

Quality parameters of digital aerial survey and airborne laser scanning covering the entire area of the Czech Republic

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Abstract

The paper illustrates the development of digital aerial survey and digital elevation models covering the entire area of the Czech Republic at the beginning of 21st century. It also presents some results of systematic investigation of their quality parameters reached by the author in cooperation with Department of Geomatics at the Faculty of Applied Sciences of the University of Western Bohemia in Pilsen and the Land Survey Office.

Keywords: digital aerial survey, orthophoto imagery, aerial laser scanning, digital elevation model, digital surface model, Czech Republic

1. Introduction

Year 2010 became a turning point as far as gathering of up-to-date geospatial data from the whole territory of the Czech Republic concerned. Aerial survey with digital cameras in RGB and NIR spectral bands with on-the-ground resolution of 0.20 m covered 100 % of the state territory in the course of 2010-12. Periodically repeated digital image records serve as a database for photogrammetric processing – preferentially of digital colour orthoimagery of the Czech Republic with on-the-ground resolution of 0.25 m. The era of taking aerial photographs on film and their subsequent rastering by means of precise photogrammetric scanners was de facto closed for this purpose. At the same time aerial laser scanning of 68.4 % of the state territory was successfully realized within the Project of New Hypsometry of the Czech Republic [1]. Its main goal is to provide bodies of state administration with High Resolution Elevation Data in form of Digital Elevation Model and Digital Surface Model of the entire state territory by 2015. New models of hypsometry will fulfil all requirements of the INSPIRE project as well. The Czech Office for Surveying, Mapping and Cadastre, Ministry of Defence and Ministry of Agriculture are investors of both projects. Land Survey Office and Military Geographical and Hydrometeorological Office are main compilers of digital image and LIDAR data. The author and Department of Geomatics at the Faculty of Applied Sciences of the University of West Bohemia in Pilsen have collaborated in definition and evaluation of quality parameters of all resulting products from the very beginning of development of all above mentioned projects.

2. Development of aerial survey for production of the CZ Orthophoto

In order to reach complete coverage of the Czech Republic with aerial photographs or digital images in 3year period total area of 78 865 km² was divided into 3 zones (West, Central, East) in 2003 respecting the layout of the State map series in scale 1 : 5000 (Fig.1). From 2003 to

2008 wide angle aerial photographs, mostly in scale 1 : 23 000 from relative flight height 3500 m have been exposed on colour negative film and transformed into raster form by precise photogrammetric scanners. Such parameters allowed to produce digital colour orthophoto imagery with pixel size 0.50 m on the ground. Since 2009 orthophoto imagery with higher resolution (0.25 m on the ground) has been required and other survey flight parameters - photo scale 1 : 18 000 and lower flight height 2740 m have to be chosen.

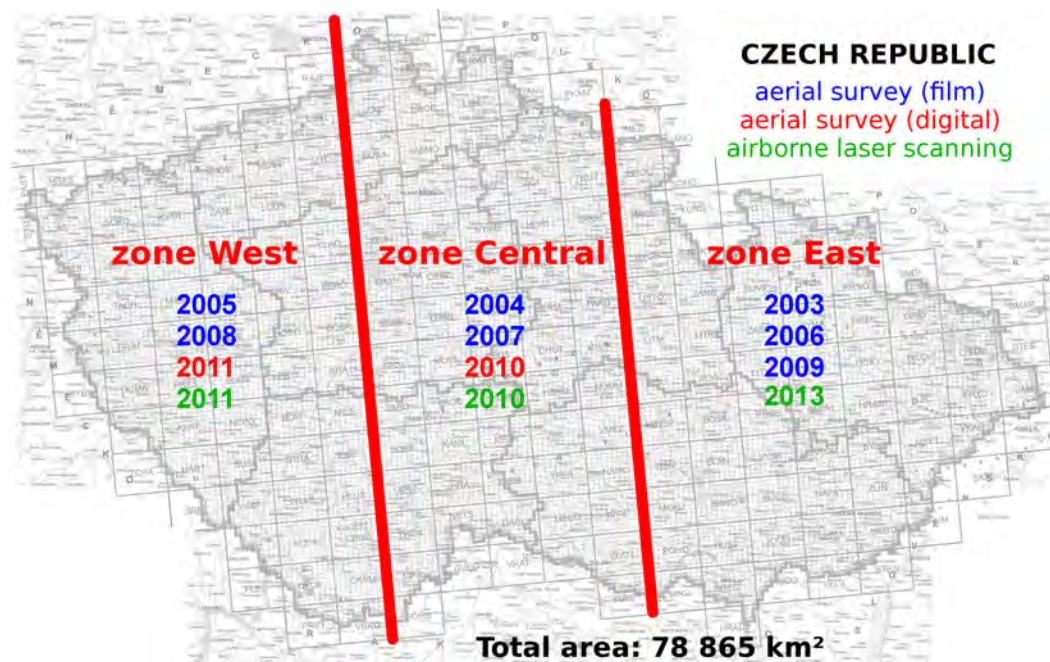


Figure 1: Schedule of aerial survey and airborne laser scanning of the Czech Republic

Since 2010 aerial photography on a film has been replaced by digital aerial survey using digital large format metric cameras for simultaneous registration of images in PANCHRO, R,G,B and NIR spectral bands. Minimum size of a sensor element 6 micrometers allowed to reach economically the on-the-ground resolution between 20 and 25 cm of the pixel size. All private firms taking part in tenders for digital aerial survey have used Vexcel UltraCam X or Xp cameras. Table 1 shows a complete review of methods used for aerial survey of the entire area of the Czech Republic [4].

Digital aerial survey covered the Central zone in 2010 and the zone-West in 2011. The rest of state territory (22.8 % - almost 28 thousand km² in zone-East) was imaged in 2012 commonly with one half of the Central zone, because there is an intention to reduce recent 3-year period into 2-year period since 2012. (Fig. 2). All projects of aerial surveys have been funding by the Czech Office for Surveying, Mapping and Cadastre and the Ministry of Agriculture.

The main product of periodical aerial surveys – the CZ Orthophoto (Ortofoto ČR in Czech) serves first of all for needs of state authorities and public administration. Some important examples of its application should be introduced here:

- updating of the Land Parcel Information System; orthophoto is documenting the areas recently cultivated by farmers when they ask for financial support from the funds of

Year	Method of aerial survey and rastering	Average scale of photographs / images	On-the ground pixel size (pixel of CZ Orthophoto)
2003-2008	analogue, on colour film + scanning into the raster form	1 : 23 000	0.46 – 0.48 m (0.50 m)
2009	analogue, on colour film + scanning into the raster form	1 : 18 000	0.27 m (0.25 m)
2010	digital (PAN, R, G, B, NIR) direct raster registering – UC XP	1 : 32 000	0.19 m (0.25 m)
2011	digital (PAN, R, G, B, NIR) direct raster registering – UC X, XP	1 : 35 000	0.21 – 0.25 m (0.25 m)
2012	digital (PAN, R, G, B, NIR) direct raster registering – UC XP	1 : 36 000	0.22 m (0.25 m)

Table 1: Recent development of aerial survey parameters for the CZ Orthophoto production

European Union,

- updating of the Fundamental Base of Geographic Data (known under acronym ZABAGED®) that is a topological-vectorial spatial data base at level of 1 : 10 000 Base Map of the Czech Republic,
- updating of a military Digital Landscape Model 25, a similar database at level of 1 : 25 000 Military Topographic Map,
- providing the Infrastructure for Spatial Information in Europe (INSPIRE) with recent orthophoto imagery of the Czech Republic.
- as an substantial part of the Digital Map of Public Administration.

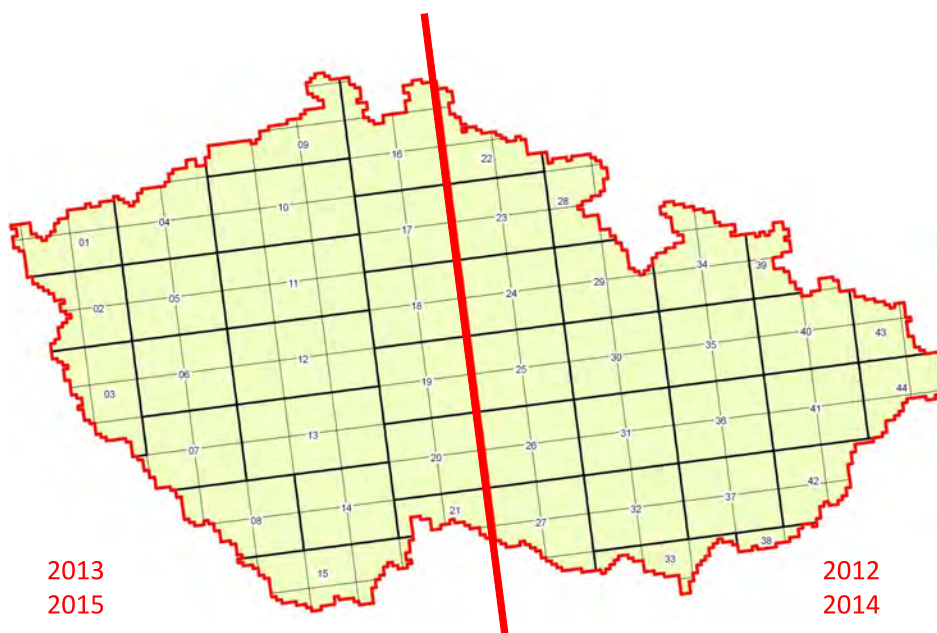


Figure 2: Digital aerial survey of the Czech Republic in two-year interval since 2012

3. Quality parameters of the CZ Orthophoto

The quality of the CZ Orthophoto enables to use this product to some other tasks [6]:

- discovering some discrepancies, gross and systematic positional errors in planimetric representation of objects in digitized cadastral maps (see Fig. 3),
- colour infrared orthophotos are widely used to national inventory of forests.

From 2004 the Laboratory of digital photogrammetry at the Faculty of Applied Sciences in Pilsen, and later the author in collaboration with Department of land surveying of the Land Survey Office have been continuously assessing the absolute positional accuracy of the CZ Orthophoto [4] using more test fields containing hundreds of check points measured mostly by GPS Real Time Kinematic method with positional accuracy better than 10 cm, and identical points well identified in the orthophoto. Remarkable seems to be high absolute positional accuracy of orthophoto from digital images in spite of their distinctly lesser scale [5] [8] [9] (see Table 2).

Method of image data registering	Number of points	cY [m]	cX [m]	mY [m]	mX [m]	mXY [m]	ΔY_{max} [m]	ΔX_{max} [m]
colour film 1 : 16 650 (2008) raster scanning pixel size 20 μm	732	-0.17	0.08	0.36	0.33	0.35	1.88	- 1.67
digital images 1 : 32 000 (2010) pixel 6 or 7.2 μm	430	0.05	-0.03	0.14	0.16	0.15	0.55	0.60
digital images 1 : 35 000 (2011) pixel size 6 μm	301	0.02	0.07	0.21	0.24	0.23	0.63	0.89
digital images 1 : 36 000 (2012) pixel size 6 μm	90	.0,04	-0.05	0.20	0.23	0.22	0.48	0.53

Explanations: c ... systematic error
m root mean square error
 Δ_{max} maximum error

Table 2: Results of testing the absolute positional accuracy of the CZ Orthophoto

Following check point types have been chosen for evaluation of absolute positional accuracy of the CZ Orthophoto:

- visible on-the-ground corners of a building
- foot of a pylon, telegraph pole or lamppost
- on-the-ground corner of a fence, underpinning or masonry wall
- midpoint of a circular manhole, drainage and well cover,
- corner of a kerb or road surface
- X or T form of white line intersections on a road surface

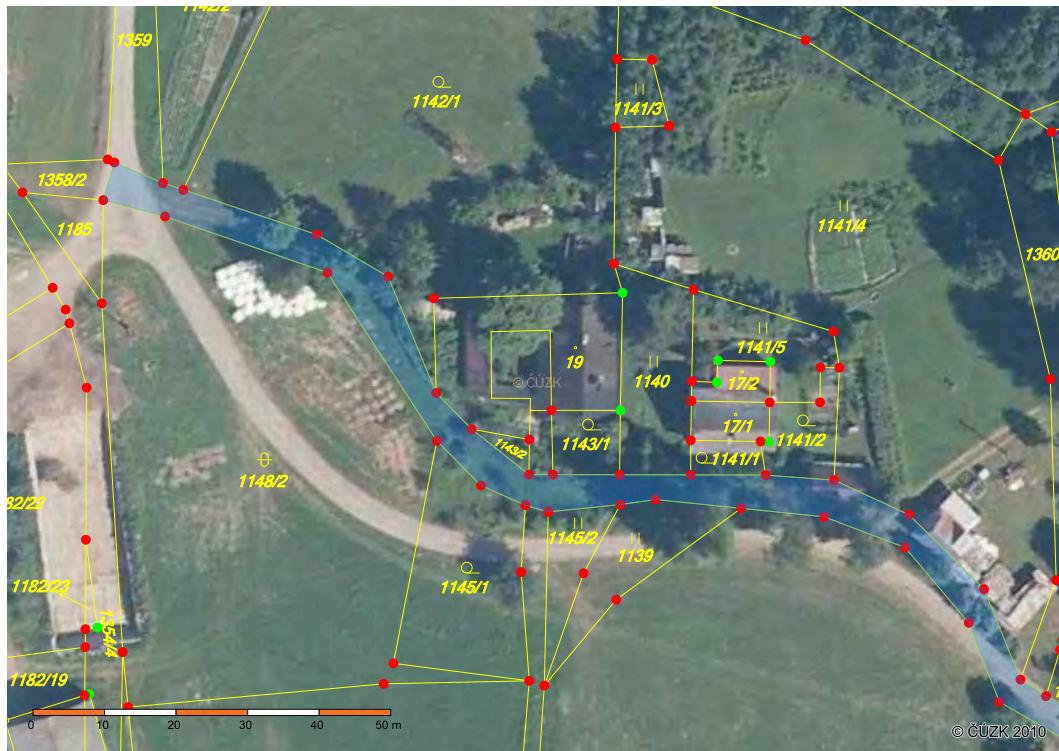


Figure 3: Original cadastral survey of a local road 50 years ago and reality as shown in the CZ Orthophoto

High absolute positional accuracy of the CZ Orthophoto made from digital aerial images in 2010-12 (see Tab. 3) has been reached thanks to compliance with keeping of three principles:

1. targeting of optimally distributed ground control points within the block of aerial images; predominantly of monumented triangulation points having known and accurate absolute position defined in the compound coordinate reference system (S-JTSK, Balt-po vyrovnání). Their number should not be less than 1 per 25 digital images, e.g. 40 GCP within the block of 1000 images,
2. on-the-board registration of elements of exterior orientation by GPS/IMU apparatus that makes the spatial geometry of a block stronger,
3. modern and effective software for digital automatic aerotriangulation (AAT) that enables quickly change the input parameters and repeat the computation (MATCH-AT version 5.2.1 or 5.4.2 has been used in two processing centres).

4. Development of digital elevation models in the Czech Republic

Until the year 2000 the Czech Republic was completely covered with hypsography based on graphical contour lines with two-metre interval represented in the Base Map of the Czech Republic in scale 1 : 10 000 (Fig. 4). In the course of establishing the Fundamental Base of Geographic Data (ZABAGED®) in topological-vectorial form, above mentioned hypsography has been digitized into a 3D model forming the Triangulated Irregular Network called

Year	Number of AAT blocks	RMSE of residuals on ground control points use for AAT			Number of AAT blocks	RMSE of residuals on check control points not use for AAT		
		m _X AAT [m]	m _Y AAT [m]	m _H AAT [m]		M _X [m]	M _Y [m]	M _H [m]
2010	17	0.113	0.100	0.200	12	0.160	0.140	0.300
2011	17	0.089	0.080	0.216	11	0.111	0.104	0.268
2012	23	0.067	0.074	0.137	22	0.184	0.173	0.256

Table 3: Results of testing the accuracy of digital automatic aerotriangulation

ZABAGED®-výškopis 3D vrstevnice. Another digital elevation model (DEM) in the form of 10 x 10 m grid called ZABAGED® - 10x10 m grid was derived from the previous one. Typical elevation accuracy of those models is: 0.7 - 1.5 m in open terrain without continuous vegetation cover, 1 - 2 m in built-up areas and 2 - 5 m in forests (accidentally up to 20 m in the mountains).

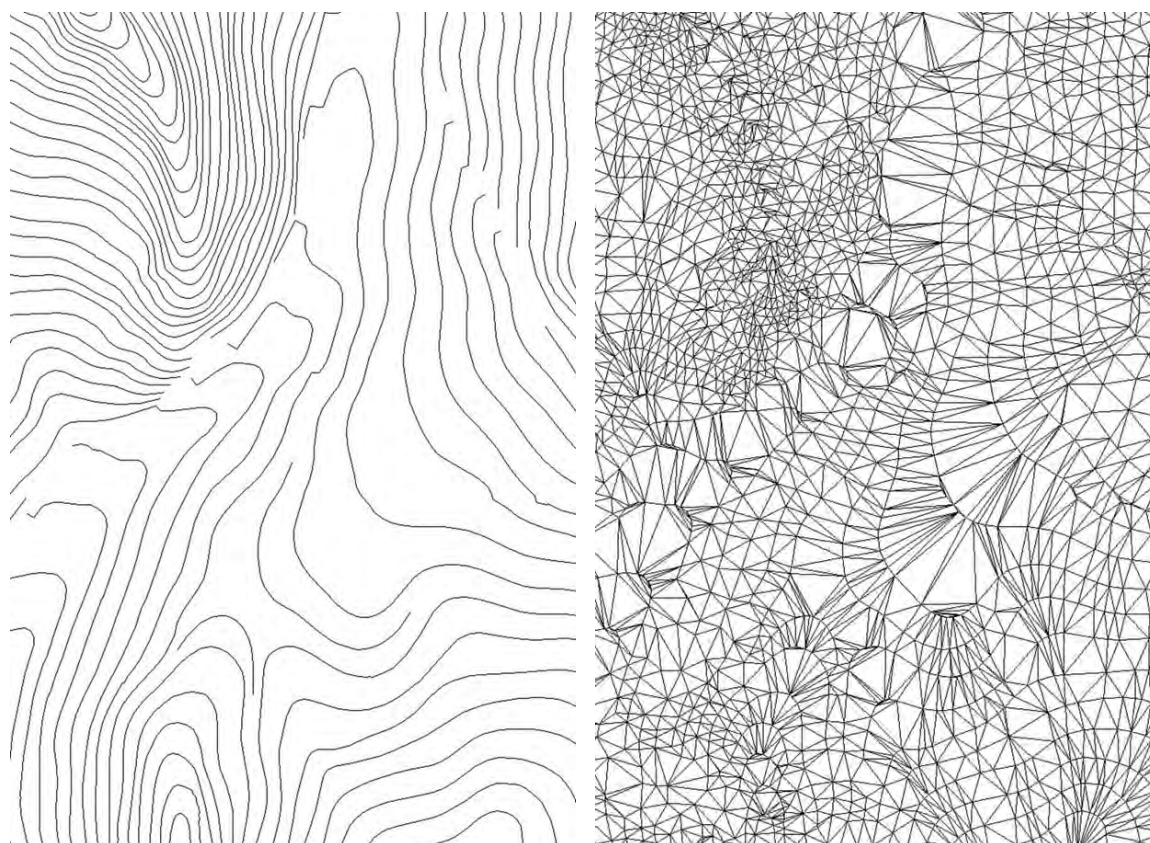


Figure 4: Original contour lines in the Base Map 1 : 10 000 and their TIN representation after vectorizing

More demanding requirements on elevation accuracy for production of orthophotos with high on-the-ground resolution (25 cm and better) and frequent demands for 3D modelling of terrain ground and surface initiated generation of the Project of New Hypsometry of the Czech Republic within the period from 2009 to 2015. As the most effective method the airborne laser scanning (ALS) was chosen for this purpose [1] [7].



Figure 5: Laser scanning system LITEMAPPER on the board of L-410 FG aircraft

In contrast with gathering the aerial photos and digital images by Czech or foreign private firms only, the airborne laser scanning has been accomplished by three state administration authorities: Ministry of Defence, Ministry of Agriculture and the Czech Office for Surveying, Mapping and Cadastre. Their tasks have been distributed according to disponsible capacities.

Army of the Czech Republic dispones with a special photogrammetric aircraft L-410 FG of the Czech production suitable for both airborne laser scanning and digital aerial survey as well. Usual speed of a survey flight or airborne laser scanning is 250 km per hour. The flight heights range from 1200 m to 3200 m. In case of airborne laser scanning there is a Laser Scanning System LITEMAPPER hired out by German firm IGI installed on the board of L-410 FG (Fig.5). Parts of that system are: Laser Scanner RIEGL LMS Q680, GPS NovaTel equipment and IMU produced by the firm IGI.

Fig. 6 illustrates state of airborne laser scanning at the end of 2011. In 2012 the flights with L-410 FG had to be frozen through the necessity of its general overhaul. Individual blocks for laser scanning and data processing occupy the area from 10 x 10 km up to 10 x 40 km depending on maximum difference of elevations inside. The flight lines are parallel to E-cordinate axis of UTM projection used by the Army of the Czech Republic. There are two UTM 6-degree zones in the Czech Republic but a unique national coordinate reference system (S-JTSK) generally used by the civilian sector (e.g. in cadastre).

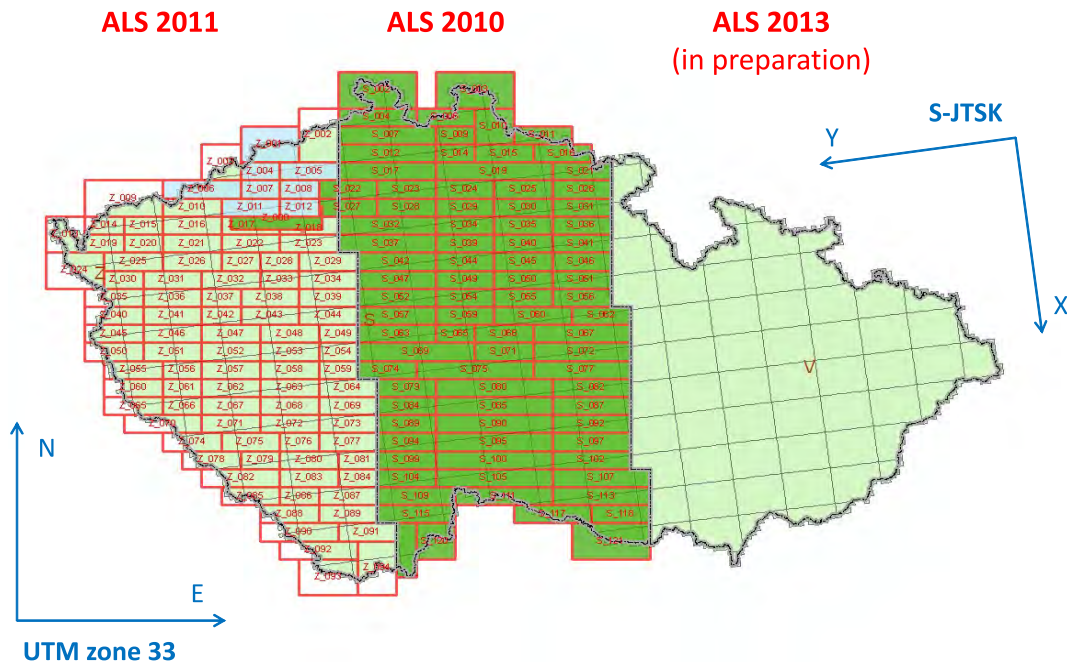


Figure 6: Coverage of the Czech Republic with airborne laser scanning data (March 2013)

5. Quality parameters of new digital elevation models

There are three final products of aerial laser scanning within the bounds of the Project of New Hypsometry of the Czech Republic:

- Digital Elevation Model DMR 4G as a grid 5 x 5 m oriented paralelly to axes of national coordinate reference system S-JTSK or to the UTM grids in zones 33 and 34 (Fig. 7). This product should be always ready for distribution till 6 months after gathering ALS data. Its implicit elevation accuracy given by RMSE is 30 cm in open terrain and 1 metre in forested area. Suitable applications are: high resolution ortophoto production, draining of precipitation from a catchment basin, modelling of ecological disasters [2].
- Digital Ground Model DMR 5G in the form of Triangulated Irregular Network representing most of terrain break lines too should be ready for distribution till 12 months after gathering ALS data. Its implicit elevation accuracy given by RMSE is 18 cm in open terrain and 30 cm in forested area. Suitable applications are: new hypsometry of the Czech Republic (especially contour lines for State map series in scale from 1 : 5000 to 1 : 50 000), modelling of floods, modern spatial planning [3].
- Digital Surface Model (DMP 1G) ready for distribution till 18 months after gathering ALS data. Its implicit elevation accuracy given by RMSE is 40 cm on solid objects or bare ground and 70 cm on the surface with full-grown vegetation. Suitable applications are: optical visibility in rough terrain, night flying of helicopters, propagation of electromagnetic waves, true orthophoto in built-up areas.

The Land Survey Office organized a comprehensive testing for accuracy assessment of the DMR 4G using 240 horizontal test areas in Central zone of the Czech Republic (each equipped

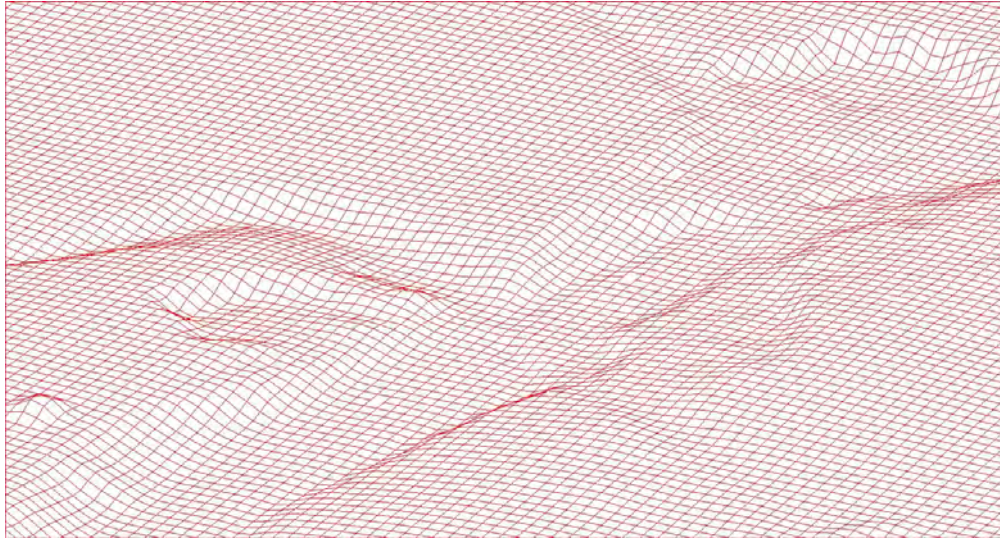


Figure 7: DMR 4G covering 68,4 % of the Czech Republic (March 2013)

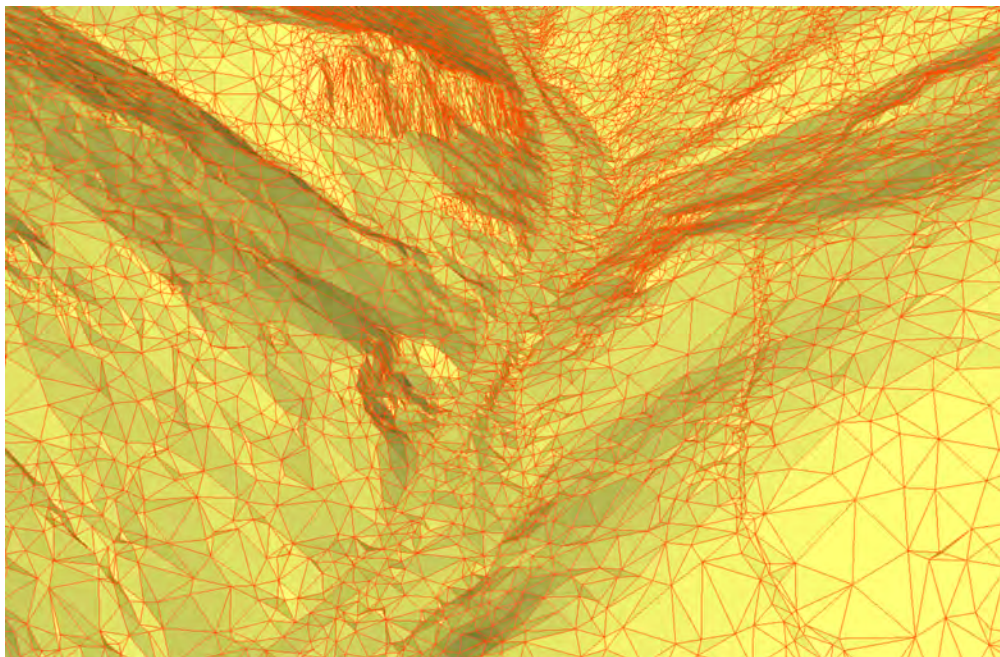


Figure 8: DMR 5G covering 33,4 % of the Czech Republic (March 2013)

with 30 – 100 check points) for determination of an average systematic error in elevations within the whole area mentioned above. It was -0.15 m (under the ground surface). After mass elimination of this systematic error the standard deviation reached 0.08 m only!

970 representative points of terrain surfaces were chosen and geodetically measured in 6 terrain types with various land cover. The results of comparison with identical points (Table 4) interpolated from the grid 5×5 m showed that expected elevation accuracy has been generally reached except for break lines of roads, embankments and trenches where this grid

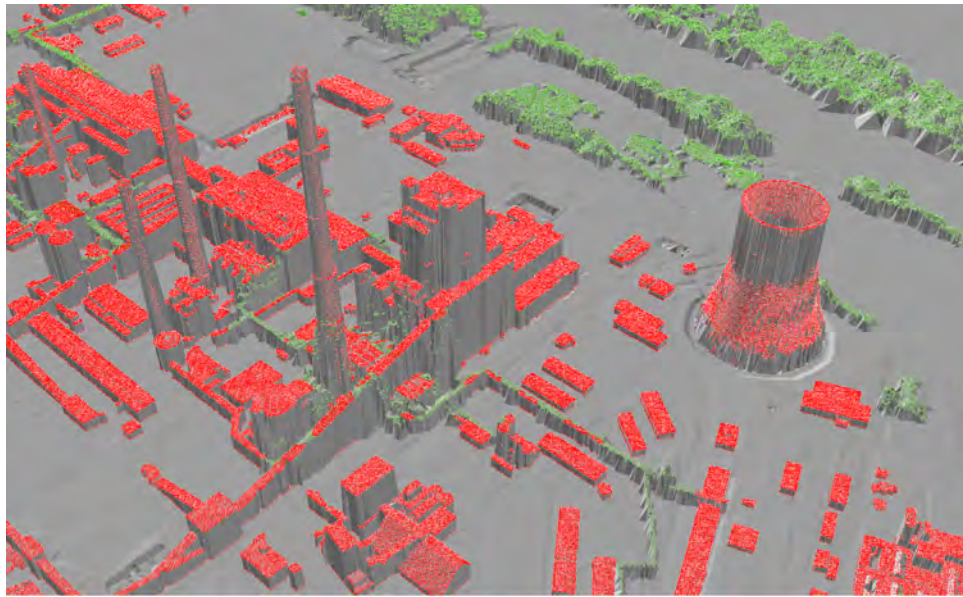


Figure 9: DMP 1G covering 32,9 % of the Czech Republic (March 2013)

is too smooth for such an application [2].

Category of surface and land cover	Systematic error [m]	RMSE (H) [m]	Maximum error [m]
Roads and highways	-0.25	0.34	0.77
Hard surfaces without vegetation	-0.01	0.07	0.26
Parks in built-up areas	-0.09	0.14	0.22
Arable land	-0.01	0.13	0.66
Meadows and pastures	-0.09	0.18	0.85
Shrubs , parkways, forests	-0.02	0.13	0.85
Average value	-0.08	0.17	0.60

Table 4: Results of testing the DMR 4G elevation accuracy

That's why the main product of aerial laser scanning of the whole state territory will be the Digital Ground Model of 5th generation (DMR 5G). Its density (up to two points per square metre) allows to represent most of important terrain break lines, but it will be appropriately reduced on plane or less curved surfaces [3].

Category of surface and land cover	Systematic error [m]	RMSE (H) [m]	Maximum error [m]
Break lines of roads and highways	-0.11	0.18	0.66
Hard surfaces without vegetation	-0.09	0.13	0.37
Arable land	-0.07	0.14	0.56
Meadows and pastures	-0.03	0.21	0.42
Shrubs, parkways, forests	-0.06	0.13	0.46
Average value	-0.07	0.14	0.49

Table 5: Results of testing the DMR 5G elevation accuracy

All products of digital aerial survey and airborne laser scanning from the entire area of the Czech Republic have been already/or will be step-by-step at disposal on Geoportal of the Czech Office for Surveying, Mapping and Cadastre (<http://geoportal.cuzk.cz>).

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