Repeat aerial survey of a mining site in Kiruna, Sweden

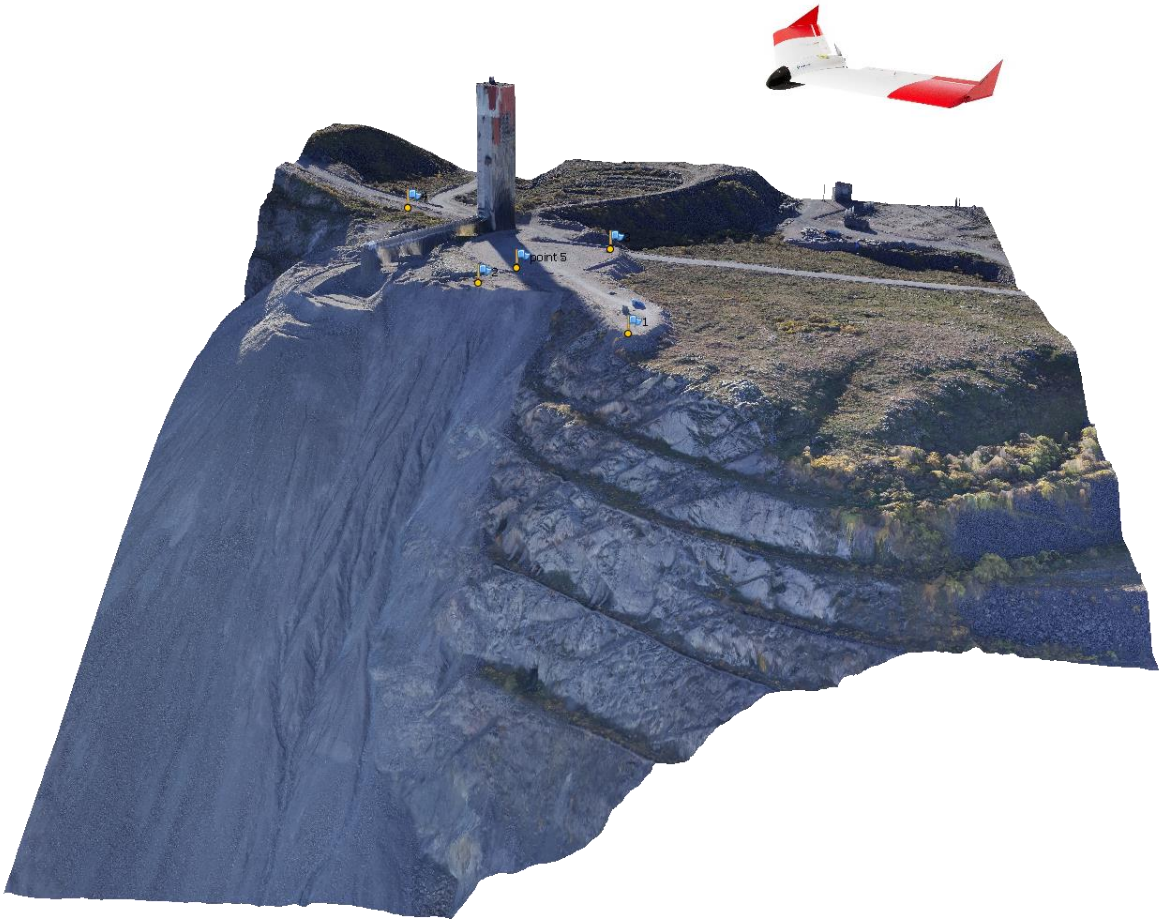

Figure 1. The test site on top of the Kirunavaara Mountain, Kiruna, Northern Sweden.

Summary

An Iron-ore mining site in Kiruna, Northern Sweden was repeatedly surveyed with a small unmanned aircraft system (UAS) on two different dates. Results show that the point measurement accuracy was 0.8, 0.8 and 1.3 cm (RMS) in Easting, Northing and Height. The height accuracy (RMS) of individual grid points in the surface model (DSM) was 3 to 4 cm for smooth and vegetated horizontal surfaces and 5 to 8 cm for steep smooth and rough surfaces.

Background

The UAS-survey demonstration was part of the conference program of the Nordic Mining Surveyor's meeting held in Kiruna sept. 16–18, 2014. The objective of the demonstration was to show the complete workflow from initial flight planning and flight operations to data processing and accuracy assessment. The goal was to produce the following products:

- Dense point cloud
- Surface model
- Orthophoto mosaic
- Textured 3D-model

Site

The demonstration area was at the top of the Kirunavaara Mountain which is the site of the LKAB company´s iron-ore mine. The topography was varying with both horizontal surfaces and steep slopes made up of waste rock to near-vertical walls of exposed bedrock. Parts of the area were covered with alpine vegetation types mainly consisting of low shrubs and scattered deciduous trees (figure 1).

Reference data

The conference organisers had initially prepared for the UAS demonstration by establishing a set of five signalled ground control targets. The target coordinates were measured with a high-grade RTK-GPS system. The size of the surveying area was kept relatively small (about 150 x 100 m) in order to be practical for mapping with a helicopter-type UAS that was also scheduled for the demonstration. After the initial flight it was decided to increase the number of points to provide a more comprehensive dataset for accuracy assessment. The final set consisted of 16 points. Each one was marked with white spray paint. The initial set were large double triangle patterns (100 x 70 cm) whereas the additional 11 points were marked with small circular dots, 10 cm in diameter (figure 2).

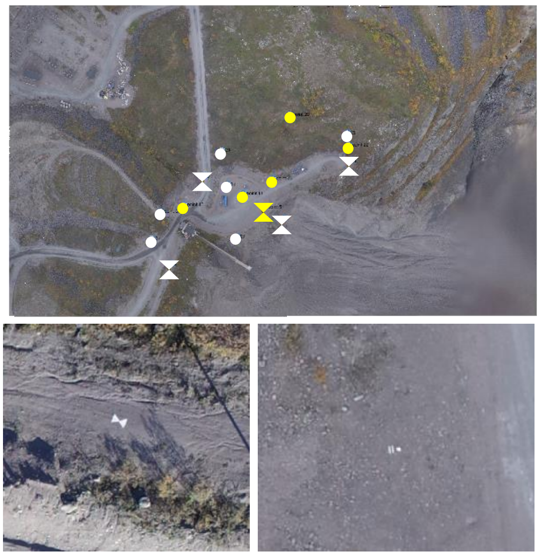

Figure 2. Ground reference points used for photogrammetric processing (white) and as independent check points for evaluation (yellow). Two different types of spray-painted patterns were used. The larger (100x80cm) double triangle targets were highly visible (lower left). However the small circular dots (10 cm diameter) were found to be adequate for a flying height of 150 meters and more practical to establish (lower right).

The SmartOne UAS

The aerial survey was performed with a Smartplanes SmartOne-C aircraft (figure 3). A rugged tablet computer was used as ground control station running the Smartplanes GCS ground control station and Aerial Mapper quick-look mosaicking software.

Figure 3. The Smartplanes SmartOne-C unmanned aircraft has a wingspan of 120 cm, a take-off weight of 1.2 kg (including camera) and a flight endurance of 45 minutes. The aircraft is hand launched and recovered by skid landing.

Camera

The camera used was a Ricoh GR (Figure 4) which is the current standard camera provided with the SmartOne UAS. It has a large APS-C size sensor (24 x 16 mm) with 16 Mpix resolution and a wide-angle fixed focal length lens (F=18.3). The high quality lens in combination with a large sensor and a relatively moderate Mpix count provides for both low noise levels and adequate resolution. It also dramatically improves the photo quality in poor light conditions compared to other cameras with smaller sensors. Another important feature is that the camera does not have an antialiasing filter which results in sharper and more distinct textures which in turn improves the accuracy in the photogrammetric processing.

Figure 4. The Ricoh GR camera is a high-end compact camera. It features a large APS-C size sensor and a fixed wide angle lens f=18.3 mm, 1:2.8.

Flight

The flight conditions were favourable with low wind speed (2-5 m/s) on both days. The sky was clear on the first day. On the second day thin clouds were present. The photo altitude was set to 150 meters above ground level which corresponds to a ground sampling distance (GSD) of 4.5 cm. The photo overlap (both along and across track) was set to 80 percent which is the standard setting for high accuracy surveying. The focus was fixed to infinite distance. The target exposure time was set to 1/1000 of a second to minimise blur effects and the aperture was set to widest opening (1:2.8) to capture as much light as possible.

The photo-block size was specified to 440 x 310 m, primarily in order provide a full multiple-view coverage of the point targets but also to cover a bit more of the steep slopes and near-vertical rock surfaces directly east of the survey area. It was also slightly extended to the west so that it would cover an area with some interesting buildings and electric power installations.

After completing the take-off checklist the aircraft was hand-launched into the wind (Figure 5). After climb-out the aircraft was "parked" in circular holding pattern at 100 m above the take-off point. After performing the normal in-flight checking of the aircraft status using the ground station the aircraft was commanded to proceed with the photo block. Once the photo-block had been completed after 14 minutes the aircraft returned to the parking holding pattern and was subsequently brought in for a precision landing in assisted flight mode where the pilot can guide the plane using a RC-control unit.

Immediately after landing the photos (154 in total) were uploaded to the ground station computer and a quick-look photo mosaic was generated within a few minutes to validate the quality of the collected dataset before leaving the site.

Figure 5. Hand launch of SmartOne aircraft. Photo: LKAB

Processing

The datasets from both dates were processed with Agisoft Photoscan photogrammetric software (and later also using the Pix4D Mapper software with equivalent results). When processing the dataset from the first flight (2014-09-16) the 4 points in the corners of the survey area were used for georeferencing and the one in the centre was used for evaluation. When processing the second flight dataset (2014-09-17) the points were split into two sets. 9 of them were used for geo-referencing and the remaining 7 as check-points for evaluation.

The photogrammetric processing generated dense point clouds with 68 points per square meter, gridded surface models (DSM) with 18 cm ground sampling distance (GSD), orthophoto mosaics with a GSD of 4 cm and textured 3D-models (triangular mesh draped with photo textures), figure 6.

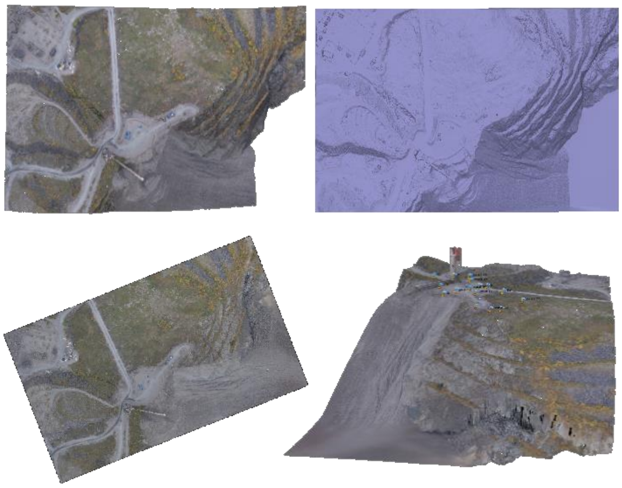

Figure 6. Processing results from the second flight (2014-09-17): dense point cloud (top left), surface model (top right), orthophoto mosaic (lower left) and a textured 3D-model (lower right).

Point accuracy

The accuracy of point target measurements was evaluated as the differences observed between predicted and actual coordinates for the check-point targets. The error of the single point evaluated for the first flight was 1.0, 0.3 and -1.4 centimetres in Easting, Northing and Height (Table 1). The second flight with 7 check points showed RMS-errors of 0.8, 0.8 and 1.3 centimetres in Easting, Northing and Height. The largest errors were 1.1, 1.7 and 2.6 cm and the systematic errors (bias) were 0.5, 0.6 and 0.8 cm (Table 2).

Table 1. Point measurement accuracy on check points no. 5 of the first flight (2014-09-16), n=1

Point ID	***X err. (cm)***	***Y err. (cm)***	***Z err. (cm)***
5	1.0	0.3	-1.4

Table 2. Point measurement accuracy on signalled check points of the second flight (2014-09-17), n=7

Point ID	***X err. (cm)***	***Y err. (cm)***	***Z err. (cm)***
11	0.4	1.7	0.7
14	0.4	0.7	2.6
15	0.8	1.1	1.5
16	1.1	1.0	-0.4
20	0.7	-0.8	1.2
22	-1.1	0.8	-0.4
5	0.8	0.6	0.4
RMS(cm)	**0.8**	**0.8**	**1.3**
Max (cm)	**-1.1**	**1.7**	**2.6**
Average (cm)	**0.5**	**0.6**	**0.8**

DSM accuracy

The DSM accuracy was evaluated by differentiating the surface models of the two dates (figure 7) and analyse the statistical differences within regions of different slope and surface types (figure 8). Assuming that the errors are independent and of equivalent magnitude for the two dates the precision of an individual DSM can be estimated by dividing the observed variance in half (table 3).

Some systematic difference trends can be noted outside of the area with GCPs. There is an increasing bias up to around 10 centimetres in the north-east corner (area b in figure 8). This is probably because the models can tilt slightly around the minor axis of the ground control.

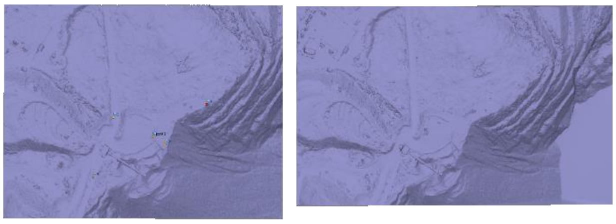

Figure 7. Surfaces models produced from the first (left) and second flight (right).

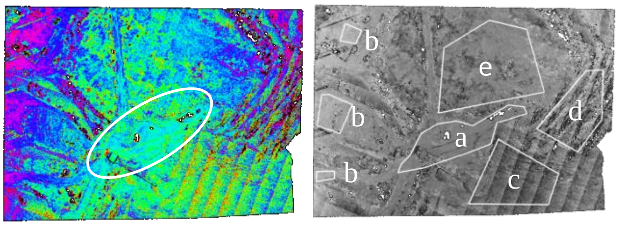

Figure 8. Differences between the two surface models indicated by colour (left) and greyscale (right). The range from red-blue and black-white corresponds to a height difference of 15 centimetres. Green colour and neutral grey shades indicates a height difference of less than 5 cm. The ellipse in the left figure shows the area with ground control points. The polygon outlines in the right figure show the areas used to derive statistics for various surface and slope types: a) horizontal smooth plane, b) horizontal smooth plane outside of the GCP area, c) Steep slope of waste rock, d) near-vertical walls of exposed rock, e) vegetation

Table 3. Height differences between DSMs from two dates for different types of surfaces, 18 centimetres GSD.

Surface type	Average difference (cm)	Standard deviation (cm)	Individual DSM precision (cm)
Smooth horizontal (within GCP area)	-1.3	4.6	3.2
Smooth horizontal (outside of GCP area)	9.8	4.4	3.1
Smooth steep slope	-6.6	7.1	5.0
Near vertical rock	1.6	12	8.4
Grass/shrubs	-0.1	5.1	3.6
Total	**0.1**	**7.2**	**5.2**

Conclusions

This study demonstrates that the Smartplanes SmartOne UAS equipped with the Ricoh GR camera can be used to efficiently survey a typical mining site and produce high resolution surface models with an accuracy in the order of 3 to 8 cm. Point target height measurements with centimetre-level accuracy can be achieved.

SmartPlanes

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