TERMS FOR THE DETERMINATION OF SPATIAL OBJECTS BY THE UNMANNED AERIAL SYSTEMS USED FOR LAND CONSOLIDATION

Ing. Jana Zaoralová, Ph.D[1]

Ing. Milan Kocáb, MBA[1]

Ing. David Vilim[3]

Ing. Lubomir Soukup, CSc.[2]

Ing. Karel Radej, CSc.[1]

[1] Research Institute of Geodesy, Topography and Cartography, p.r.i, Zdiby, **Czech Republic**

[2] Czech Academy of Sciences, Prague, **Czech Republic**

[3] Geoline, ltd., Prague, **Czech Republic**

ABSTRACT

The article deals with the creation and verification of a new procedure for the determination of spatial objects contained in the VFP (land exchange format in the Czech Republic) necessary for complex landscaping and landscape protection by UAS (Unmanned Aerial Systems).

It focuses on verifying spatial accuracy on a pilot sample of data obtained by double scanning at the Obratan test site and establishing input parameters and conditions for site mapping so that the new method of unmanned aerial systems complies with the existing legal and technical regulations in the implementation of the land modifications valid in the Czech Republic.

The result is a methodology that includes research results aimed at determining the spatial accuracy of the points, its usage parameters and the reliability of the deployment. It also contains information about UAV (Unmanned Aerial Vehicles) calibration, deployment profitability, and software data processing methods. The second objective is the harmonization of legislation and the creation of a procedure for the acquisition of geospatial data in land consolidation where UAS methods have so far not been accepted.

Keywords: land consolidation, unmanned aerial systems, spatial accuracy of measurement

INTRODUCTION

The use of drones for the rapid production of orthophotomaps and subsequently large scale maps of high accuracy for land improvement was tested at Obrataň in Pelhřimov, Vysočina.

The area for evaluation of the parameters and the suitability of the methodology was selected so that the sample data was both building, line construction, vegetation, landmarks, sufficient height ratios and enough elements to compare with the classical method. The area of the area was chosen to be about 72 ha. Land consolidation was carried out on this site, and UAS measurements were essentially performed as a re-measurement by another method.

MAIN TECHNICAL PARAMETERS FOR UAS AT MAPPING

Droning quality mapping is a prerequisite for imaging with a quality camera [4] (scanner) located on the drones. A sensor located in an unmanned airplane and taking aerial photographs shall be a digital camera with a minimum sensor size of 13x17mm and the pixel size on that sensor shall not be greater than 4,5μm. UAS also includes programmable means for scheduling flight planning, flight trajectory recording, manual control as well as qualified ground pilot and control imaging personnel.

When UAS is used as the method for determining detailed point and altitude points, the following parameters must be followed:

- Longitudinal overlap p => 75%, transverse overlay q => 60%, and Ground sample distance (GSD) linear distance must be less than or equal to 4.5 centimeters.
- The scanning must be carried out so that at least eight pictures are taken outside the boundaries of the landscaping on any part of the landfill boundary on all the runways.
- The starting points must be stabilized, starting points are indicated by a target of a suitable material of approximately three and a half times the size of the GSD.
- The layout of the starting points must be regular throughout the land plot and these points must lie outside the perimeter so that they form an "envelope" around the border and are displayed on at least six pictures.
- The number of starting points must match the number of fractions divided by 100 plus one, it is about 10 points; in the area of mapping for land consolidation purposes, the control points are set up in the number of one point per 3ha of the mapping area; these points are established by the same procedures as the starting points but do not enter the photogrammetric data processing and serve solely to control the quality and accuracy of the measurement of the detail points; the starting points must be located at the level of the terrain or painted on suitable paved areas in a color that creates sufficient contrast with the area on which the starting point is located.
- The detail point signaling is performed when the own detail point is less than three and a half times the size of the GSD, or when its contrast with the surroundings does not allow a clear interpretation of the detail point in the orthophotomap.
- The imaging block has to be photogrammetricly processed using known proven density-matching techniques such as Surface Reconstruction from Imagery (SURE), Semi-Global Matching (SGM), Stereo Multi Matching (SMM) or Structure from Motion (SfM).

ANALYSIS OF SPATIAL ACCURACY OF THE CONTROL POINTS LOCATED IN CITY ORATAŇ

Coordinates of control points were measured in two independent stages with different UAS systems. The first stage of the measurement was performed by the Trimble UX5 HP system and took place on June 12, 2017, the second stage was measured in November, the flight was conducted on 23 November 2017 by MAVinci Sirius. It was, therefore, an independent observation of the same site in different seasons (in uneven weather) by various apparatuses.

In the first stage, the interest territory was flown both unidirectionally, i.e. only in the longitudinal direction and, on the other hand, both in both longitudinal and transverse directions. Therefore, it is expected that the accuracy of the points determined in the different flying modes will be different. In the second phase, the interest area was flown only one way. The subject of the accuracy analysis is therefore 3 sets of control point coordinates.

Fig. 1: Placement of input (blue) and control points (red) in the first and second measurement steps

The source for processing was the checkpoint coordinate lists, which were determined by the camera from the dron and the removal from the orthophotomap or eventually the cloud of points, and by repeated land surveying [1], [2], [3] using GPS devices using the RTK method and the polar method. It is necessary to compare these independently determined coordinates and estimate the accuracy of points determined by the dron. Position coordinates are processed separately from point heights. The required probability estimate must take into account the accuracy of the geodetically determined points. This input precision is given for individual points from a selected set of geodetically determined points.

Fig. 2: Planning of runways and overlays

The accuracy of the position of the control points is expressed using the standard deviation (mean error) and the standard deviation of the heights. We look for a determined standard deviation of $\sigma_{XY,dron}$, an unknown standard deviation of heights $\sigma_{Z,dron}$. We assume that checkpoint heights have a normal probability distribution and that the position coordinates have a two-dimensional symmetric normal distribution. This assumption applies to both the heights and coordinates determined by the droning camera, and for geodesically geared heights and coordinates.

Estimation of input precision of geodetic positioning of points

For each control point, the standard deviation of the height $\sigma_{Z,i}$ and the coordinate standard deviation $\sigma_{XY,i}$ are given along with its coordinates in the S-JTSK system and height. These accuracy parameters were automatically determined by GPS devices at 53 points in the second stage. These figures are slightly different (in mm for positional coordinates, up to 2 cm at altitudes), even though all the checkpoints were focused in exactly the same way. Therefore, it can be assumed that the observed deviations are the result of random interferences and consider all geodetic points as equally accurate.

The most credible estimates of standard deviations and their confidence intervals were calculated at a materiality level of 0.95.

$$\sigma_{Z,gd} = 17 \pm 6.4\, mm\ , \quad \sigma_{XY,gd} = 12 \pm 5.5\, mm\ .$$

Preliminary, approximate estimate of output accuracy

The standard procedure for estimating the accuracy of the set of points is based on the idea that the coordinate differences (or height differences) calculated from the two given coordinate lists belong to one and the same random variable with a zero mean value. The accuracy of this random variable is then usually determined as a sampling standard deviation $s_{\varepsilon,XY}$, $s_{\varepsilon,Z}$ according to the formula:

$$s_{\varepsilon,XY} = \sqrt{\frac{\sum_{i=1}^{n}(x_{dron,i} - x_{gd,i})^2 + (y_{dron,i} - y_{gd,i})^2}{2n}}$$

$$s_{\varepsilon,Z} = \sqrt{\frac{\sum_{i=1}^{n}(z_{dron,i} - z_{gd,i})^2}{n}}$$

These accuracy characteristics for the three given control point coordinate lists are given in Table 1.

Tab. 1: Approximate estimate of output accuracy

List of coordinates	Number of points		$s_{\varepsilon,XY}$	$s_{\varepsilon,Z}$
	position	height		
Stage 1 one-way	108	66	57 mm	251 mm
Stage 1 bidirectionally	111	65	62 mm	137 mm
Stage 2 one-way	77	55	40 mm	128 mm

This standard procedure could be used only if the input accuracy of the control points was more than the expected accuracy of the dron determination ($\sigma_{dron} > 10\,\sigma_{gd}$). However, this assumption is not fulfilled and therefore it is necessary to propose a different way of estimating the standard deviations $\sigma_{XY,dron}$, $\sigma_{Z,dron}$, which would respect the significant inaccuracy of the geodetic determination of the coordinates and heights of the control points.

Such an estimate can be made using the Bayesian approach [5] using Jeffreys' a priori probability density. Posterior probability density then comes in the form of:

$$f(\sigma) = \frac{2^{1-\frac{m}{2}}\sigma(ms_{\varepsilon}^2)^{\frac{m}{2}}(\sigma^2+\tau^2)^{-\frac{m}{2}-1}e^{-\frac{(ms_{\varepsilon}^2)}{2(\sigma^2+\tau^2)}}}{\Gamma\left(\frac{m}{2}\right) - \Gamma\left(\frac{m}{2}, \frac{(ms_{\varepsilon}^2)}{2\tau^2}\right)} \;. \tag{1}$$

This relationship can be used both for estimating the coordinate standard deviation $\sigma_{XY,dron}$ and for estimating the standard deviation of the heights $\sigma_{Z,dron}$. However, other values of σ, τ, m, s_{ε} are required.

For $\sigma = \sigma_{Z,dron}$, it is necessary to put into formula (1):

τ … specified standard deviation of heights, $\tau = \sigma_{Z,gd}$,

m … the number of points on which both heights were determined,

s_{ε} … selective standard deviation of heights, $s_{\varepsilon} = s_{\varepsilon,Z}$.

For $\sigma = \sigma_{XY,dron}$, it is necessary to put into formula (1):

τ … specified coordinate deviation, $\tau = \sigma_{XY,gd}$,

m … twice the number of points on which the coordinate differences were determined,

s_ε … selective coordinate standard deviation, $s_\varepsilon = s_{\varepsilon,XY}$.

The shape of the probability density f calculated according to formula (1) shows for different data files Figure 3 and Figure 4.

The most probable estimate of parameter σ is the probability density mode (1). It is calculated according to the formula:

$$\hat{\sigma} = \sqrt{\frac{\theta + \sqrt{\theta^2 + 4(m+1)\tau^4}}{2(m+1)}}\ , \qquad (2)$$

where

$$\theta := m(s_\varepsilon^2 - \tau^2)\ .$$

Estimation of positional and treble accuracy

The most probable estimates of standard deviations $\sigma_{XY,dron}$, $\sigma_{Z,dron}$ calculated according to formula (2) are in Table 2 for all 3 coordinate lists.

Tab. 2: Estimation of the coordinates of drones' 3D model dots

List of coordinates	number of points		$\boldsymbol{\sigma_{XY,dron}}$	$\boldsymbol{\sigma_{Z,dron}}$
	position	height	[mm]	[mm]
Stage 1 one-way	108	66	61 ± 6.1	249 ± 45.3
Stage 1 bidirectionally	111	65	56 ± 5.6	135 ± 24.9
Stage 2 one-way	77	55	38 ± 4.8	125 ± 25.8

Together with the standard deviation values, confidence intervals are also given in Table 1. The correct value of the standard deviation lies in the appropriate interval with a probability of 0.95. The confidence interval values were calculated using the probability density integral (1). Graphs of these probability densities corresponding to the six standard deviations in Table 2 are shown in Figure 3 and Figure 4. The numerical values on the horizontal axis of the graphs in these figures are in mm.

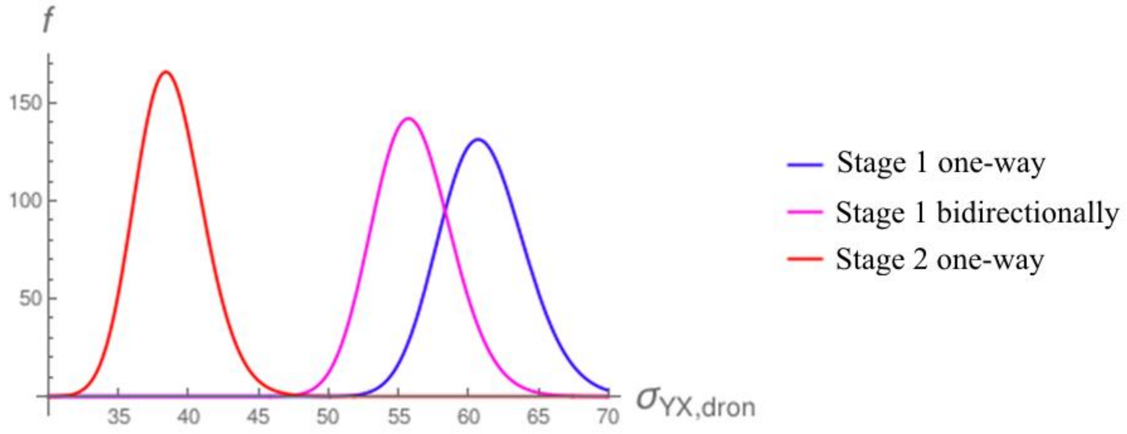

Fig. 3: The probability density of the standard deviation of the position coordinates for the different coordinate sets

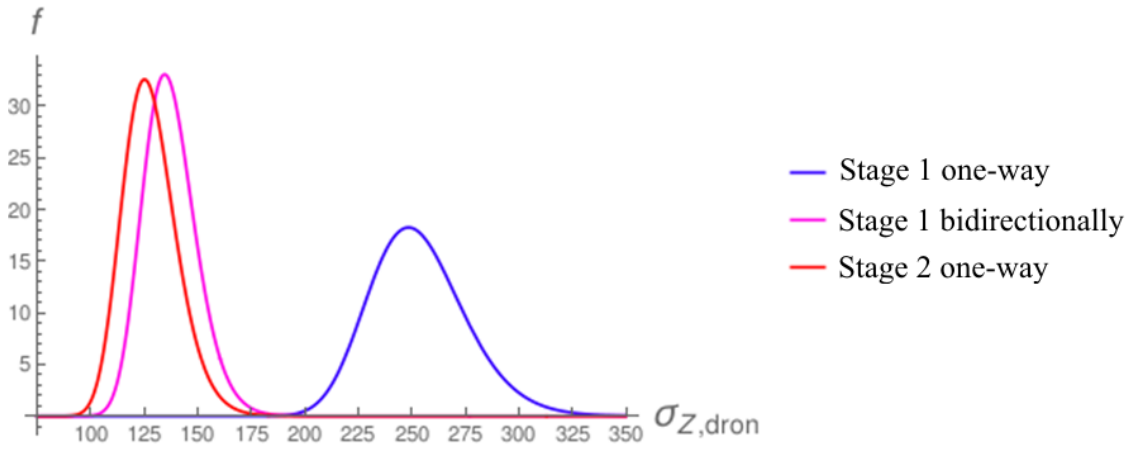

Fig. 4: The probability density of the standard deviation of the heights for the different coordinate sets

CONCLUSION

In the presented accuracy analysis, a method of estimating the standard deviation of the coordinates of droned-pointed points is proposed. This estimate was based on a checkpoint coordinate list containing the coordinate of the points determined by the drones and, on the other hand, independently by georeferenced GPS devices by polar measurement. The proposed method takes into account the inaccuracy of geodetic checkpoints.

The results of the analysis are clearly presented in Table 2. The uncertainty of the resulting standard deviations is quantified in this table by confidence intervals at the materiality level of 0.95. A graphical representation of this uncertainty is provided in Figure 3 and Figure 4.

The best result was achieved in the November stage. The standard deviation was 38 ± 5 mm and the standard deviation 125 ± 26 mm. The least accurately, the area of interest was captured in a one-way flight in June. At that time, an accuracy of 61 ± 6 mm was reached at the position and 249 ± 45 mm in height. All these data are valid provided that the geodetic focus of the control points has an accuracy of 12 ± 6 mm in position and 17 ± 6 mm in height. If the geodetic focus would be less accurate, then the droning sensitivity estimation would shift to smaller standard deviation values, but the confidence intervals would significantly increase.

Subject to the aforementioned scanning conditions, accuracy is sufficient to use the land consolidation method.

ACKNOWLEDGEMENTS

The work on this paper was supported by the Technology Agency of the Czech Republic under EPSILON programme No. TH02030291.

REFERENCES

[1] Act on the Cadastre of Real Estates (Cadastral Act), as amended by Act No. 86/2015 Coll., No. 139/2015 Coll., No. 318/2015 Coll., No. 106/2016 Coll. And No. 298/2016 Coll., Czech Republic.

[2] Law on surveying and amendment of some acts related to its implementation, as amended by Act No. 120/2000 Coll., Act No. 186/2001 Coll. And Act No. 319/2004 Coll., Act No. 413/2005 Coll., Act No. 444/2005 Coll., Act No. 124/2008 Coll., Act No. 189/2008 Coll., Act No. 223 / 2009 Coll., Act No. 281/2009 Coll., Act No. 380/2009 Coll., Act No. 350/2012 Coll., Act No. 257/2013 Coll. And Act No. 298/2016 Coll., Czech Republic.

[3] Decree on cadastre of real estates (cadastral decree), as amended by Decree No. 87/2017 Coll., Czech Republic.

[4] Václav Šafář: Non-metric cameras, SGM methods and their application in the field of surface mining and cadastral mapping. Geodesy, Cartography and Geographic Information Systems 2014, 6pp, Technická univerzita v Košiciach, Košice, Slovensko.

[5] Soukup Lubomír: Positional accuracy of spatial object after a geometric transformation - Bayesian approach. Proceedings of the International Symposium on Spatial Data Quality. ISSDQ '04, pp. 335-344, ISBN 3-901716-30-0, Technical University Vienna.