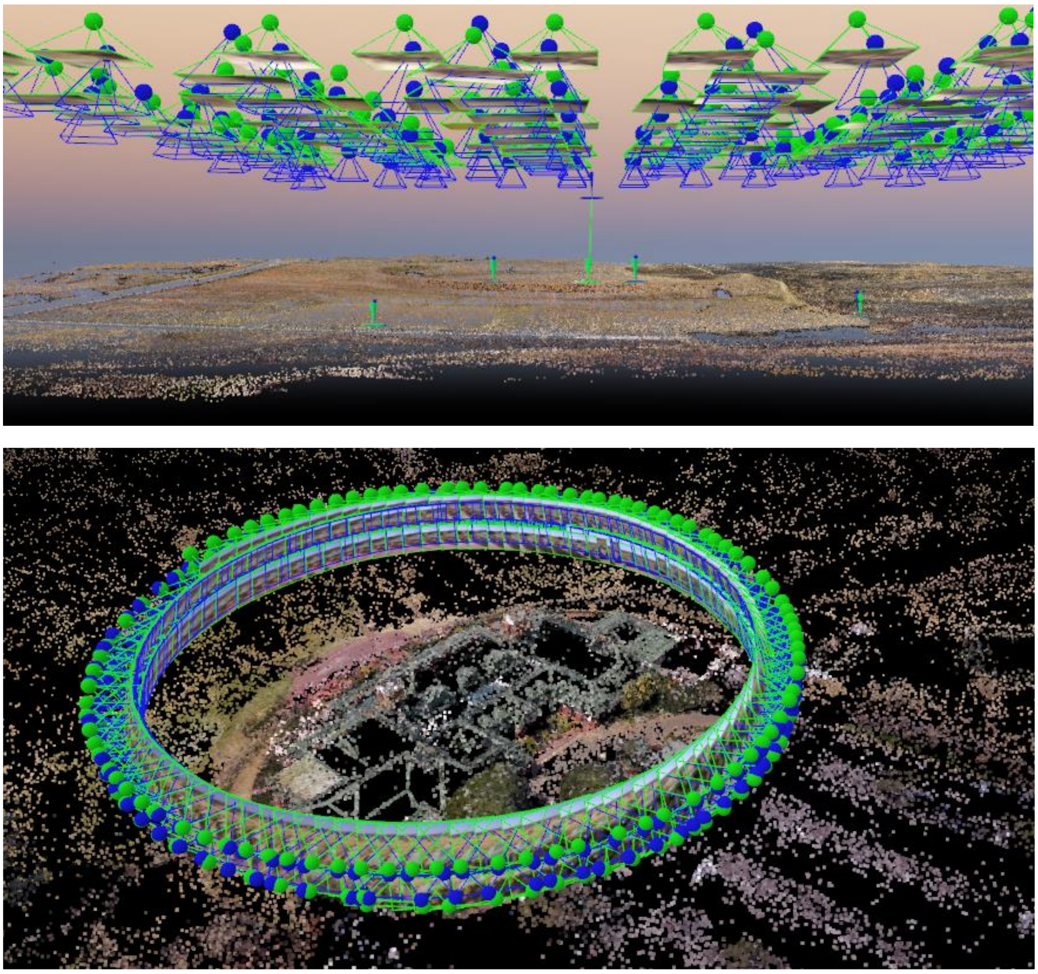


Figure 14: Point cloud generation for terrains predominantly with grid-based datasets (top) vs. Point-of-interest (POI) datasets for model rendering (bottom).

- Absolut geo-referencing and scaling of point cloud, with addition of matched pixel groupings.

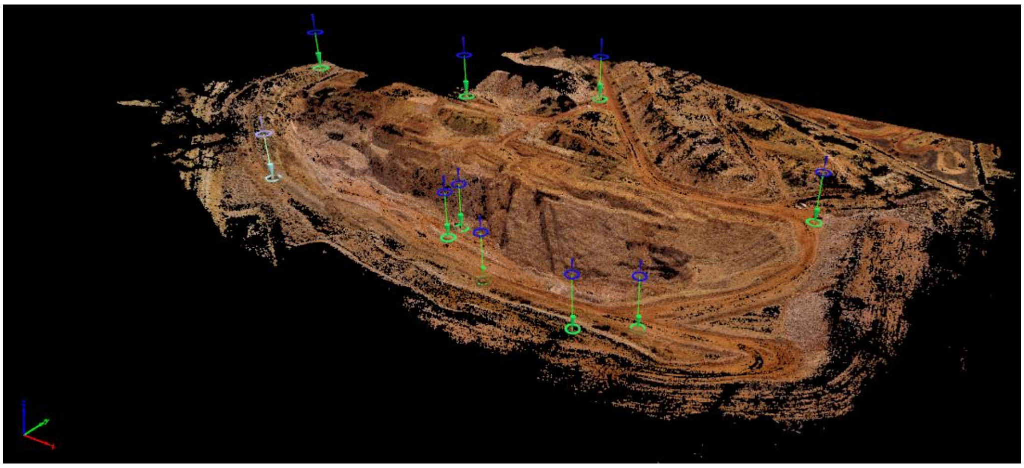


Figure 15: Absolute geo-referencing and scaling of reconstructed terrain / model.

- Point cloud data are connected to form solid terrains / models (meshing), with addition to image context over the meshed terrain / model.

Figure 16: Fully reconstructed terrain / model with overlaid image context.

- If there are very complex areas in the terrain / model, especially very detailed small areas, the models need to go through a final “sanitation” process. (A lot of the time this also depends on which measurement- and image processing techniques are implemented)

Figure 17: Point cloud filtering and sanitation process to improve quality of more detailed area.

4.2 Deliverables

There is a set of deliverables available from current photogrammetry processes with RGB cameras (with purpose to extend in future with additional camera types and point cloud rendering equipment).

- Geo-referenced orthomosaic maps
- Geo-referenced digital elevation maps
- Contour line maps
- 3D exportable point clouds (for modelling and image processing software tools)
- 3D exportable meshed models (for modelling and terrain analysis software tools)
- Terrain dimension and volume calculations

Figure 18: Geo-referenced orhtomosaic map from of aerial image dataset (example: mining pit)

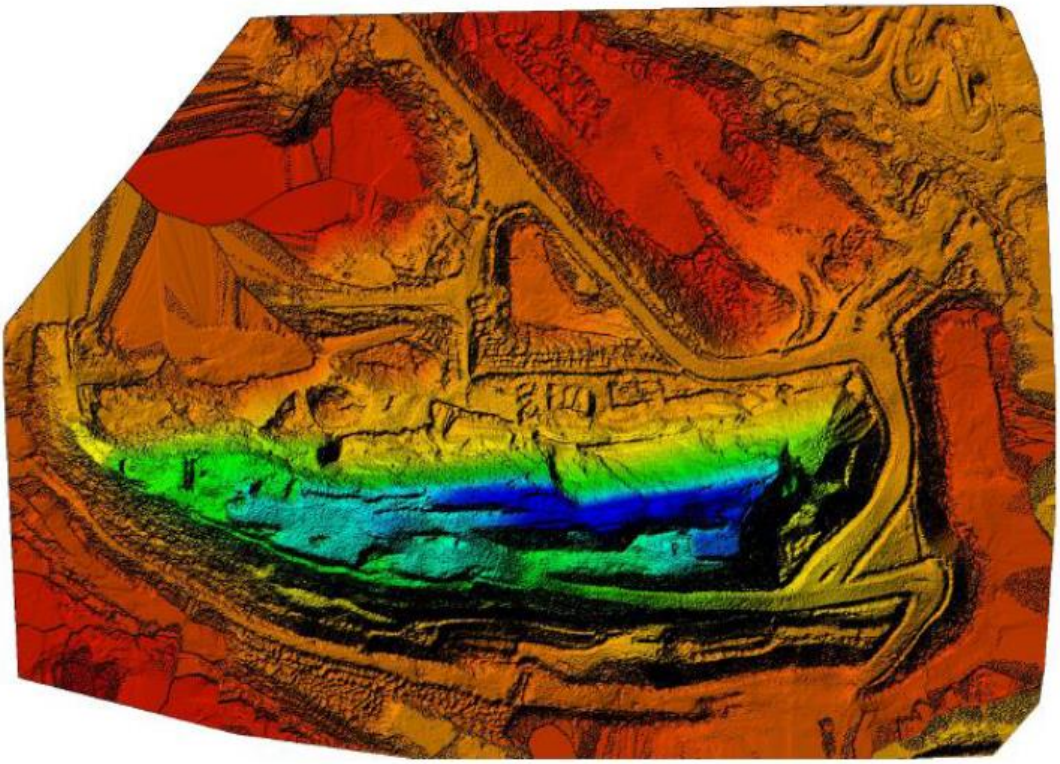


Figure 19: Digital elevation map (DEM), from reconstructed 3D terrain (example: mining pit)

Figure 20: Contour line map, created from reconstructed 3D terrain (example: mining pit)

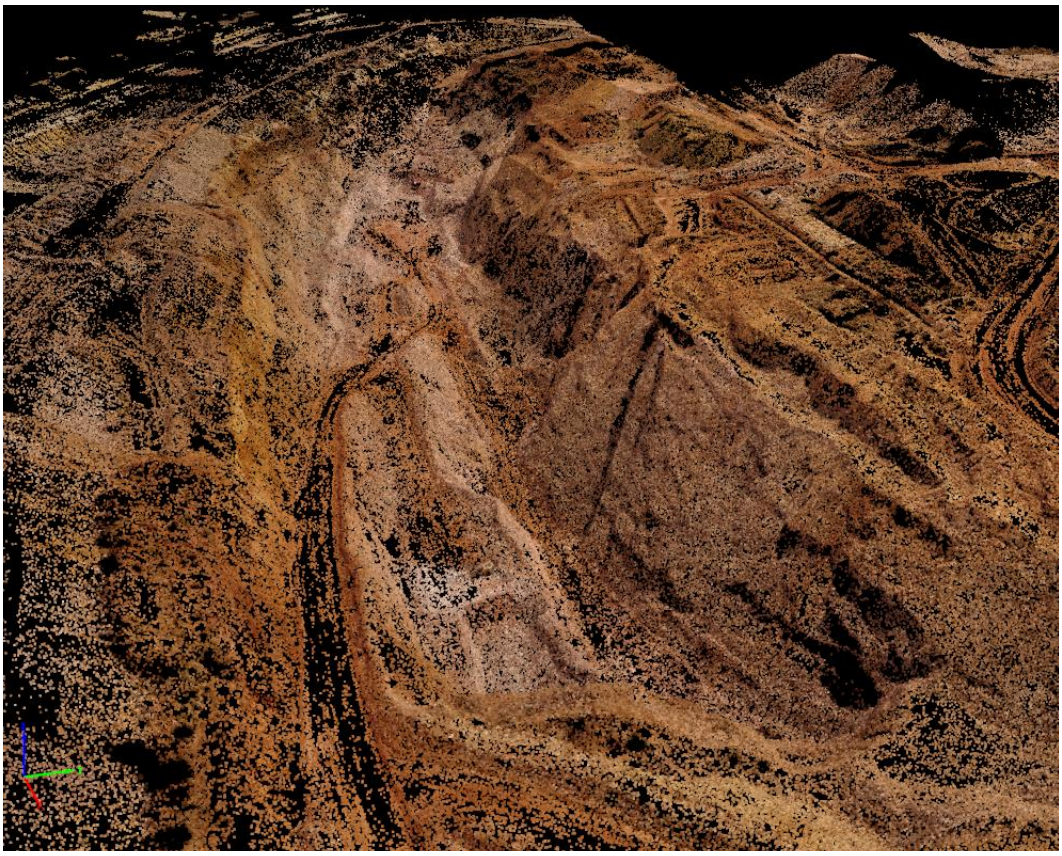


Figure 21: Scaled 3D point cloud reconstruction from surveyed area (example: mining pit)

Figure 22: Scaled, fully constructed, 3D terrain of surveyed area (example: mining pit)

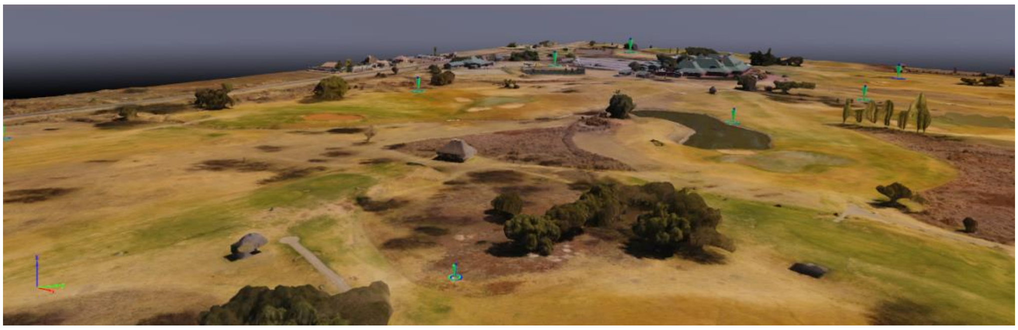


Figure 23: Scaled, fully constructed, 3D terrain of surveyed area, with identified reference location markers (example: golf course)

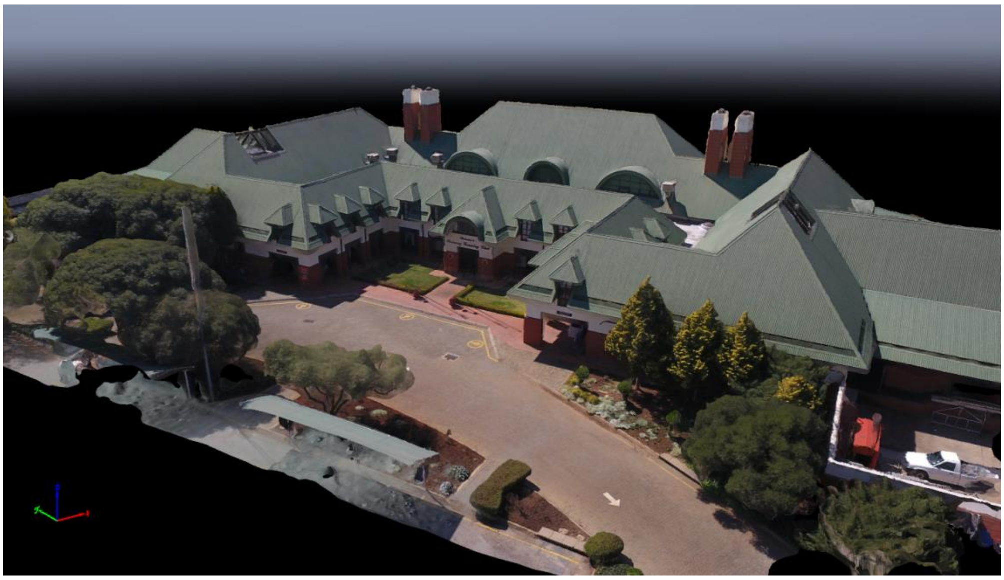
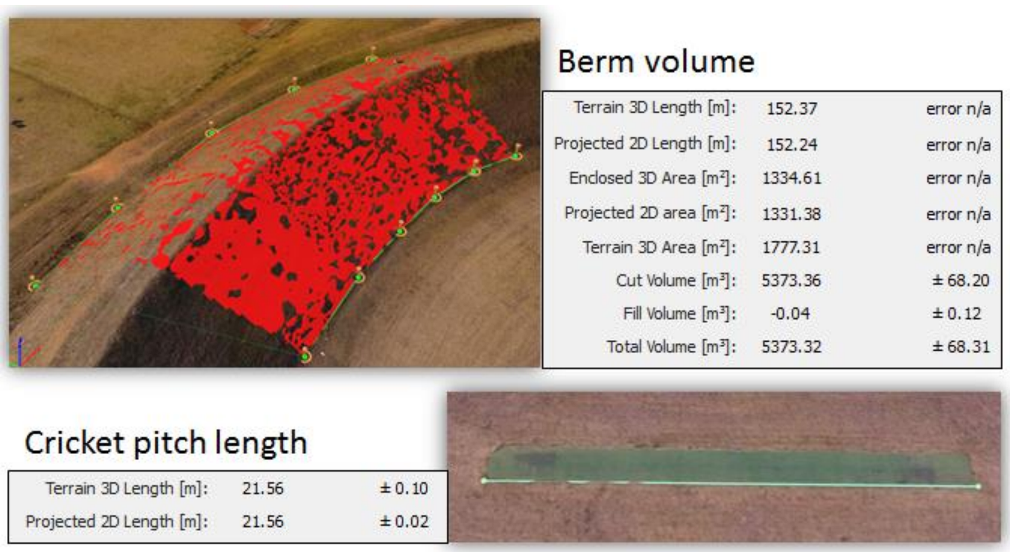


Figure 24: Scaled 3D reconstruction of more detailed area (example: building)



Berm volume

Terrain 3D Length [m]:	152.37	error n/a
Projected 2D Length [m]:	152.24	error n/a
Enclosed 3D Area [m²]:	1334.61	error n/a
Projected 2D area [m²]:	1331.38	error n/a
Terrain 3D Area [m²]:	1777.31	error n/a
Cut Volume [m³]:	5373.36	± 68.20
Fill Volume [m³]:	-0.04	± 0.12
Total Volume [m³]:	5373.32	± 68.31

Cricket pitch length

Terrain 3D Length [m]:	21.56	± 0.10
Projected 2D Length [m]:	21.56	± 0.02

Figure 25: Dimension and volume calculations based on scaled reconstructed 3D terrain