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An accuracy assessment of als-derived DTM and photogrammetric-derived DSM: case study of Łysica massif

M. Hajdukiewicz, *I. Romanyszyn *(Kielce University of Technology)*

SUMMARY

The article presents research of the accuracy of the digital terrain model (DTM) based on measurements photogrammetric and air laser scanning (ALS) in the Lysica massif in the Świetokrzyskie Mountains. The high accuracy of DTM of ALS measurements, meeting the requirements of ISOK specification, has been confirmed. Significant errors were found on the topographic map, which was the material for inventory of forest habitats. In extreme cases, altitude errors of the spot heights exceeded 5 m, i.e., the Skala Agaty top, whose actual height is 613.9 m a.s.l., was shown on the topographic map as only 608,4 m a.s.l.

Keywords: aerial laser scanning (ALS), digital terrain model (DTM) ALS-derived, digital forest map

Introduction

The digital terrain model (DTM) and the digital surface model (DSM) is very important study material for the purposes of forest taxation and other analyzes related to forest management, as well as forest protection. The source of data for these models may be topographic maps, photogrammetric survey, ALS or field survey. The accuracy of the models is a derivative of the accuracy of the survey or source data. In the case of using topographic maps in the scales of 1: 10,000 and 1: 25,000 (contours digitizing) the accuracy is relatively low and depending on the type of terrain and plant cover. The error in determining the height on such DTM is related to the contour interval value as its decimal fraction and varies from 0.3 of to over 1 (Dudek & Lewandowski, 1983). A photogrammetric measurement provides higher accuracy of DTM and DSM. The accuracy of the measurement depends on the altitude of the flight. Due to this, a different level of accuracy can be expected when using a manned aircraft and the UAV. The accuracy of the altitude measurement better than the photogrammetric measurement is ensured by airborne laser scanning (ALS) (Kurczyński, 2012).

Area, material and method of research

The research described was carried out on the Łysica plateau in Świętokrzyskie Mts., Poland. Łysica is the highest peak of the Świętokrzyskie Mts., situated in the western part of the Łysogóry ridge. Łysica massif is extended from WNW to ESE direction (Fig. 1), and two tops could be marked on it: the main (western) top, and eastern top, named Skała Agaty. The geological structure of the Łysica massif is the same as the Łysogóry ridge (Hajdukiewicz & Romanyshyn, 2017). The basement is dominated by hard and resistant to weathering quartzite of Upper Cambrian age. The relief is typical for low mountains. Denivelation exceeds 300 m slightly, the slope angle is in the range of 10 to 30 degrees. The intensity of the erosion processes is currently low, all the area is covered by the forest, except small area of the boulder fields.

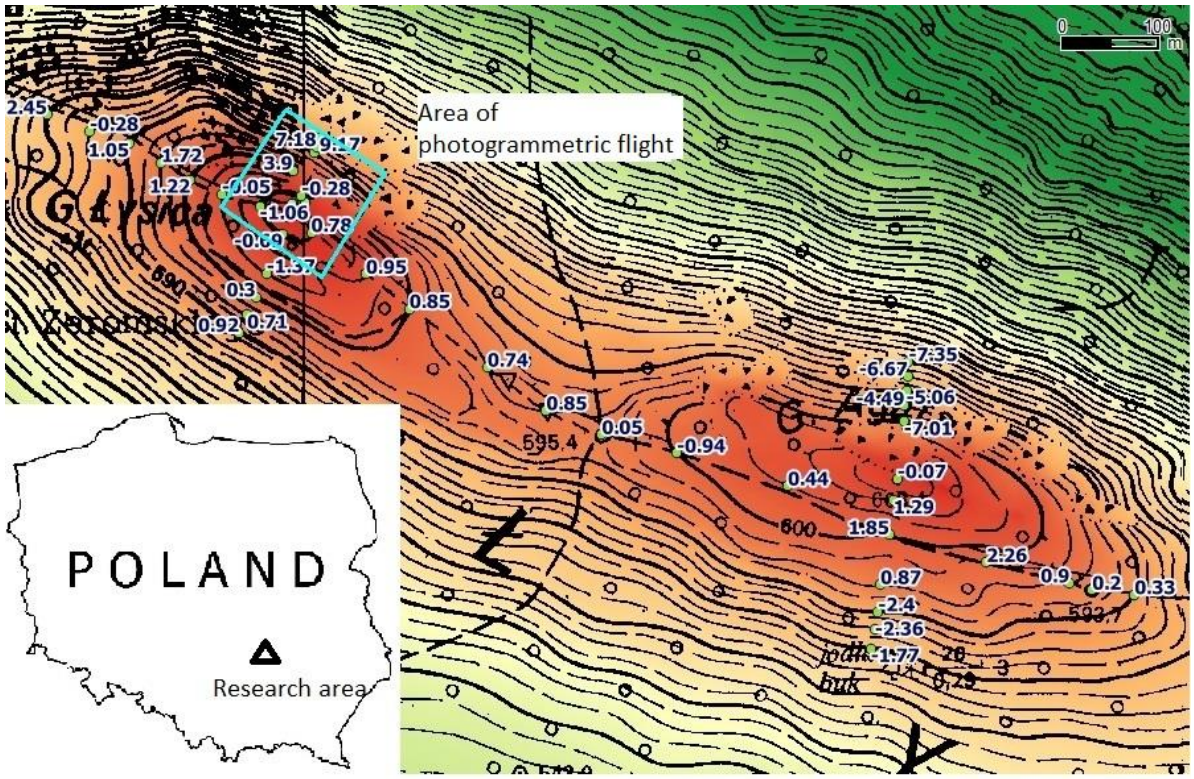

Figure 1 *The location of the research area, topography of the Łysica massif, and location of the photogrammetric flight and measurement points for ALS – derived DTM and counters comparison. The height differences indicated in m.*

The research consisted of control measurements of the height of the studied area, carried out using the GNSS and tacheometric methods, and a photogrammetric flight using UAV. The most important points were surveyed using GNSS static method and aligned to the points in the neighborhood to establish the survey points network for the tacheometric measurement. These points are presented in the Table 1. The accuracy of the X, Y coordinates is related to the measurement method (GNSS static or RTK), but thanks to the alignment, H coordinate accuracy refers to GNSS static method for each one point (Romanyshyn & Hajdukiewicz, 2019). The surveys were compared to the heights derived from the DTM obtained from Centre of Geodesy and Cartography Documentation (pol. CODGiK). This DTM is the effect of latest (2014) ALS survey of research area, made as part of information system for land protection project (pol. ISOK). The last stage of analysis was the comparison of this DTM to the topographic map contours in 1: 10000 scales. The comparison included RMS, mean maximum and minimum values of the differences between the height obtained in the survey points from DTM/DSM, and surveyed in the field. Points were located on the area none covered by forest (Figure 2). The photogrammetric flight was carried out over the part of the west peak plateau not covered by the forest, while the control measurements to verify the altitude of contours and the ALS terrain model were carried out for the area (also forested) of both peaks of Łysica.

Table 1 *GNSS surveys of the main network points on the top of Łysica Mt. - coordinates, measurement method, and an alignment method*

Point	**Survey method**	**Coordinate $X_{(PL\text{-}2000)}$, m**	**Coordinate $Y_{(PL\text{-}2000)}$, m**	**Alignment method**	**Coordinate $H_{(PL\text{-}KRON86\text{-}NH)}$, m**
12 Góra Łysica AB4940 (state network point)	GNSS Static	5639587.249	7492721.223	GNSS Static + geometric leveling	611.614
P1 (Łysica)	GNSS Static	5639584.139	7492722.505	GNSS Static + geometric leveling	611.448
P2 (Łysica)	GNSS Static	5639600.027	7492740.166	GNSS Static + geometric leveling	610.980
Cross (Łysica)	GNSS RTK	5639599.056	7492728.165	GNSS Static + geometric leveling	613.223
Boulder (Łysica)	GNSS RTK	5639598.782	7492726.362	GNSS Static + geometric leveling	613.609

Surveys and analysis

The photogrammetric flight was carried out at the end of April 2021, in the season without leaves on the trees, at a height of 50 m above the highest point of the terrain, using a UAV DJI Mavic 2 pro. A set of the GCP marked as contrasting crosses was located on the flight area, and surveyed using the GNSS RTK method. The set of the photos acquired was processed using Agisoft Metahape 1.6.5 software. The accuracy of the alignment of the photo block, expressed as the RMS error from the residuals of the bundle adjustment is: 0.003 m (x), 0.007 m (y), and 0.005 m (H). It was achieved thanks to the high resolution of the photos (1 cm / pix). Since the accuracy of the GNSS RTK measurement is by an order of magnitude lower, it can be assumed that the resolution and geometrical features of the photos did not affect the accuracy of the altitude measurement on the DSM and DTM obtained from this block of the photos. The resolution of the DSM generated in the form of a regular grid was 2.64 cm/pixel.

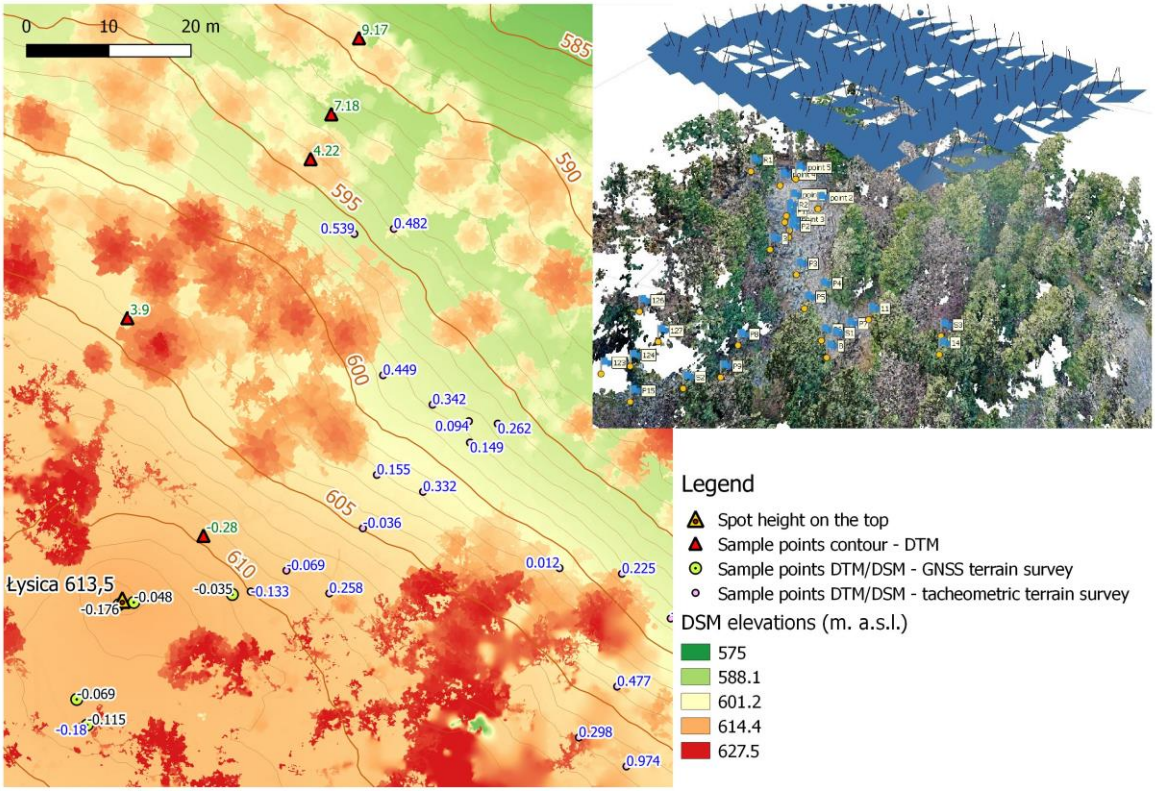

Figure 2 *The set of sampling points on the area of photogrammetrical flight. Residuals of DSM – terrain survey indicated in meters. Contours generated of the ALS - derived DTM. Sketch of the flight and point cloud in upper right corner of the figure.*

The sample of 28 points, surveyed using GNSS static, GNSS RTK and tacheometric methods was used for the accuracy assessment of the terrain models. The results of the comparison are presented in Table 2, part A. Farther, the obtained results were compared with the analysis of the accuracy of the contours in relation to DTM from the ALS measurement, as shown in Table 2, part B. The comparison of the RMS errors shows that the accuracy of the photogrammetric measurement with the UAV is higher than the accuracy of the DEM with ALS measurements. The mean error indicates a tendency to underestimate the height by ALS measurement and to overestimate it in the photogrammetric UAV measurement.

Table 2 *Comparison of terrain models (DTM, DSM), terrain survey and contours of 1:10000 topographical map*

Survey place	A: top plateau of Łysica		B: along profiles
Difference	DEM (ALS – terrain survey (m)	DSM (UAV – terrain survey (m)	DEM (ALS – contour (m)
Maximum	0.13	0.54	9.17
Minimum	-0.93	-0.18	-7.35
Mean	-0.27	0.12	-0.04
RMS	0.37	0.26	3.16

Conclusions

As can be deduced from the analysis the terrain model obtained from photogrammetric measurements using UAV – derived aerial photos, is characterized by very high accuracy. However, it requires the use of advanced filtering algorithms for automatically measured points, as often points identified on

low vegetation are confused with measurements of the terrain surface. Also, the high accuracy of DTM of ALS measurements, meeting the requirements of ISOK specification, has been confirmed. Significant errors were found on the topographic map. In extreme cases, altitude errors of the spot heights exceeded 5 m, i.e., the Skała Agaty top, whose actual height is 613.9 m a.s.l., was shown on the topographic map as only 608.4 m a.s.l. It confirms the high suitability of ALS-derived DEM in the mapping of habitat areas.

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