UAV PHOTOGRAMMETRY ACCURACY AND HIGH GSD INHOMOGENEITY

Usage of UAVs for flat roof drainage calculations

GSD terrain - roof [cm]	Flying height [m]	Building height approx. [m]
1 – 0.6	37	16
2.5 – 2.1	91	16
5 – 4.6	183	16

	n° GCPs	n° CPs	n° terrain CPs	n° roof CPs
Agisoft GSD 1cm, 2.5cm, 5cm	5	75	36	39
	7	75	36	39
	12	75	36	39
	30	75	36	39
BCC GSD 1cm, 2.5cm, 5cm	5	75	36	39
	7	75	36	39
	12	75	36	39
	30	75	36	39
Pix4D GSD 1cm, 2.5cm, 5cm	5	75	36	39
	7	75	36	39
	12	75	36	39
	30	75	36	39

	n° terrain GCPs	n° roof GCPs	n° terrain CPs	n° roof CPs
Agisoft GSD 1cm, 2.5cm, 5cm	7	0	58	35
	6	1	58	35
	5	2	58	35
	4	3	58	35
	3	4	58	35
BCC GSD 1cm, 2.5cm, 5cm	7	0	58	35
	6	1	58	35
	5	2	58	35
	4	3	58	35
	3	4	58	35
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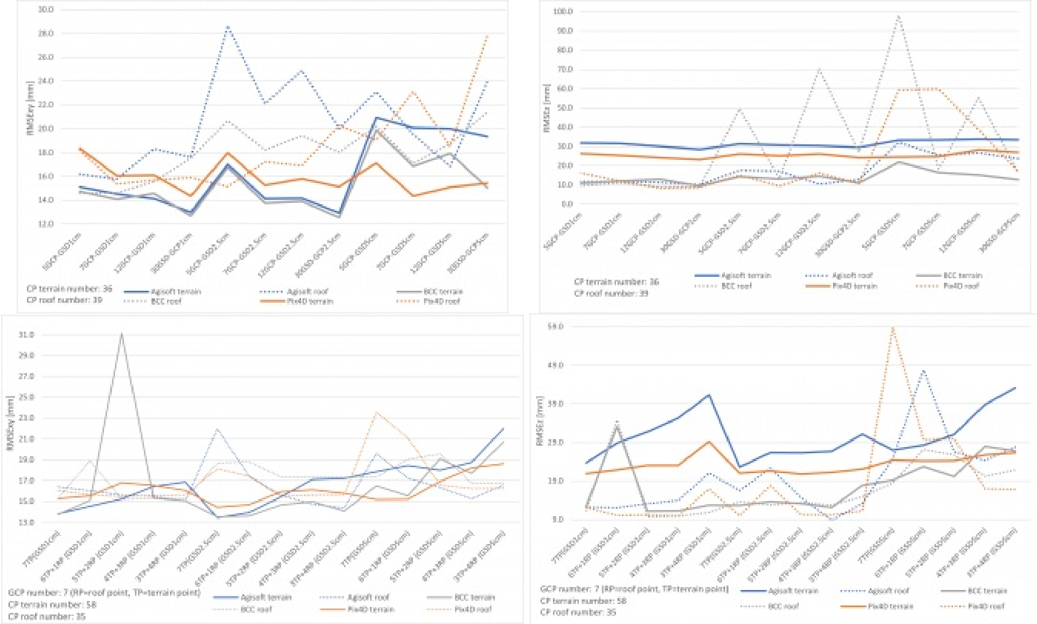
	5	2	58	35
	4	3	58	35
	3	4	58	35

Modelling of urban areas, with emphasis on flat roof drainage calculations, is one application field in which the use of UAVs has significantly increased in recent years. A calibration base, built at the Brno University of Technology' research centre in the Czech Republic, was observed from three different flying heights to explore the possibilities and limitations of UAV photogrammetry using low-cost sensors in the urban environment with high GSD inhomogeneity. The project also evaluated three currently available processing software solutions.

Today, the challenge of droughts is a topical issue both in the Czech Republic and in general. Water-supply problems are solved using water retention technology both in the countryside and in urban areas. Rainwater can be accumulated for later use or can soak into the soil. Accurate determination of rainwater runoff from roofs is an important step for effective planning. A correct roof drainage calculation depends on the roof shape and roof area and, in the case of planar roofs, in particular the accurate determination of the slope. The minimum slope of a flat roof should be 2%. Low-cost unmanned aerial vehicles (UAVs or 'drones') equipped with commercial cameras are frequently used for geospatial data acquisition. Thanks to their obvious advantages of affordability, speed and efficiency, UAVs are increasingly popular tools among geospatial professionals, and they can also be utilized effectively for the precise measuring of the spatial positioning of flat roofs. In line with the advancement of computer vision, many software solutions based on the Structure from Motion (SfM) algorithm have been developed, facilitating fast and efficient production of 3D object models. However, the geometric accuracy of such representations is affected by various factors including flight design, camera quality, the SfM algorithm and the georeferencing strategy.

The number and distribution of the ground control points (GCPs) is critical in the georeferencing stage. The geometric accuracy of the SfM photogrammetric 3D model is highly dependent on the georeferencing strategy. Accuracy is greatly dependent on the number of the GCPs introduced in the bundle adjustment (BA). The ratio of the number of GCPs and the number of photos should be 1:100-1:15 to achieve maximum vertical accuracy.



Software comparison

There have been various studies to analyse the use of UAVs in built-up areas, one of which was a project involving the UAV monitoring of a building zone in Hannover, Germany. The study involved photogrammetric analysis using various software packages. The testing field consisted of 33 GCPs placed on the terrain. GCP accuracy was around 2cm and image resolution was 1.7-3cm. The results showed a root mean square error (RMSE) of planar coordinates corresponding to 2cm and RMSE of elevation of 4-5cm, although the points near the boundary had high z-residual up to 9cm. Analysis of flat areas (car parks, roofs) indicated height differences between epochs in the range from -15cm to 15cm. The results of other studies using different software solutions have also shown potentially serious problems caused by the high inhomogeneity of the ground sample distance (GSD).

Based on a comparison of relevant studies, an accurate calibration field was designed at Brno University of Technology's Centre for Advanced Materials and Structures (AdMaS) to evaluate the capability of UAV imaging geometric accuracy. This field consisted of 105 GCPs placed on the terrain and also on roofs to evaluate the effect of GCPs at different heights. The geometric accuracy is crucial for the reasonable application of such photogrammetric outputs, namely for modelling urban areas and flat roof drainage calculations. The GSD inhomogeneity of images is high and the accuracy varies depending on, among other things, the pixel size, GSD and the number of GCPs. Today's photogrammetric software solutions mostly enable automatic calculation of the bundle adjustment. These are usually software packages with the minimal possibility of user intervention. The Pix4D, Agisoft, and Bentley's ContextCapture software packages were chosen for testing the roof spatial positioning accuracy.

Figure 1: AdMaS Centre â€“ Brno University of Technology, Czech Republic.

AdMaS calibration base

To achieve high-quality UAV testing results, it was proposed to set up a precise calibration base consisting of 105 GCPs, uniformly distributed over the area. The calibration base at Brno University of Technology's AdMaS centre enables UAV photogrammetric imaging at a GSD of 1-6 cm. Emphasis was placed on height segmentation; the GCPs were defined in various height levels including terrain, terraces and roofs. Four high-rise buildings with flat roofs were convenient for the accuracy testing with steep changes in GSD in the image. The height of buildings varied by around 16m. GCPs were marked by a square black and white target measuring 19x19cm. 3D coordinates were determined independently twice using terrestrial methods and the points of the measuring network were determined using GNSS. 3D coordinates recorded in ETRS89 were transferred into the Czech national coordinate system S-JTSK.

Figure 2: Ground control points.

UAV imaging

Imaging was planned for three height levels corresponding to an average GSD of 1cm, 2.5cm and 5cm on the terrain. A DJI Phantom 4 Advanced was used for the imaging. Side lap and end lap of the images was 85%. Three sets of images were captured with a total of 909 vertical images. Flight speed and shutter speed were defined with respect to the image blurring. Due to the building heights, the GSD in each image varies depending on the flying heights. For average values see Table 1.

Table 1: GSD inhomogeneity.

Processing

The choice of production photogrammetry software is an important question affecting the quality of the results. Many software packages provide different workflows and parameters for the implementation of SfM processing and multi-view stereo (MVS) algorithms for the point cloud generation. Three well-known commercial software packages – Pix4D, Agisoft Metashape and Bentley ContextCapture (BCC) – were compared based on the quality parameters and three metrics: RMSE of spatial coordinates X, Y, Z of check points (CPs).

Figure 3: Spare point cloud and the DJI Phantom 4 Advanced.

Firstly, the values of the projection centres were determined from dGPS/INS. Furthermore, image coordinates of the GCPs and CPs were measured, and tie points were automatically matched. Interior orientation parameters (IOPs) were calculated by self-calibration within the bundle adjustment (BA) process. A total of 30 GCPs, placed on the terrain, and 75 CPs, placed on roofs and the terrain, were used for the calculations and result evaluation. Different variants of GCPs and CPs in terms of number and distribution were proposed for BA (Table 2).

The final RMSE was calculated for the independent CPs. RMSE was observed separately for the coordinates of the roof CPs and the terrain CPs (Table 2).

Table 2: Distribution of terrain GCPs.

In the second phase, the calculation was based on seven terrain GCPs. The number of the terrain and roof points was gradually changed for each computational variant. Details of the distribution of the GCPs and CPs are shown in Table 3.

Table 3: Distribution of terrain and roof GCPs.

Results

The RMSE of planar coordinates and elevations of CPs were analysed using 5, 7, 12 and 30 GCPs. Coordinates of CPs were not included in BA calculations. The RMSE was observed with respect to the number of GCPs, software, GSD and location of the CPs (roof or terrain). RMS_{xy} of CPs placed on the terrain was stabilized with the usage of 7 GCPs; this trend was seen in all GSD variants, and further increasing the number of GCPs did not provide any significant accuracy improvement. The lowest $RMSE_{xy}$ of terrain CPs was observed for the image set with a GSD of 1cm, although the $RMSE_{xy}$ obtained using the GSD 2.5 cm and 5cm image sets was comparable and sub-pixel accuracy was achieved (see Graph 1). On the other hand, the $RMSE_{xy}$ of roof CPs showed slightly worse results.

Analysis of the software results showed differences between BA calculations in Pix4D, Agisoft and BCC. The $RMSE_z$ of terrain CPs was approximately two times worse than $RMSE_{xy}$ using Pix4D and Agisoft. However, BCC demonstrated a similar accuracy in the plane and elevation (see Graphs 1 and 2).

The $RMSE_z$ of CPs placed on roofs was mostly two times better than the $RMSE_z$ of CPs placed on the terrain. However, BCC calculations proved high $RMSE_z$ instability on roofs using GSD 2.5cm and 5cm (see Graph 2).

The final 3D model of the AdMaS object was produced using the optimal computational variant, GSD 1cm, and additional oblique images for the correct façade interpretation.

Figure 4: 3D model of AdMaS.

Conclusion

This project focused on UAV accuracy testing for flat roof drainage calculations with emphasis on production software, the number of GCPs, their distribution and the GSD. The testing proved the feasibility of high accuracy on roofs and also on the terrain. By using 1cm GSD images (on the terrain) and seven GCPs placed on the terrain, planar accuracy on roofs was achieved corresponding to approximately 2.5x pixel size and elevation accuracy of roofs corresponding to approximately 2x pixel size. This accuracy is satisfactory for drainage calculations, which means that UAVs can be effectively used for determining the flat roof parameters. Using images with a larger GSD does not dramatically worsen the geometric accuracy on roofs. Therefore, sub-pixel accuracy can be achieved, but the stability is strongly dependent on the production software.

Graph 1: RMSExy.

Graph 2: RMSz.

Graph 3: RMSExy.

Graph 4: RMSEz.

Further reading

- Sanz Ablanedo E., Chandler J.: Accuracy of Unmanned Aerial Vehicle (UAV) and SfM Photogrammetry Survey as a Function of the Number and Location of Ground Control Points Used, *Remote Sensing*, 2018
- Unger, M. Reich, C. Heipke: UAV-based photogrammetry: monitoring of a building zone, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume XL-5, 2014
- Alidoost, H. Arefi: Comparison of UAS-based photogrammetry software for 3D point cloud generation: A survey over historical site, *International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences*, Volume IV-4/W4, 2017

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